AN ABSTRACT OF THE THESIS OF

Scott Lee Johnson for the degree of Doctor of Philosophy in Agricultural and Resource Economics presented on October 24, 1989.

Title: An Economic Evaluation of On-Farm Strategies for Reduction of Nitrate Groundwater Pollution: The Case of Irrigated Production in the Columbia Basin

Redacted for privacy

Abstract approved: ______________________________

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Technological advances in agricultural production over the past 40 years have contributed to the high standard of living enjoyed by many in the United States. Extensive use of chemicals to enhance yield and improve crop quality has played a major role in creating this highly productive U.S. agricultural system. Increased chemical use has imposed some significant environmental costs. One environmental concern receiving increased attention is pollution of groundwater by nitrates.

The objective of this dissertation is to examine the economic effects on an irrigated Columbia Basin farm of adopting alternative strategies that reduce agricultural-related groundwater pollution from nitrates. The research involved the development and implementation of a multi-method approach which linked a farm-level linear programming crop mix model, field-level dynamic optimization models, crop simulators, and a geohydrology model of ground water nitrate movement.

The analysis focused on optimal irrigation and nitrogen fertilizer

scheduling for winter wheat, field corn, and potatoes, the principal crops in the study area, given the presence of various groundwater regulatory options. These options included input taxes, restriction on nitrogen applications, restrictions on nitrate leachate, and Pigovian taxes. The analysis also examined the relationships between the physical environment and the economic factors affecting nitrate pollution.

The results of the dynamic optimization and linear programming models provide some important insights into the problem of nitrate pollution. First, careful management of soil moisture is critical to the reduction of pollution rates. Second, some nitrate leachate is unavoidable in the production of irrigated crops within the study area. Third, weather events play a significant role in explaining the existence of nitrate leachate under optimal irrigation and fertilization practices. Fourth, input taxes and restrictions on nitrogen application rate may not always reduce pollution rates. Fifth, Pigovian taxes appear to be the most efficient means of reducing nitrate levels, although they would be difficult to impose. Finally, federal government farm program provisions relating to price supports increase pollution rates and idlement requirements reduce pollution rates.

An Economic Evaluation of On-Farm Strategies for Reduction of Nitrate Groundwater Pollution: The Case of Irrigated Production in the Columbia Basin

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed October 24, 1989

Commencement June 1990

APPROVED:

Redacted for privacy

Professor of Agricultural and Resource Economics in charge of major

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Dean of Graduate School

Date thesis presented October 24, 1989

This dissertation is dedicated to the memory of my father, Capt. William R. Johnson, who died in 1987. He instilled in me the values of hard work, education, and conservation which kept me going through long process of preparing of this document.

ACKNOWLEDGEMENT

I am deeply indebted to my committee and a number of other individuals for their help and support in course of my study at Oregon State and in the process of preparing this dissertation.

I would especially like to thank my major professor Dr. Richard Adams for all his wisdom, guidance, and support during the laborious task of preparing this dissertation. I would also like to acknowledge the significant contributions of Dr. Gregory Perry to this document and thank him for the nearly unlimited access he afforded me to his computer. I would like to thank Dr. John Bolte and Dr. Thomas Hodges for the enduring patience in explaining various aspects of CERES and agronomy to me. And I want to thank Dr. David Glyer for his assistance formulating the solar radiation model and his helpful comments on the final draft.

I want to acknowledge Dr. Jonathan Istok as the source of the geologic description of the study area in the introduction and co-author of the geohydrology simulator and would like to thank for his help acquiring data for hydrologic conditions in the study area.

I would like to thank Mary DeBacon and my family for all their love and moral support.

Finally, I need to note: The contents of this dissertation were developed under a grant from the Department of Interior, U.S. Geological Survey (number 14-08-0001-G1486). However, the contents do not necessarily represent the policy of that agency, and you should not assume endorsement by the Federal Government.

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CHAPTER 1: INTRODUCTION

Background

Farmers in the U.S. have benefited from many technological advances since World War II. The development of commercial fertilizers, herbicides, and pesticides have, in particular, resulted in large yield increases and permitted more intensive cultivation of farm land. Development of irrigation technology, combined with federal subsidization of irrigation projects, enabled millions of arid acres in the West to be brought into crop production. The resulting increase in agricultural productivity has lowered food costs, thereby contributing to the prosperity enjoyed by many Americans.

The technological advances in U.S. agriculture have not come without costs to the environment. For many years, most of the attention on agriculture-related environmental problems has been directed at soil erosion and surface water pollution. Some improvements in these environmental problems have been noted. Recently, researchers have identified many modifications in farming practices that can substantially reduce soil erosion. Furthermore, under the 1985 Food Security Act, farmers who participate in government farm programs whose fields include highly erosive soils converted to cropland since December 23, 1985 are required to begin implementation of conservation plans by 1990. Such plans must be completed by 1995. (Baum, Young, and Crutchfield, 1989).

Groundwater pollution problems, by contrast, have only recently been viewed as a serious environmental concern. Furthermore, some measures to improve surface water quality may have caused increased groundwater pollution. Measures to reduce runoff, for example, have resulted in increased amounts of water leaving the root zone through leaching (Crowder and Young, 1988).

The potential impact of groundwater pollution on human health and other values in the U.S. may be greater than surface water pollution. Consider the following facts. 1) Nearly half (116 million) of the people in the U.S. depend on groundwater as their primary source of drinking water (USGS, 1980). 2) Farmers in the United Stated applied over 7.2 million tons of nitrogen, a major source of groundwater pollution, in various forms in 1985 (USDA, 1987). 3) Irrigated agriculture accounts for roughly one-quarter of the nation's crops and nearly one-seventh of the nation's cropland or 49 million acres (USDC, 1983 and Farrell, Sanderson, and Vo, 1984). The role of groundwater as a major source of drinking water, combined with the high costs of purifying a polluted aquifer, make groundwater pollution an important water resource issue. In areas of intensive agricultural activity, the threat to groundwater quality may be severe.

Despite the potential for groundwater pollution from agriculture, of the counties surveyed in the U.S. to date, fewer than three percent have wells that contain nitrate levels above government tolerances (Nielsen and Lee, 1987). In addition, most of the groundwater pollution in the country can be traced to chemicals leaching into aquifers from municipal landfills, surface impoundments, and illegal dumps. In some areas (including areas of Oregon), however, intensive agricultural production has resulted in contamination of groundwater aquifers.

Groundwater pollution from agricultural sources is principally in the form of nitrates[1] or other water soluble chemical residuals[2] that have been leached into the aquifer. Agricultural-related nitrate pollution can be traced to nitrogen fertilizer usage and intensive livestock production. Concerns over such pollution arises because of significant effects on human health.

> Human and animal health can . . . be endangered by excess concentration of nitrates, . . . Under certain conditions, bacteria in the intestinal tracts of both humans and animals reduce nitrates to nitrites. When absorbed into the bloodstream, nitrites change hemoglobin into methemoglobin, which cannot carry oxygen to body tissue. Oxygen levels are lowered, and when more than 70 percent of the hemoglobin is changed into methemoglobin, death may result. Infants under six months, especially those with digestive disorders, are particularly vulnerable. In addition, according to Lijinski, some of the nitrosamines formed by the action between nitrites and certain organic compounds produce cancer in laboratory animals (Swanson, Taylor, and Van Blokland, 1978; p. 1).

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[1]Nitrates (NO_3) are a form of nitrogen which is water soluble, and thus can move into the groundwater.

[2]Chemical residues in groundwater other than from nitrates, such as herbicides, will not be directly addressed in this study. However, to the extent that water percolation rates are decreased, the rate of leaching for these residues can also be expected to decrease over time as well.

The blood condition, which is called methemoglobinemia (blue baby disease), has been found to result in an eight percent fatality rate (Fan, Willhite, Book, 1987). Furthermore, high blood nitrate levels have been associated with increased risk of stomach cancer in humans (Cordle, 1986). The federal government has defined the safe level of nitrite-nitrogen in groundwater to be 10 parts per million (ppm) (or 10 mg N/l) and 5 mg N/l to be the threshold for continued monitoring. Oregon's Department of Environmental Quality has found nitrate levels up to 80 mg N/l wells located in North Central Oregon farming areas. It also found that, of 25 wells tested, 18 had levels exceeding 5 mg N/l and 11 had levels exceeding 10 mg N/l (Pettit, 1988).

Groundwater pollution from industrial sources is primarily related to the method by which industry disposes of unwanted byproducts. Groundwater pollutants from agriculture, on the other hand, are often production inputs applied by the farmer to the soil but, for one or more reasons, move below the crop's root zone and into the deep soil profile below. In addition, the degree of groundwater contamination by a particular farming operation is dependent on specific soil type, management practices, and depth of the aquifer (among other factors, many of which are unique to individual farms). Thus, control of non-point agricultural groundwater pollution will require a different approach than that used to control industrial or highly localized sources of groundwater pollution.

There are at least five options available to reduce nitrate pollution from agricultural sources. These include: (1) improved fertilizer and water management; (2) restrictions on the quantities of fertilizer and (or) irrigation water (if appropriate); (3) taxes on fertilizer usage; (4) taxes on nitrate leachate; and (5) changes in cropping pattern (either voluntary or mandatory). As noted by Aldrich (1980; p. 258), "The fundamental guiding principle to assure efficient utilization and to minimize loss is to supply nitrogen as nearly as feasible to the time it is needed by the crop." The farmer must also take into account rainfall and irrigation patterns. Intensive fertilization management may result in smaller, more frequent fertilizer applications and may increase management and production costs. Similarly, improved irrigation management will require better understanding of soil characteristics and may increase production costs.

Because of increasing awareness of groundwater pollution and its potential consequences for human health, the U.S. Congress has passed legislation to expand the regulatory power of the U.S. Environmental Protection Agency (EPA) and other federal agencies to groundwater problem areas.

> "The Water Quality Act, passed by Congress in February 1987, expanded the regulation of pollutants of groundwater, surface water, and coastal waters . . . The act extends emphasis beyond point sources of pollution such as industrial plants to nonpoint sources such as agricultural areas. Under the legislation, farmers whose practices are judged to contribute to nonpoint-source water pollution could be subject to State or local restrictions on land use and agricultural chemical use (C. Edwards, 1988; p. 4)."

Of course, government-imposed changes in management practices by farmers are politically unpopular in the agricultural community. For this reason, most regulatory agencies have used education programs to encourage farmers to improve their practices (Pettit, 1988). Critical to any voluntary program is an understanding of the economic benefits associated with changes in management practices, as well as the potential costs that may be incurred. An understanding of the economic costs and benefits associated with government imposed regulations is also needed by policymakers faced with regulatory proposals.

Objectives

The overall objective of this dissertation is to examine the farm-level economic effects of adopting alternatives strategies for reducing agricultural-related groundwater pollution from nitrates. More specifically, this dissertation will first propose methodology that combines several types of simulation and optimization techniques to 1) capture the major aspects of farmers' water and nitrogen fertilizer decisions, and 2) reflect the physical environment in which those decisions take place, including the relationship between nitrogen application and transport. Using this methodological framework, the dissertation then focuses on an empirical analysis of economic and environmental implications of various policy options, including improved fertilizer and water management, restrictions on fertilizer application rates, taxes on fertilizer usage, pollution (Pigovian) taxes on nitrate leachate, and changes in cropping patterns.

Empirical Setting

The empirical setting of this study is the Columbia Basin of Oregon, specifically eastern Morrow and western Umatilla counties. Figure 1.1 shows the location of these two counties within the State of Oregon. Aquifers in these counties currently have some of the highest nitrate levels in the state, well above the current U.S. standard of 10 ppm (nitrogen) (Vomocil, 1986). The two counties contained about 137,000 acres of center-pivot irrigated farmland and 244,000 total irrigated acreage in 1987, with potatoes, corn, alfalfa, and winter wheat being the major crops (Miles, 1988). The high water and nutrient demands associated with production of these crops, coupled with the generally sandy soils of the region, facilitate leaching of nutrients into the groundwater. Farms with center-pivot irrigated fields typically have sufficient water rights to ensure water is not a limiting resource in crop production. Farm in this portion of the Columbia Basin are typically highly capitalized operations of from 2,000 to 12,000 acres. The region is semi-arid, with mean annual precipitation of 8.87 inches, and mean July and January temperatures of 73.8 and 32 degrees Fahrenheit. In terms of climate and soils, the study area is somewhat similar to other regions of the Columbia Basin, although with less diversity in irrigation systems.

There are two principal types of aquifers in the study area: sedimentary and basalt. Figure 1.2 provides a map of the major aquifers in the study area. <u>Sedimentary aquifers</u> (sa) occupy the greatest

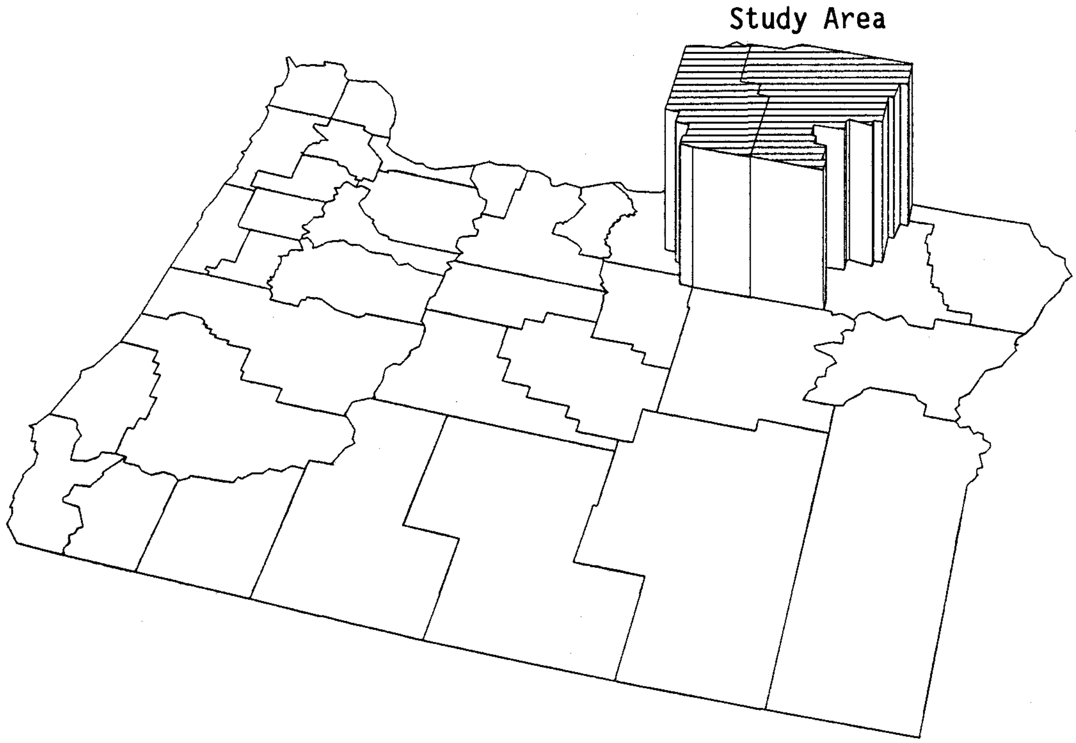

Figure 1.1. Counties in the State of Oregon in Which the Groundwater Study was Conducted.

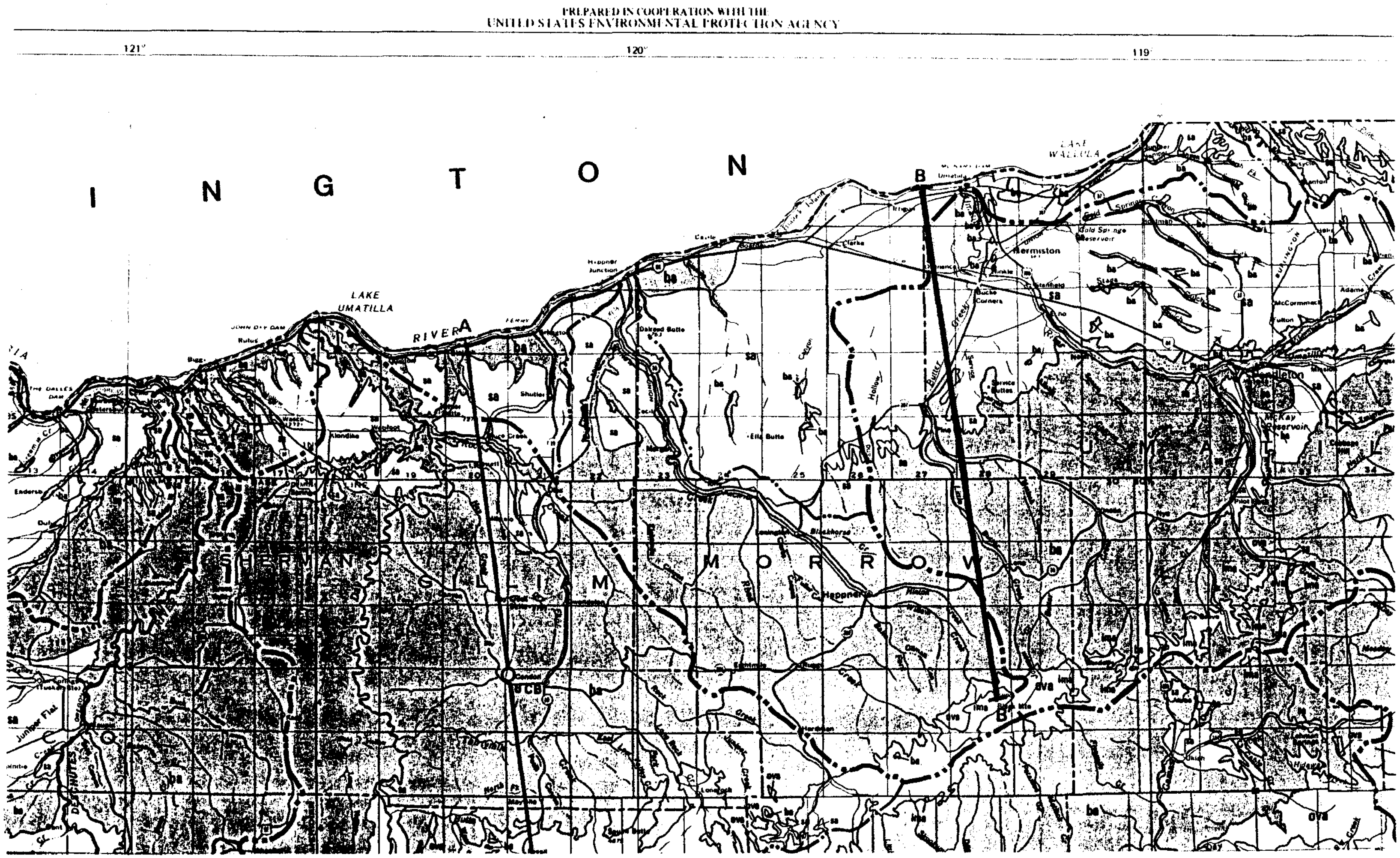

Figure 1.2. Major Aquifer Units in Study Area.
(Source: Gonthier, 1985)

proportion of the study area. These aquifer types occur in deposits of unconsolidated sand and gravel, and in several semi-consolidated sandstone units. In upland plateau areas the sedimentary units are largely unsaturated, whereas in the lowland areas they are saturated. The alluvial deposits generally disappear at the boundaries of the major valley margins. In lowland areas, the sedimentary aquifers are in good hydraulic connection with surface water (primarily irrigation and drainage ditches). Aquifers generally are unconfined (the upper boundary is the water table), but deeper aquifers tend to be confined (the upper aquifer boundary is a low permeability layer). The lower boundary for many sedimentary aquifers is the low permeability, igneous rocks of the Columbia River basalt group. The shallow, unconfined aquifers are very permeable and can providing high well yields. The source of the porosity is primarily intergranular, with a small amount of fractures in the more highly consolidated units. Typical ranges for hydraulic properties are: specific capacity: 5×10^{-3} to 1.25×10^{-2} (m^3/second/m), hydraulic conductivity: 1×10^{-3} to 3.3×10^{-3} (m/second), and transmissivity 0.01 to 0.25 (m^2/second). Groundwater recharge from precipitation ranges from 25 to 100 millimeters per year (Gonthier, 1985).

Although basalt formations underlie the entire study area, the basalt aquifers (ba) occur only in zones of fractured and high permeability basalt scattered within high-density, low permeability lava flows. Figure 1.3 portrays a schematic of a geologic cross-section B through B' (in Figure 1.2) the study area. The saturated thickness of these aquifers is irregular, ranging from zero to few hundred meters.

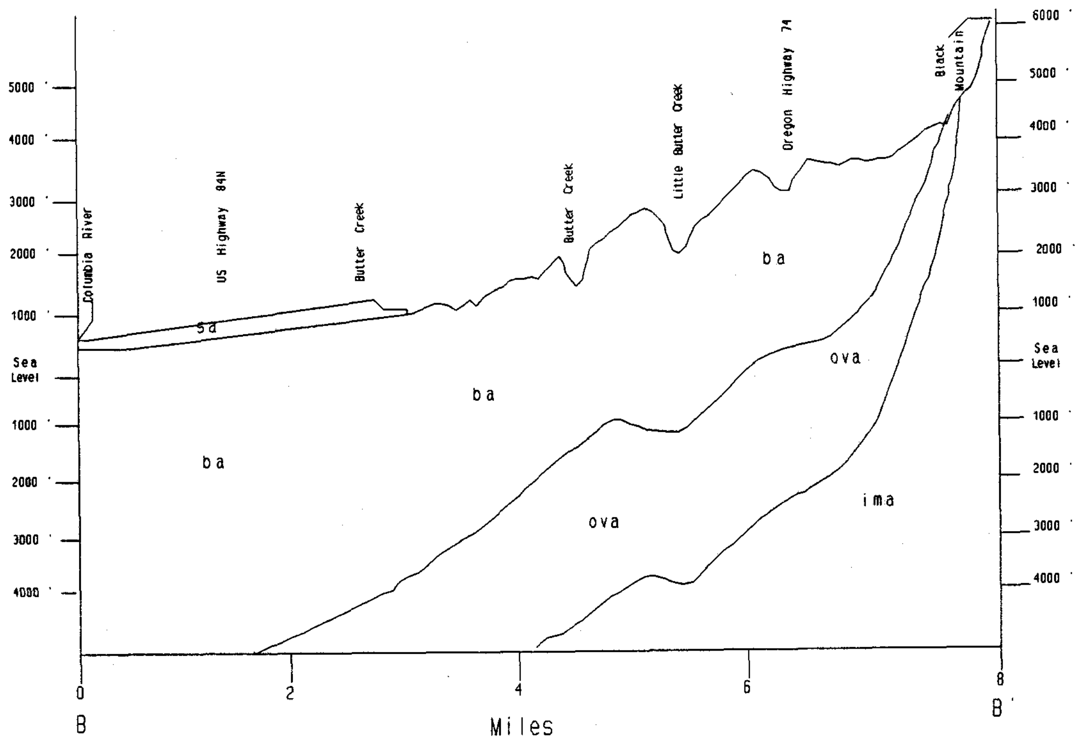

Figure 1.3. Schematic of the Geological Cross-Section Through the Study Area Showing Basalt (ba) and Sedimentary (sa) Aquifers.

These aquifers tend to be unconfined and often occur as "perched water table" aquifers with limited lateral extent. In upland areas, water occurs at greater depth than in lowland areas. The hydraulic properties of the basalt aquifers vary widely due primarily to the geologic structure and stratigraphy of the basalt units. Typical ranges for hydraulic conductivity: 0.3 to 3 (m/second), and transmissivity: 1×10^{-3} to 10^{-2} (m^2/day). Groundwater recharge from precipitation is from 25 to 75 millimeters per year (Gonthier, 1985).

The focus of this study is on the sedimentary aquifer units because they are the most common formation underlying irrigated production areas. The sedimentary deposits have very small organic carbon content below the root zone. In this study, it was assumed that denitrification does not occur in the vadose zone because of these low carbon levels. Thus, any nitrate leaving the root zone will eventually reach underlying aquifers.

Overview of Dissertation

The rest of this dissertation will focus on a detailed discussion of the methodology, data, and results from the analysis. Specifically, the next chapter is a discussion of the various models used in this study and their integration as an assessment methodology. These models include crop simulation, hydrological simulation, dynamic optimization, and linear programming. The third chapter describes the nature of data used in this dissertation. Chapter four focus on the results from application of the models to the empirical problem, and associated sensitivity analyses.

Chapter five concludes with a discussion of the policy implications of these results. Additionally, there are several appendices that provide further information concerning data and documentation for the computer models used in the analysis.

CHAPTER 2: METHODOLOGY

Introduction

As discussed in the preceding chapter, the overall objective of this dissertation is to estimate the farm-level economic consequences of complying with alternative strategies to reduce nitrate [NO_3] groundwater pollution. The analysis centers on a representative irrigated farm in the Columbia Basin of Oregon. The results of this study are intended to determine how changes in production practices can minimize on-farm costs of complying with alternative nitrogen control strategies. Production practices include adjustments in timing and quantities of water and nitrogen fertilizer applications, as well as changes in cropping patterns.

Proper assessment of the on-farm economic effects of reductions in nitrate leachate levels requires an optimization model capable of capturing the economic dimensions of the problem; i.e., multiple decision variables and production relationships reflecting on-farm variability with respect to crop practices, soil and aquifer properties. Field and sub-field variability typically encountered in the real world requires that the whole farm problem be decomposed to specific fields. Decomposition is often used to subdivide large, complex (and often unsolvable) problems into several smaller, simpler problems. These models then can be solved in a hierarchical manner (Haimes, 1977; Yaron and Dinar, 1982). In this way, different components of the system can be handled with the most appropriate technique.

The problem addressed here is decomposed into four sub-problems. First, production relationships are needed to express crop yields as a function of the crop production factors that influence groundwater pollution (i.e., application rates for irrigation water and nitrogen-based fertilizers). Second, a simulation model of the vadose zone[3] is needed to predict NO_3 levels in the underlying aquifer from computed deep percolation[4] of water and NO_3. Third, an economic model of production behavior is required to identify a set of factor decisions that optimize undiscounted-before-tax-net returns[5] for given field and groundwater pollution levels. Fourth, an economic model is needed to determine the crop mix that optimizes before-tax-net returns while meeting a total farm pollution nitrogen restriction. Figure 2.1 illustrates this multi-method approach, indicating how the components fit into an overall assessment framework. The result is a whole farm estimate of the costs associated with reductions in the levels of nitrates moving into the groundwater.

The first set of models in this multi-method approach are crop simulators for field corn, winter wheat, and potatoes which forecast both yield and nitrogen percolation for a given set of inputs and weather conditions. The second component is a dynamic optimization model designed to maximize net farm income for a specific crop on a given field with

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[3]The vadose zone is the region of the soil strata between the root zone and the aquifer.

[4]Deep percolation occurs when water "percolates below the root zone" (Donahue, Miller, Shickluna, 1977; p.569).

[5]Using only variable costs (e.g. pumping or fertilizer) pertinent to the decision process, per unit costs, and crop revenues.

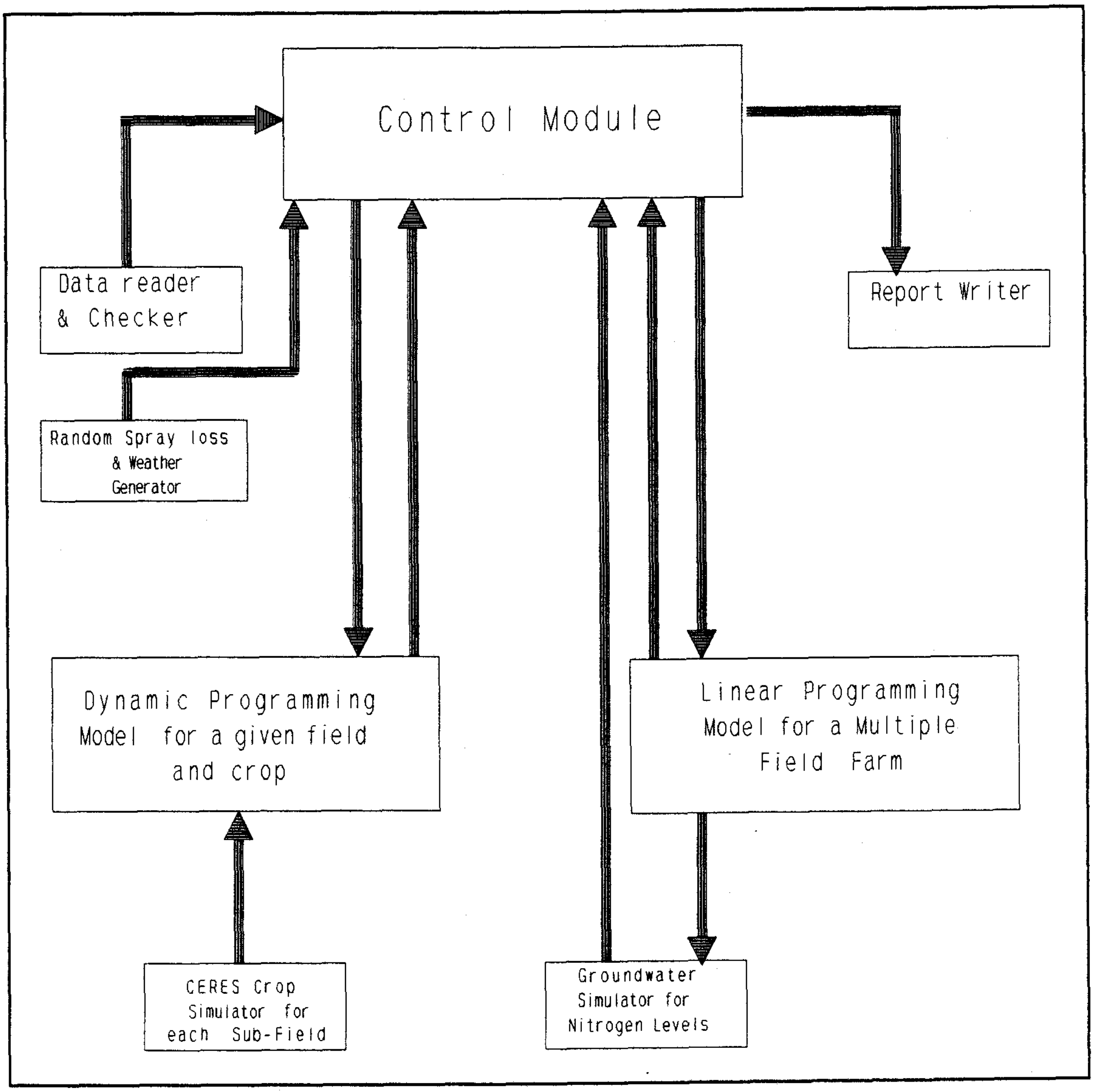

Figure 2.1. Schematic of Economic Optimization Procedures.

respect to quantities of irrigation water and nitrogen fertilizer. The third is a linear programming model that examines the effect of several policy options on optimal crop mix. The final component is a groundwater model which estimates the effects of a given pattern of nitrogen percolation on groundwater nitrate concentrations. This chapter contains a discussion of the important features of each component model. First, however, the economic causes of agricultural groundwater pollution are reviewed.

The Economic Problem: The economic causes and solutions to groundwater pollution.

Deep percolation of nitrates (below the root zone) often occurs at rates in excess of socially optimal levels occurs for a variety biological and economic of reasons. The principal reason for nitrate pollution is that a farmer does not necessarily perceive nor incur all the social costs associated with nitrate pollution generated in the production of field crops. Social costs of pollution include human health consequences (such as the cost of additional water filtration equipment by users of the polluted aquifer), recreational costs due to decreased productivity of sport fisheries, general ecological costs, bequest value, and loss in existence value. This disparity between private and social costs create conditions for a misallocation of resources and thus economic inefficiency. Misallocations are inefficient because they affect the competitive equilibrium of the economy. Further, this misallocation can be viewed as a "Pareto-relevant externality," defined by Baumol and Oates (1975; pp. 17-8) as:

> Condition 1. An externality is present whenever some individual's (say A's) utility or production relationships include real (that is, nonmonetary) variables, whose values are chosen by others (persons, corporations, governments) without particular attention to the effects on A's welfare ...
>
> Condition 2. The decision maker, whose activity affects others' utility levels or enters their production functions, does not receive (pay) in compensation for this activity an amount equal in value to the resulting (marginal) benefits or costs to others.

A state of economic efficiency "implies that resources are in the right place at the right time and perform the appropriate functions for the proper amount of return" (Buse and Bromley, 1975; p. 342). Alternatively, it can be defined as the state at which "there is no alternative allocation that leaves everyone at least as well off and makes some people better off" (Varian, 1987; p. 15).

The use of comparative economic efficiency for ranking alternative states of nature is commonly utilized by economists, but it is only one of many normative criteria that can be employed. For example, the use of the efficiency criterion depends on assuming an initial allocation of income. However, one could use alternative criteria that focus on improving the condition of the least well off in society, such as in the Rawlsian principle of social justice (Rawls, 1974). Discussion of the issues concerning use of efficiency or other criteria are beyond the scope of this dissertation and are discussed elsewhere (Clark, 1985; Demsetz, 1969; and Dahlman, 1979). For the purposes of this research, alternative methods for reducing nitrate groundwater pollution will be evaluated using the economic efficiency criterion and institutional considerations concerning the feasibility of implementing each method.

The source of the problem externality in groundwater pollution is poorly defined property rights to the groundwater. It is possible for a government agency to allocate the use of water from a given aquifer among landowners. However, it is much more difficult to allocate pollution rights within an aquifer because of the complexities of regulating pollution from non-point sources. Polluters typically have open access to the aquifer and only pay a small fraction, if any, of the cost of their actions in the form of polluted drinking water for personal consumption. As Demsetz (cited in Clark, 1985; pp. 19-20) points out: "If a person seeks to maximize the value of his communal rights, he will tend to overhunt and overwork the land because some of the costs of his doing so are borne by others." Given the communal nature of the aquifer, conditions exist under which farmers may apply water and nitrogen that results in the leaching of nitrates into groundwater at rates that are higher than is economically efficient.

Economists have suggested several solutions to deal with environmental externalities. These include restricting quantities of inputs, taxing inputs, restricting the quantity of pollution directly, and taxing pollution (Baumol and Oates, 1975). The goal of the policymaker is to select the most socially efficient solution to the problem, given the administrative and technical limits of each option. Clearly, the easiest alternative to implement is an excise tax on fertilizer, because 1) the industry is generally regulated in most states and 2) the number of manufacturers of nitrogen-based fertilizer is small in comparison to the number of farmers simplifying the application of a tax. Assuming profit maximizing behavior, this alternative will decrease the quantity of nitrogen used on crops. However, the effectiveness of input taxes is limited for several reasons: 1) The inelastic nature of demand for fertilizer insures a less than proportional response in usage from changes in the price of fertilizer (Roberts, 1986; Carman, 1979; Roberts and Heady, 1982; and Chern and Just, 1978); 2) taxes on fertilizer have no direct effect on water management on irrigated land which may be essential to reducing leachate; and 3) the farmer's incentive is still to maximize net income, not to minimize nitrate leachate when making decisions on timing and quantity of water and fertilizer. Furthermore, the relationship between nitrogen usage and leachate rates can vary from farm to farm and even from field to field; therefore, any across-the-board tax will be economically inefficient (Stevens, 1988; and Griffin, 1987). Hence, although excise taxes on fertilizer are easy to implement, they are not likely to have much impact on nitrate pollution.

Regulating timing and quantity of fertilizer applications is another feasible option, but it is much more difficult to implement. The form of such regulation could be similar to pesticide regulations, where use is restricted by timing or other label requirements. For fertilizers, specific timing and quantity requirements could be mandated for different soil type and crops. Regulations for fertilizer applications would be significantly harder to enforce than input taxes, given the diversity of soils, crops, and topography across U.S. farms. The effects of regulations on nitrate pollution levels would depend, in part, on the ability of government agencies to define a set of best management practices (BMP's) for various irrigated and non-irrigated crops on different classes of soil. A BMP for a given crop and soil would likely include conditions for application in terms of soil nitrogen levels, stage of development, and climatic conditions. The definition of these BMP's, which balance private benefits and social costs of nitrate pollution, would be a major research undertaking, especially for fields that have multiple soil types. Even if BMP's could be defined, they do not address the issue of water management in irrigated production. Serious leaching could still occur if soil moisture levels are maintained at levels above field capacity. Thus an appropriate BMP would likely fail to control adequately the pollution externality.

Regulations on fertilizer usage can generate a relatively efficient and practical means of reducing nitrate leachate under some non-trivial conditions with respect to BMP's. For example, BMP's for soil with high leachate potential must balance the economic benefits to the farmer generating leachate with the social costs of nitrates in groundwater. The BMP approach is further complicated by several other elements. First, the estimated benefits to farmers typically are based on a representative farm for a given region and crop mix; they may not reflect the actual costs of production and yields on any given farm in the region. Second, the social costs of a polluted aquifer may vary substantially from aquifer to aquifer. Third, economic efficiency requires that these BMP's vary from region to region due to spacial and agronomic variability (Kolstad, 1987). Finally, BMP's must reflect the linkage between nitrogen applications and soil moisture which jointly determine leachate levels.

Regulating water timing and quantity is another option but, like fertilizer regulations, it is difficult to implement. Regulating irrigation practices has many of the same problems as regulating on fertilizer practices. They are difficult to define for all possible crop and soil conditions, and they are difficult to enforce given the large number of irrigated farms in the U.S.

Direct controls on nitrate leachate are, in theory, more effective than controls on fertilizer quantity and timing because they focus directly on the problem. Ideally, a government agency would set target leachate rates for each farm within a region and let each farmer decide how to meet them. However, it is impossible for an individual farmer to estimate accurately nitrate leachate rates without expensive monitoring equipment and complex computer software. Furthermore, it would be very difficult to provide the appropriate incentives to induce them to do so. Therefore, leachate regulations would likely take the form of BMP's for <u>both</u> water and nitrogen usage which require only a potentiometer and frequent soil nitrogen tests. Such BMP's would be based on probabilistic constraints given the natural variability of nitrate leachate (Beavis and Dobbs, 1987). Thus, they could be used efficiently to reach specified pollution rates with some level of certainty. This alternative has some of the same practical problems that are associated with direct controls on fertilizer use. They would be difficult both to define and to enforce. Direct controls on both soil moisture and fertility level do, in theory, have the potential for large reductions in nitrate leachate. Nonetheless, controls cannot insure economically efficient rates of pollution without site-specific BMP's because of the large variability of benefits and costs likely to exist across agricultural regions.

A preferred approach to the pollution problem is to tax the pollution (Pigou, 1962). Such taxes on nitrate leachate have the potential, in theory, to be more efficient than direct controls on leachate. An efficient tax would be set at the marginal social costs of nitrate leachate reaching the aquifer. Thus, with the tax on leachate included in the private costs of production, the farmer makes irrigation and fertilization decisions based on the full social costs of nitrate leachate, eliminating the market failure which is creating the misallocation of resources. The resulting quantity of leachate can then be considered economically efficient. Furthermore, farmer payment levels to the government under a fertilizer excise tax system are likely to be higher than under Pigovian Tax system to achieve the same level of nitrate leachate control because of the inelastic nature of fertilizer demand (Stevens, 1988). The Pigovian tax approach makes the strong assumption that the government can both estimate the quantity of leachate generated by cultural practice, by aquifer, by crop, by farm, and by field and estimate the marginal social costs of nitrate pollution in that setting.

There is also the significant problem of enforcement. Unlike direct controls, however, the government is not required to estimate the private benefits to the farmer from leaching a given quantity of nitrate.

The setting of pollution tax levels would be a complex process for any aquifer. To set the tax rate, one has to define the social costs (damage) function for nitrate pollution in terms of kilograms of nitrates leached. One approach would be to use option price techniques such as in S. F. Edwards (1988). These techniques can provide estimates of overall option, existence, and bequest values of clean groundwater and the associated effects on surfaces water. But, these types of social costs are extremely difficult to reduce to a per-kilogram-of-nitrate-in-solution basis required by a system of Pigovian taxes. A second approach is the examination of the costs of filtering nitrates out of the drinking water, either at centralized treatment plants or at individual wells. Using this economic damage approach, one can estimate the costs of leachate per kilogram. In fact, one recent study found that at an initial concentration of 15 mg N/l (a typical level of pollution in the study area) it would cost $26.42 per kilogram of nitrate-nitrogen in solution to achieve a final concentration of 5 mg N/l (Walker and Hoehn, 1988). However, this mitigation cost approach ignores some of the other social costs which are included in the option price approach.

Of the four general regulatory strategies to control nitrate groundwater pollution discussed in this section, none are perfect on both theoretical or practical terms. To summarize, fertilizer excise taxes are easy to administer if set at uniform levels, but they are hard to target in terms of soils with high leachate potential and are likely to be ineffective at tax rates that are set at politically acceptable levels. Direct controls on only fertilizer can be somewhat more effective. However, they do not address the critical area of water management, and they are difficult to define and enforce. Direct controls only on irrigation practices also can be somewhat effective. But, they do not address fertilizer management, and are difficult to define and enforce. Direct controls on leachate are potentially effective in reducing pollution, but they are also difficult to define and enforce. Finally, Pigovian taxes can be effective and economically efficient. However, setting the appropriate tax rate and estimating leachate levels are complex and extremely difficult tasks. Using this framework, the goal of the research in this dissertation is to examine some form of these alternatives on the economic behavior of an individual farm. This analysis does not address important issues related to how a government agency would implement any of these alternatives.

The Family of CERES Models: Methods for simulating crop growth

Crop yield is influenced by many factors, some under the control of the producer and some dependent on climate or other characteristics of the particular production location. A model relating (in a mathematical sense) crop output and quality to some of the more important production factors is required to analyze alternative pollution reduction options. For our purposes, the model must be sufficiently detailed to accurately estimate daily percolation of water and nitrogen below the crop root zone. These criteria suggest a more complex model than those used in much of the previous irrigation research, such as that by Hexem and Heady (1978) and Doorenbos et al. (1979).

Previous researchers have utilized several functional forms to relate crop yields to aggregate water and nitrogen use (exclusive of specific timing). These include polynomials (Hexem and Heady, 1978; and Zacharias, Huh, and Brandon, in press), and empirical equations proposed by Mitscherlich (Hexem, Sposito, and Heady, 1976), and von Liebig (Grimm, Paris, and Williams, 1987). These techniques provide moderately good estimates of yield based on total irrigation water and fertilizer applied, but they cannot forecast deep percolation of NO_3 because they lack weather, soil, and application timing components.

There have been numerous studies of optimal irrigation strategies[6]. Many studies simply maximize yield through optimal irrigation timing (Minhas, Parikh, and Srinivasan, 1974; Ahmed, van Bavel, and Hiler, 1976; and Heerman, Haise, and Mickelson, 1976). Various studies have focused on irrigation under limited water supplies. Some of these studies optimize irrigation timing with respect to net farm income for a single homogenous field (Dudley, Howell, and Musgrave, 1971) and others for the total farm (Yaron and Dinar, 1982). Some techniques merely optimize timing with fixed application quantities (McGuckin et al., 1987, and

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[6]See Bosch, Eidman, and Oosthuizen (1987) for a full review of the economic literature related to irrigation water.

Dudley, Howell, and Musgrave, 1971), while others optimize both the timing and the quantity applied (Heerman, Haise, and Mickelson, 1976; Rhenols and Bras, 1981; and Ahmed, van Bavel, Hiler, 1976). These studies generally use additive (Haerman, Haise, and Mickelson, 1976, and Bernado et al. 1987) or multiplicative (Hall, 1968) production functions, which are separated into plant development stages. Indeed, Vaux and Pruitt (1983) point out that "inter-stage dependence is not a feature which has been incorporated into any economic work " (1983, p. 89). The Zavaleta, Lacewell, and Taylor (1980) study is an important exception to this in that a crop simulation model (which incorporated stage interdependence) was used to optimize irrigation water use. The likely reason for not imposing stage dependence in previous research is that it avoids the requisite complex, non-separable production function which cannot easily be estimated econometrically without a large data set and substantial computational resources.

A family of models that perhaps provide the most detailed production interrelationships are the Crop-Environment REsource Synthesis [CERES] class of plant simulation models (Ritchie, Godwin, Otter-Nacke, 1986; Jones and Kiniry, 1986). This family of models consist of FORTRAN 77-based routines that simulate the major factors affecting plant development over time and provide detailed output on the predicted structure of plant development and final yield. The common link between all CERES models is the use of Ritchie's "official" CERES water and nitrogen balance routines along with the same basic assumptions of plant phenology and growth. This family of crop models can estimate yield based on weather, crop genetics, crop residue, soil moisture, and soil nitrogen conditions. Each model provides a detailed accounting of water and nitrogen balances on a daily basis for different soil layers as well as water and nitrogen loss resulting from deep percolation and runoff. Finally, many of these models have been widely validated throughout the world.

The current study uses the CERES models for corn, wheat, and potatoes. The quality of the CERES yield forecasts varies from crop to crop; corn and wheat models generally providing quite accurate yield estimates. The potato model, however, is still under development and thus provides less accurate yield estimates. Nevertheless, the similarity between these models in phenology[7], weather, water, and nitrogen related computations is a desirable feature, especially when considering production strategies for the same farm. Unlike many of the simpler production relationships embedded in the plant yield-water use models (such as Doorenbos et al., 1979), CERES permits simulation of stress conditions within a single period that will result in total crop failure. In generalized form[8], CERES yield functions can be expressed as:

$$Y = y\,(S_0,\ Wth,\ Sa,\ NO_3,\ NH_4,\ ON,\ G) \tag{2.1}$$

[7]Phenology refers to the techniques used to determine the stages of development for each crop.

[8]The degree of abstraction in equation (2.1) is apparent when one notes that the FORTRAN 77 source code for the CERES models range from 1500 to over 3000 lines of code.

where yield [Y] is a function of initial soil conditions [S_0], weather over the season [Wth], daily soil moisture [Sa], daily levels of nitrogen in the forms of nitrate [NO_3] and ammonium [NH_4], nitrogen held in organic compounds [ON], and crop genetics [G]. Other nutrients such as potassium and phosphorus are assumed to exist in sufficient quantities so as not to limit plant development. The model does not directly handle other factors such as salinity, tilth, disease, or pest levels. CERES computes production relationships such as energy, water, and nutrient balances on a daily basis.

In simple terms, the CERES models estimate daily potential photosynthesis based on weather, accumulated biomass, leaf area, and genetic characteristics; CERES then uses water and nitrogen stress estimates to calculate actual photosynthesis. Photosynthate (energy) is distributed to the various parts of the plant for maintenance and growth. The distribution of potential photosynthate depends on the stage of plant development. The timing of the developmental stages, including the harvest date, are determined endogenously, based solely on thermal time[9] except for emergence and termination dates for potatoes[10]. CERES computes

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[9]Water and (or) nitrogen stress are <u>not</u> factors considered in the development stage timing except for restrictions on the models to insure that there is sufficient moisture for germination. The sole exception to this is if the crop is killed due to nitrogen or water stress.

[10]Both the emergence date and termination dates for potatoes are determined exogenously from the model. The emergence date must be computed exogenously because the wide variability in seed quality and storage techniques make it difficult to model. The termination of potatoes must be computed exogenously because, under current cultural practices, the farmers apply herbicide to kill off the plants prior to harvest in August and September.

thermal time (in degree centigrade days), based on aggregated temperature data within a given stage of development.

The model includes accounting methods for soil water and nitrogen. The soil profile is divided into homogenous layers for a given field. CERES keeps track of changes in soil moisture, root biomass, NO_3, NH_4, and organic matter levels for each layer. The soil water routines calculate snow pack[11], surface runoff, saturated movement between layers[12], unsaturated flows between layers[13], plant water uptake, surface evaporation, and deep percolation. The soil nitrogen routines account for movement of NO_3 caused by saturated and unsaturated water flows between layers, denitrification of NO_3[14], reactions to convert NH_4 to NO_3, plant uptake of NH_4 and NO_3, NH_4 gained from decaying organic matter (e.g., alfalfa), and deep percolation of NO_3[15]. Once water or nitrogen leaves the soil profile by deep percolation, it is gone forever from the model; there

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[11]The snow pack routines are only needed in the winter wheat model.

[12]Saturated flows are always downward and caused by gravity.

[13]Unsaturated flows are created by soil moisture potential differentials between the defined layers. In simple terms, water can move from one layer to another if the second layer is sufficiently dry relative to the first layer. The water movement, based on this differential in moisture, includes layers above and below the layer in which it is currently held. These flows are computed independent of whether saturated flows occur on a given day.

[14]Denitrification is defined as "the biochemical reduction of nitrate ... to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen" (Donahue, Miller, and Shickluna, 1977; p. 596).

[15]CERES assumes that nitrogen as NH_4 or in crop residue cannot move between layers.

is no allowance in the CERES model for unsaturated flows downward to or upward from the vadose zone.

Root depth and biomass are functions of net photosynthesis and soil characteristics. Roots grow to the depth of the deepest defined soil layer (as defined by the user) if there is sufficient plant energy and time. Thus root depth at a given time in the growing season also may vary depending on the level, if any, of water and nitrogen stress[16].

Treatment of water and nitrogen balances in CERES are somewhat asymmetric. Insufficient quantities of either water or nitrogen will inhibit growth of the plant, thereby reducing final yield, but excess quantities generally do not inhibit yields[17] in the model. Most of CERES's stress calculations are based on what is commonly called 'The Law of the Minimum'. The Law can be expressed as:

$$B = \text{Min}\ (\ f(Sa),\ g(N),\ M\ ) \qquad (2.2)$$

where B is biomass from a single days growth, f(Sa) is the maximum biomass as imposed by soil moisture levels, g(N) is the maximum biomass as imposed by soil nitrogen level, and M is the maximum biomass imposed by other factors such as weather and genetics (Waggoner and Norvell, 1979; and

[16]The fact that root growth rate over time is affected by stress creates complications in defining the appropriate state spaces for water and nitrogen in the optimization model. This issue will be discussed later in this chapter.

[17]The exception to this is potatoes which do exhibit declining yields in the face of excessive nitrogen applications.

Lanzer, Paris, and Williams, 1987). In economic terms, the stress calculation assumes a von Liebig-like production function for daily carbohydrate production such that the rate of technical substitution is zero between soil moisture, soil nitrogen, and other factors (moisture and nitrogen levels are technically independent until one becomes limiting, in which case they are complements).

Yields increase as water and nitrogen stresses are reduced through application of appropriately timed water and fertilizer. From this general formulation, one can see that the marginal productivities of water and nitrogen are inextricably linked; for example, in a period in which soil moisture is allowed to fall below the yield maximizing level, the minimum amount of nitrogen required to avoid nitrogen stress is reduced. Excessive quantities of water can only indirectly inhibit growth: because the model allows for deep percolation of water and NO_3, excessive quantities of irrigation water (or rainfall) can cause deep percolation of NO_3. Thus, in turn, excess water can induce nitrogen-based stress and reduced yields through the loss of NO_3 from the root zone.

Since applications of water and (or) nitrogen incur costs, the dynamic optimization model will minimize the excess quantities of both inputs. This is despite the fact that CERES's production relationships generally do not exhibit a Stage III level of production (i.e., negative marginal products). Optimal economic solutions will be confined to the Stage II area of production because the optimization model will only apply additional irrigation water and (or) fertilizer if the marginal costs are less than marginal revenue. Thus, the asymmetric nature of CERES does not create a significant practical problem for this study. Also, as mentioned in the introduction, the location of the representative farm for this study is in a semi-arid climate with sandy well-drained soil, so there are no serious problems associated with becoming water logged from excess rainfall or irrigation. The possibility of "burning" the crop by applying excess nitrogen can be handled with constraints on the decision space in the optimization algorithm.

The CERES models were originally developed as separate computer models to allow researchers to engage in 'what if' analyses for management decisions on fields with various genetic, climatological, and soil factors. As such, each original model contains interactive input, output, and growth accounting routines that significantly increase processing time and are unnecessary for this study. Additionally, there are other opportunities for reductions in processing time within the models, for improved portability, and for improved replicability of the results.

To increase speed, portability, replicability, and efficiency of CERES, the computer code was significantly restructured into a series of smaller subroutines. The main routine of CERES[18] was then made a

[18] The resulting version of CERES still requires substantial computing resources for a single experiment (i.e., functional evaluation). It takes approximately 4 CPU seconds to simulate the growth of winter wheat from sowing date to harvest with a Definicon 785-4 co-processor. This computer uses a Motorola 20 mz 68020 CPU with a 68882 floating point unit and 4 mega-bytes of RAM. The Definicon was the primary computer used for software development in this study and for which all subsequent CPU time figures are based. Other computers were used for various "production" runs, including FPS 164, FPS 264, and Digital 8700. Baseline tests of

subroutine of the field-level optimization model. Yield, soil moisture, and soil nitrogen information are passed directly to the optimization model from the main CERES routines. Because of the restructuring and improvements the CERES algorithms, the results from an individual experiment will not be the same as the 'standard' CERES model for a given crop[19]. Facilities were added to allow stopping and restarting the simulator in the middle of the simulated growing season[20]. Calculations of several additional values were added to aid in the link to the dynamic optimization model. These included total available soil moisture in the root zone[21] and total elemental nitrogen (NO_3 plus NH_4 plus fresh organic nitrogen)[22] in the root zone for the day before the pre-specified restart date[23]. These two aggregate values are then used to compute the state variables in the optimization model.

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numeric precision of different computers indicate difference of at most two percent in net returns for the same run. To minimize these problems, whenever possible all the runs for a given crop were run on the same computers.

[19]A full discussion of the major changes in the CERES model is presented in the Appendix A.

[20]The importance of starting and stopping CERES is described in the discussion of the optimization model. The technique to accomplish this is found in the Appendix A.

[21]This differs from soil moisture in the total possible root zone which is defined in the CERES models. If root depth is less then the depth of the first two soil layers (typically 15 to 30 cm), the computed root depth is the depth of the first two layers.

[22]All subsequent references to nitrogen quantities will be in terms of elemental N except when specified. For example, if a 50 kg bag fertilizer has a certified context of 10 percent nitrogen then it would have 5 kg of elemental nitrogen.

[23]This date is important because the restart date referred to here will correspond to the day proceeding the current decision stage of the optimization model.

It should be noted that, in CERES, moisture (or nitrogen) in one layer is not a perfect substitute for moisture (or nitrogen) in another layer, nor is NH_4 a perfect substitute for NO_3. Thus, the state descriptors do not fully define the true state of the system. However, Burt (1982, pp. 385-7) emphasized the importance of minimizing the dimensionality of the state space to keep dynamic optimization problems tractable, suggesting that the resulting errors introduced were generally acceptable. Accounting variables for predicted deep percolation of water and NO_3 were added to CERES so that environmental constraints could be applied in the optimization model. Other CERES information used in the optimization model include evapotranspiration [ET], root depth on the day before the restart date, harvest date, and final yield.

The Deep Profile: A Geohydrology Simulation Model

CERES does not calculate water or nitrogen balances below the defined root zone. Therefore, the CERES models must be linked to a groundwater model to predict the effect of a given pattern of water and nitrogen percolation on groundwater nitrogen concentrations. This model will be used to determine the number of years required for a given pattern of nitrate leachate flows from the root zone to approach EPA's drinking water standard for NO_3 (10 mg N/l).

The groundwater model is based on simple mass-balance calculations. The soil strata under a given field are shown in Figure 2.2. The

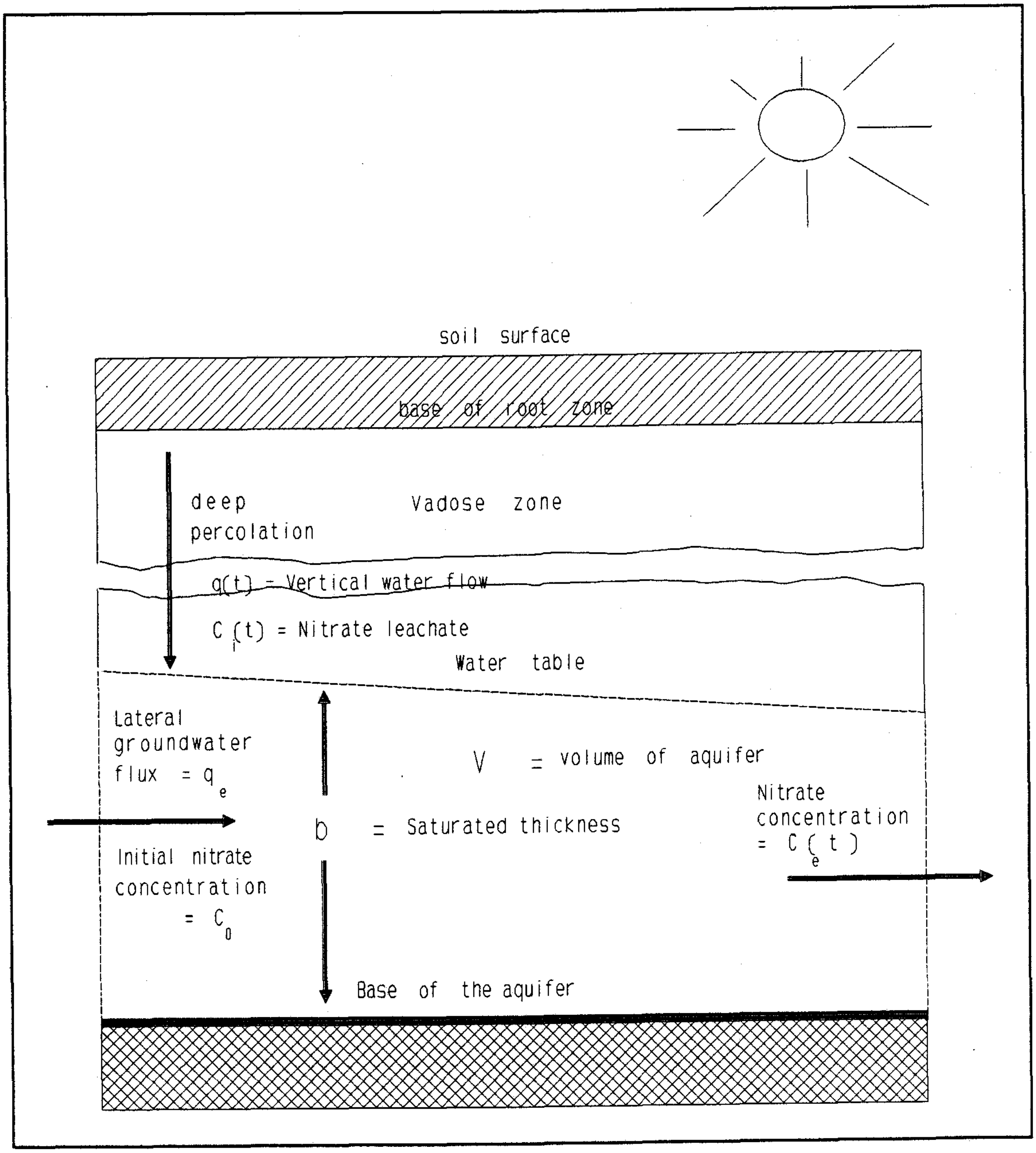

Figure 2.2. Depiction of the Control Volume for the Mass Balance Calculation.

following assumptions are made in this model: 1) saturated thickness of the aquifer is constant beneath a given field, 2) lateral groundwater flux is constant and is much larger than deep percolation, 3) nitrate in percolating water is not degraded (biologically) as it flows from the base of the root zone to the water table, 4) nitrate in percolating water is completely mixed in the aquifer volume [V], and 5) leaching water and nitrates are assumed to enter the water table instantaneously once they leave the root zone. This last assumption is reasonable given the relatively short time required for leachate to move through the vadose zone into the aquifer. Given these assumptions, the groundwater model can be written as:

$$M(t) = M(t-1) + q_e (C_o - C_e(t)) + q(t)\ C_i(t) \quad (2.3)$$

where:

$$C_e(t) = M(t-1)/V \quad (2.4)$$

$$V = Area * b \quad (2.5)$$

or

$$M(t) = M(t-1)\ (1 - q_e/V) + q_e\ C_o + q(t)\ C_i(t) \quad (2.6)$$

$$M(0) = C_o\ V \quad (2.7)$$

$$q_e = 0.1 \text{ meters/day} \times CA \quad (2.8)$$

Equation (2.3) defines the mass of NO_3 in the aquifer at time t [M(t)]. It relates the mass of NO_3 to lateral groundwater flux [q_e], initial nitrate concentrations in the flux [C_o], the quantity of percolating water [q(t)] (estimated by CERES), nitrate concentration in percolating water [$C_i(t)$] (estimated by CERES), and nitrate concentration at time t [$C_e(t)$]. Equation (2.4) defines nitrate concentration in percolating water as nitrogen mass in the aquifer at time t-1 divided by the volume [V] of the aquifer beneath the field. Equation (2.5) defines the aquifer volume as equal to the area of the field [Area] times the average saturated thickness of the aquifer [b]. Equation (2.6) states a transformation of the mass balance relationship. Equation (2.7) defines the initial mass of nitrate in the aquifer at time zero. Equation (2.8) provides an approximation of the lateral groundwater flux as it relates to cross-sectional area of the aquifer [CA] (Gonthier, 1985).

The Economic Model: Optimizing Crop Returns

The CERES models delineate the relationships between production practices and crop yield. Linkage of CERES to a dynamic optimization model is necessary to identify the set of irrigation and fertilization decisions that optimize returns from producing one hectare of a particular crop[24], while meeting environmental constraints. Decisions identified as profit-maximizing are assumed also to maximize the farmer's utility. To further simplify the analysis, it is assumed that, once the crop is planted, the farmer can vary only the irrigation and nitrogen fertilization decisions. The maturity dates of the CERES wheat and potato models are fixed and the maturity date for CERES corn can only vary a few days in response to water or nitrogen stress. Therefore, maturity date is not a decision variable considered in the dynamic optimization model.

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[24]One hectare is a convenient size because all of the units in CERES are based on one hectare. Solving the dynamic optimization model for a single hectare provides the same solution as solving it for an entire field because it only optimizes with respect to the two variable inputs.

All other factors of production are considered fixed except as they relate to water or nitrogen usage (e.g., labor to run the irrigation pumps is a variable input). The per unit prices of water and nitrogen were assumed not to vary with quantity applied. In the optimization models, fixed costs associated with a given crop, such as land, capital, and planting costs are irrelevant in the decision-making algorithm because they are viewed as sunk costs. The initial optimization model can be written as:

$$R = \max_{f_i,\, w_i} \{r(P,\ f_i,\ w_i,\ e_i)\} \tag{2.9}$$

Subject to:

$$f_1 \leq Mxf \tag{2.10}$$

$$c * f_i \leq w_i \quad \text{for } i = 2, 3, \ldots, n \tag{2.11}$$

$$w_i \leq PC_i \quad \text{for } i = 2, 3, \ldots, n \tag{2.12}$$

$$f_i \geq 0 \quad \text{for } i = 1, 2, \ldots, n \tag{2.13}$$

$$w_i \geq 0 \quad \text{for } i = 2, 3, \ldots, n \tag{2.14}$$

The farmer wants to maximize the undiscounted return function [R] given an input and output price vector [P], exogenous factors [e_i] (e.g., weather), the soil irrigation decision [w_i] and fertilization decision [f_i] for the ith period. To optimize R requires identification of the set of fertilization and irrigation decisions that optimize R while satisfying the constraints. The first constraint restricts pre-plant fertilization to some maximum rate [Mxf] based on toxicity. This objective function [R] does not include any discounting because the model considers decisions over only one growing season. The second constraint requires that fertilization in periods 2 through n must be less than a fixed proportion (1/c) of water applied[25]. The third constraint requires that the quantity of water applied be less than or equal to pumping capacity of the irrigation system [PC_i] in the ith period. The last two constraints restrict irrigation and fertilization applications to be non-negative. The above formulation does not include any regulatory policy options to reduce groundwater pollution levels. As discussed earlier, such options can take many forms, including a general restriction on total kilograms per hectare per year or total kilograms per application, constraints on the maximum soil nitrogen levels, seasonal limits on nitrogen applications, constraints on the maximum quantities of deep percolated NO_3 per hectare per year, Pigovian taxes, or simple input taxes. This study will focus on several of these policy options. The general problem, expressed in equation (2.9), is to find the optimal decision set that minimizes the farm-level costs of meeting the constraints. To solve this problem, one could use several approaches, including explicit enumeration, optimal control, and forms of dynamic programming.

Enumeration Techniques

An enumeration technique is by far the easiest to implement and the slowest to solve. Enumeration initially involves transforming continuous

[25]These first two constraints (2.10 and 2.11) are necessary to avoid nitrogen burning. Pre-plant fertilizer applications have differential quantity limitations from nitrogen applications through the irrigation water because pre-plant nitrogen is applied directly to the soil.

variables into discrete variables; otherwise, there would be an infinite number of possible solutions to compare. This is accomplished by dividing the range of the continuous variable into fixed intervals (or sub-ranges), and assuming the midpoint of each sub-range is representative of that sub-range. This midpoint can be called a node for the interval. In this way, one can increase the model's computational performance with the acceptance of increased round-off error caused by fewer nodes.

As an example, if the (continuous) range of values of the soil moisture is divided into 15 discrete levels, soil nitrogen into 8 levels, and growing season into 30 periods, and allowed movement from any given level to 6 possible levels in the next period. The CERES algorithm would then need to simulate 5.25E+85 different decision sequences. This example is significantly smaller, in terms of number of possible movements, then any of the cases that will be examined in this study. The use of explicit enumeration was rejected because it is estimated that it would take 3.33E+78 years (assuming 2 seconds per call of CERES) to complete a single run on the computer used in this study.

Optimal Control Techniques

Ideally, one would use a discrete-time-optimal-control technique (Bellman and Dreyfus, 1962) to solve this network because the yield response functions within CERES are not fully independent of previous decisions and decision variables are continuous. Thus, it is preferable to solve the whole network at once instead of using a decomposition technique such as dynamic programming. Optimal control is an optimization technique with its foundations in the calculus of variations through the 'maximum principle'. "Pontryagin's maximum principle consists of sets of necessary conditions that must be satisfied by optimal solutions" (Pierre, 1986; p. 478). Sufficiency conditions are also necessary for control problems. First, the objective function and constraints must be convex with respect to the controls. The maximum principle, in turn, provides the theoretical basis for the numeric routines used to find a maximum point. But optimal control "by no means assures a global rather then local optimum" (Zavaleta, Lacewell, and Taylor, 1980; p. 791); without any assumptions about convexity of the n dimensional surface, a solution algorithm can identify a local, rather than global maximum.

The general continuous-time optimal control problem faced by the decisionmaker can be represented by the following equations (assuming the standard transversality conditions on the state variable):

$$\text{Max} \int_0^T R(\,w(t),\ f(t),\ Y(Sa(t),\ Ntr(t),\ V(t),\ t),\ P,\ t)\, dt \tag{2.15}$$

Subject to:

$$\dot{Sa}(t) = I(\,w(t),\ Sa(t),\ V(t),\ t) \tag{2.16}$$

$$\dot{Ntr}(t) = K(\,f(t),\ Ntr(t),\ V(t),\ t) \tag{2.17}$$

$$Sa(0) = Sa_0 \tag{2.18}$$

$$Ntr(0) = Ntr_0 \tag{2.19}$$

$$LL \le Sa(t) \le Sat \quad \text{for } 0 \le t \le T \tag{2.20}$$

$$Nmin \le Ntr(t) \le Nmax \quad \text{for } 0 \le t \le T \tag{2.21}$$

$$0 \leq w(t) \leq Pc(t) \quad \text{for } 0 \leq t \leq T \qquad (2.22)$$

$$0 \leq f(0) \leq Mxf \qquad (2.23)$$

$$0 \leq f(t) \leq c*w(t) \quad \text{for } 0 < t \leq T \qquad (2.24)$$

$$\int_0^T Np(w(t), f(t), Sa(t), Ntr(t), V(t), t)\, dt \leq Ef \qquad (2.25)$$

The decisionmaker optimizes the undiscounted net return function [R] for a given field, with respect to two control variables; 1) irrigation quantity [w(t)] and 2) fertilizer quantity [f(t)]. The two state variables in the model are 1) root zone soil moisture levels [Sa(t)] and 2) root zone soil nitrogen levels [Ntr(t)]. These state variables, along with exogenous random factors [V(t)], affect the yield function [Y(.)]. Input and output prices [P] influence returns across time t as well.

Equations (2.16) and (2.17) define the movement of the system with respect to the two state variables. Changes in soil moisture are a function of the irrigation decisions, current soil moisture, random factors, and the period in which the changes occur. Changes in soil nitrogen are a function of the fertilization decisions, current soil nitrogen, random factors, and the period in which the changes occur.

Equations (2.18) and (2.19) define the initial conditions for the state variables. Equations (2.20) and (2.21) describe the boundary conditions for the state variables. LL and Sat are lower and upper physical limits on soil moisture. Nmin and Nmax are lower and upper limits on soil nitrogen. Equation (2.22) ensures that irrigation quantities are non-negative and do not exceed to pumping capacity. Equation (2.23) requires that pre-plant fertilization quantities are less than some maximum recommended amount.[26] Equation (2.24) requires that fertilizer quantities applied after planting are non-negative and less than a fixed proportion of water applied in the same time period.

Equation (2.25) is the integral of nitrogen pollution [Np] over the growing season which eventually reaches the aquifer (i.e., Np is an accumulation of nitrate in the aquifer). This equation constrains the pollution level to be less than or equal to some specified level [Ef]. It also accounts for the effects of nitrogen leached during crop production which does not reach the aquifer until some later date.

Zavaleta, Lacewell, and Taylor developed a simple optimal control model (with eight stages) using the CERES sorghum model to obtain relationships between yield and the control variable (irrigation quantity). No constraints were included in their model, but optimal irrigation strategies were identified under deterministic and stochastic weather conditions. They used a general IMSL library routine (Zavaleta, 1978; p. 49) which minimizes a user-supplied non-linear "function of N variables using a quasi-Newton method" (Rice, 1983; p. 554). In the deterministic version, Zavaleta and his co-authors solved the equation

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[26]These last two constraints do not include minimum irrigation and fertilization levels when application rates are non-zero. Minimum levels would require integer-type variables and constraints which, in turn, would require a computationally intensive solution technique such as Bender's decomposition (Perry, McCarl, and Gray, 1988).

using thirty different weather data sets. In a stochastic example, they used an open loop feedback system to identify an optimal solution. The feedback approach first involves solving the equation using expected weather. Next, the optimal value for the first period's irrigation is fixed and the expected weather up to and including the first period is replaced with actual weather and the equation is re-solved. This process is continued until optimal decisions have been identified for all periods. Although computational capabilities have significantly improved since 1980, they still have not reached the point where the problem addressed in this study is tractable using the Zavaleta approach.

There is an additional problem when using CERES in an optimal control context; yield relationships are not differentiable between days on which CERES changes plant growth stages (which, in turn, are determined by thermal time). Thus, inaccurate gradients may result if the model identifies a solution that, in reality, is suboptimal. Solving the empirical problem in this study with stochastic optimal control techniques would require one to link CERES to a constrained optimization package such as MINOS (Murtagh and Saunders, 1983) which allows for non-linearities in both the objective function and constraints. In the case of corn, for example, the problem would require optimizing an equation with 280 non-linear variables (for a daily model) plus a proportionate number of boundary conditions[27]. Such a solution process could take significant amounts of computer time to solve for one crop. Using <u>very</u> conservative

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[27]Each iteration would call CERES once to compute the objective function and once per non-linear activity in order to compute the gradient vector.

assumptions[28] and a 90 day decision period (e.g., for corn), it would take over two weeks to solve a single problem on the minicomputer used in this study.

Dynamic Optimization Techniques

An alternative to the Zavaleta, Lacewell, and Taylor approach is to use a formulation similar to dynamic programming (DP) for the problem. As Bellman (1968; p. 36) explains,

> The calculus of variations and dynamic programming correspond to the dual approaches to Euclidean geometry. . . . Thus, we can consider a curve to be a locus of points or an envelope of tangents. The calculus of variations corresponds to a curve being taken as a locus of points; dynamic programming views a curve as an envelope of tangents.

DP is a decomposition technique useful for solving certain sequential decision problems. In practice, it compares the marginal returns of various paths to identify the optimal path for a given state and stage. DP can assure attainment of a global maximum for a given network if the optimality principle is met. The optimality principle stated in terms of forward recursion is:[29]

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[28]In this example, it was assumed that MINOS would take an average of 75 iterations per cycle to solve using an average of 280 seconds per iteration to compute the gradients, resulting in 1,470,000 calls of CERES. This example does not include time spent by MINOS in actually solving the problem.

[29]Most DP texts concentrate on the use of backward recursion techniques. In this study forward recursion is simpler to implement numerically; because of special properties of this problem, is at least twice as fast to execute as backward recursion. All references to the

> An optimal sequence of decisions in a multistage decision process problem has the property that whatever the final decision and state preceding the terminal one, the prior decisions must constitute an optimal sequence of decisions leading from the initial state to that state preceding the terminal one (Dreyfus, 1965; p. 14).

If this condition is not met, a DP model may only yield a local optimum[30]. A local (as opposed to a global) optimum can exist when the optimal decision for a given stage and state is changed as a result of the optimal solution for a later stage and state. DP is a discrete optimization technique; however, the state variables soil moisture and nitrogen are continuous. Therefore, it is necessary to use a discretization process in setting this problem up numerically for these continuous state variables. This process can affect the optimal path because it may eliminate the possibility of identifying a true global optimum. In this study, the technique used, to minimize round off error caused by the decretization procedure has been called 'discrete storage of continuous values[31]'. Typically, the objective function will increase as the interval size decreases because of the increased number of alternatives within a given range when profits are maximized.

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solution will assume the use of forward recursion. For an explanation of forward recursion see Dreyfus (1965; pp. 13-15) and Pierre (1986; pp. 390-94).

[30]In this context, local optimum means the solution for a given stage and state holding some or values in all other stages in the decision set constant.

[31]For a full discussion of this technique see Brodie and Kao (1979; 666-7).

The formulation used in this study is based on a DP solution algorithm but does not have all of the desirable properties of DP. First, DP assumes that the marginal product derived from moving from one state and stage to another state in the next stage is invariant to the path taken to reach that state. In the formulation used in this study, however, that assumption cannot be made. Second, CERES only provides the final yields from a given irrigation and fertilization pattern. Therefore, marginal yields must be inferred through comparison of final yields of decision alternatives thereby introducing opportunities for error in the decision process. Thus, to minimize any implication that the solutions resulting from this formulation are (necessarily) globally optimal, the model will be referred to as a dynamic optimization model throughout the remainder of the text.

The general dynamic optimization problem can be represented by the following equations[32]:

$$R(f(t),w(t),V(t),P(t),t) = \max_{w<W,\ f<F} \{MR_t(w(t),f(t),Sa(t),Ntr(t),P,V,t) + R(f(t-1),w(t-1),V(t-1),P,t-1)\} \quad (2.26)$$

Subject to:

$$MR_t(.) = MY(Sa(t),Ntr(t),V(t),t)(Py - Ch) - f(t)Pf - df(t)Lf - w(t)Pw - dw(t)Lw \quad (2.27)$$

$$df(t) = 0 \quad \text{for } f(t) = 0; \quad = 1 \quad \text{otherwise} \quad (2.28)$$

$$dw(t) = 0 \quad \text{for } w(t) = 0 \quad (2.29)$$

[32]These equations use notation similar to the optimal control problem except for the use of discrete time instead of continuous time

$$= 1 \quad \text{otherwise}$$

$$Ntr(t+1) = K(f(t), Ntr(t), V(t), t) \tag{2.30}$$

$$Sa(t+1) = I(w(t), Sa(t), V(t), t) \tag{2.31}$$

$$Sa(0) = Sa_0 \tag{2.32}$$

$$Ntr(0) = Ntr_0 \tag{2.33}$$

$$LL \leq Sa(t) \leq Sat \qquad t = 0,1 \ldots T \tag{2.34}$$

$$Nmin \leq Ntr(t) \leq Nmax \qquad t = 0,1 \ldots T \tag{2.35}$$

$$Wmin * dw(t) \leq w(t) \leq Pc(t) \qquad t = 0,1 \ldots T \tag{2.36}$$

$$0 \leq f(0) \leq Mxf \tag{2.37}$$

$$Fmin * df(t) \leq f(t) \leq c*w(t) \qquad t = 1,2 \ldots T \tag{2.38}$$

$$\text{sum}_{i=1}^{m} Np_i(w(1), f(1), V(1), \ldots, w(i), f(i), V(i)) \leq Ef \tag{2.39}$$

Equation (2.26) provides the basic forward recursion relationship for the dynamic optimization algorithm. Using this relationship, the producer is maximizing a before-tax-net-return function for a given hectare[33] [R] with respect to the two decision variables, irrigation [w(t)] and fertilizer [f(t)] quantities, two state variables, soil moisture [Sa(t)] and nitrogen [Ntr(t)], exogenous random factors [V(t)], and input and output prices [P]. The net return function is the cumulative sum of the daily marginal return functions [$MR_t(.)$] up to and including stage t. The marginal return function (2.27) is defined by the marginal yield function (the incremental change in yields) when moving between stages

[33]Solving the dynamic optimization for a single homogenous hectare or a weighted average of several hectares (which have different effective irrigation rates but the same gross irrigation and fertilization rates) results in the same solution set as solving the system for an entire field.

[MY(.)], the output price [Py], variable harvest cost [Ch], water [Pw] and fertilizer [Pf] costs[34], and fixed irrigation [Lw] and fertilizer [Lf] costs[35]. CERES provides estimates of final or total yields per land unit; thus, marginal (incremental) yields can only be inferred by comparing the final yields of feasible states. This is done by first giving to CERES the optimal treatment pattern up to the current stage for the state of interest, i.e., the candidate state from which it is being evaluated. Then, CERES is provided the appropriate level of water and nitrogen for transition to the current stage and state. Next, CERES receives a fixed post decision period irrigation and fertilization rule to maintain sufficient moisture and nitrogen to take the simulator to harvest. The post-decision period applications are necessary for the evaluation because CERES cannot provide yield estimates of daily marginal changes in water and fertilizer management until the growing season is completed. In the optimization model, fixed costs associated with a given crop, such as land, capital, and planting costs are irrelevant in the decision-making algorithm because they are viewed as sunk costs.

Equations (2.30) and (2.31) define the transition functions from one stage and state to the next stage for both soil moisture [Sa(t)] and nitrogen [Ntr(t)]. Equations (2.32) and (2.33) provide the initial conditions for the state variables. Equations (2.34) through (2.37) define the limits on the feasible state space at time t. Equations (2.36)

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[34]Variable costs consists of water (acquisition and pumping) and nitrogen costs.

[35]Fixed costs include such items as labor to turn on and off the pumps and labor to hook up the fertilizer tanks.

through (2.38) provide the possible decision space at time t. These equations restrict irrigation and fertilization decisions to be either zero or above some minimum amount ([Wmin] and [Fmin])[36] and they restrict the irrigation and fertilization amounts to be less than or equal to specified levels. Equation (2.39) is the sum of the nitrogen leachate function [Np_t(.)] over the time period of interest[37]. This equation constrains groundwater pollution at less than or equal to some specific level [Ef].

Figure 2.3 illustrates the general structure of this three dimensional network, described above. It shows the decision alternatives and the fundamental recursive relationships at stage i+1 for a node of 60 kg N/ha and 30 mm/m. The dashed lines are the non-optimal decision alternatives and the solid line is the optimal decision for that particular stage and state.

The dynamic optimization procedure used for this thesis, like DP, differs from discrete optimal control in several important ways. First, the method used like "DP was developed for the needs of optimal control processes which are of a much more general character than those which are

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[36]This integer-type constraint (requiring a minimum amount of irrigation if irrigation quantity is greater than zero) is based on physical limits on the equipment (e.g. maximum speed of the circles) and the fact that farmers will not apply water or nitrogen below certain levels. This type of constraint is not practical with optimal control.

[37]This period can extend well past the end of the growing season to account for any lagged effects on groundwater. To simplify the solution process, it is assumed that there is no interaction with any pollution-generating crop activity between the harvest and the end of this period of interest.

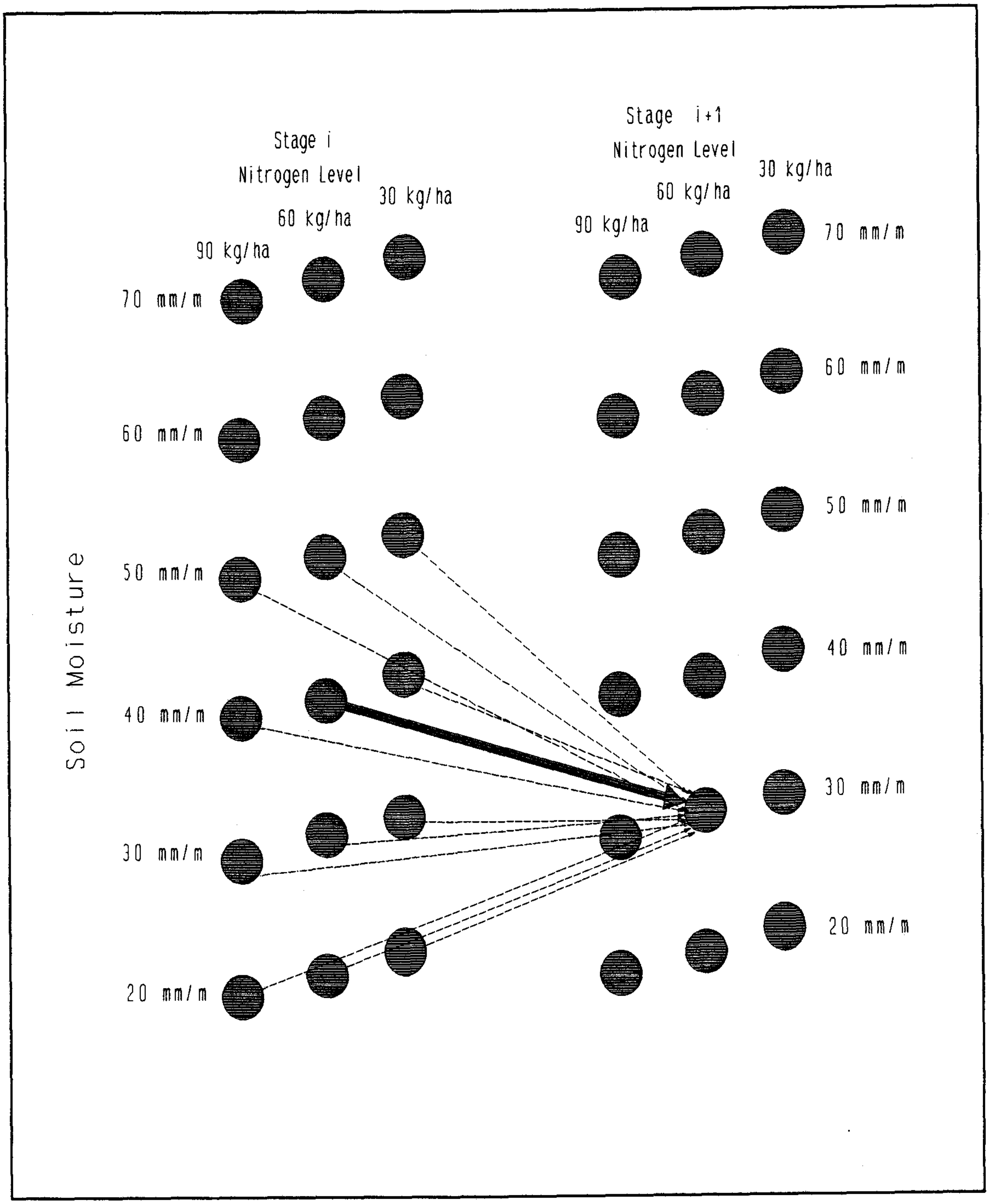

Figure 2.3. Depiction of Solution Process in the Dynamic Optimization Model which Optimizes Net Farm Income with Respect to Soil Moisture and Nitrogen.

describable by a system of differential equations" (Pontryagin et al., 1962). Second, in optimal control the choice set for the state vector is continuous; whereas, in dynamic optimization model, it is divided into a finite number of discrete levels for each element of the state vector; thus, because of this difference in resolution the two techniques can have different optimal solutions. Third, the optimization model solves networks sequentially (stage by stage) instead of all at once by satisfying the optimality principle. Fourth, when solving the network for a given stage and state, the optimization model compares the relative magnitude of the objective function between alternative paths to the current state. In contrast, optimal control uses the numerically-computed first and second order conditions to find the optimal decision set. The optimization model, like DP, "yields the entire family of solutions for all possible lengths of planning horizons"; whereas, optimal control provides only a single solution (Burt, 1982), (unless one solves the optimal control problem multiple times to form a phase diagram.)

The optimization model, like DP but unlike optimal control, does not depend on concavity/convexity to assure global optimization (Burt, 1982; p. 384). This is because it uses a stage-wise exhaustive search procedure instead of a gradient search technique. This technique often results in problems which require excessively large quantities of computer memory and computational resources, a phenomena is referred to as the "curse of dimensionality." Thus, dimensionality of the state space must be minimized to keep the problem tractable. In this case, the controls giving rise to different states must be narrowed down from continuous ranges to discrete approximations. As a result, a dynamic optimization model is a simpler problem typically than a corresponding optimal control formulation because the state space is discrete instead of continuous.

In the current application, a dynamic optimization model, like an optimal control model, must still provide CERES a full season's irrigation schedule to compute yields and net returns for each node that is evaluated. Thus, to compute the marginal returns in moving from one node to another node in the next stage, one must compute the total returns by giving CERES the optimal decision set up to that stage and state and an arbitrary decision rule[38] after that stage. The basic assumption is that the rule used after the current stage will not affect the ranking of feasible choices from the previous stage for a given node. Finally, the dynamic optimization problem can be structured in a way that is more tractable than optimal control on the type of computer used for this study. For example, one can exploit the sequential nature of the solution process to save significant CPU time (50 to 75 percent) by reducing the average amount of computer resources per usage of CERES[39]. The computer memory requirement for the corn version of the dynamic optimization model with 3 sub-fields, 10 moisture states, 8 nitrogen states, and 4 soil layers is 3 megabytes, which is well within the capacity of most mini-computers.

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[38]This arbitrary rule is to insure that the network remains within its boundary conditions. The effects of using different criteria to create this set will be discussed later.

[39]The technique for making these CPU gains will be discussed in detail later in this chapter.

Practical Considerations in Applying the Dynamic Optimization Model

Implementation of the dynamic optimization formulation requires more detail in the model specification than the general formulation discussed above. The measurement units for the state variables are millimeters of soil moisture and kilograms per hectare of soil nitrogen in the root zone. Furthermore, the depth of the root zone is endogenously determined as a function of thermal energy, growth stage and stress level, which in turn causes the state units (in terms of bars[40] of pressure) to change over time[41]. Therefore, in defining the state spaces, it is necessary to use measures of soil moisture and nitrogen that are independent of root depth. At each stage the root zone moisture and nitrogen values provided by CERES should be divided by the root depth at that stage and state. This approach also clarifies the interpretation of the optimal state vectors because the state space is independent of root depth throughout the growing season, allowing one to compare directly the optimal soil moisture in the various stages of crop development.

Electricity provides energy for two functions in the center pivot irrigation. First, electricity is used to power the motors that move the

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[40]A bar is a unit of pressure/suction used to define the force required to extract water from the soil. It is equal to 1,000,000 dynes per square cm.

[41]For example, a crop with 50 mm of water in 0.8 meters of root zone is likely to have a lower stress level, all other factors being equal, than a crop with 50 mm of water in 1.8 meters of root zone. This is because of the increased pressure required to extract water in the latter case.

sprinkler system. The quantity of electricity used per rotation is considered fixed, and independent of rotation speed. Second, electricity is also used to pump water and is assumed to be linearly related to the quantity of water delivered. An additional (variable) cost incurred when operating an irrigation system is labor to turn the pivot system on and off and monitor its operation. These labor and power costs to run the system will be treated as fixed per irrigation in this study. Total costs, however, will vary with the number of irrigations. Further, all circles will be assumed to operate on cycles of not more than 24 hours with no savings in operational costs of labor from allowing the pivot to operate more than one day at a time. Although operational costs are higher, there is nothing in the model to restrict multi-day operational of the circles. The pumping costs per unit volume are the only variable irrigation costs in this study. There is no accounting for down-time resulting from equipment failure.

Fertilizer applications also have fixed and variable costs, but the magnitude of these costs differ depending on whether the application is made pre-plant with a tractor or post-plant through the irrigation system. No optimization is attempted on the type of nitrogen fertilizer in either the pre-plant or post-plant applications. Decisions on the appropriate form of nitrogen fertilizer (i.e., ammonium nitrate or ammonium sulfate) are made exogenously[42]. In this study, only the pre-plant application of

[42]In the version of CERES used for this study, the choices for nitrogen-based fertilizer were forms of ammonium, ammonium nitrate, and nitrate. The form of nitrogen chosen for use in all the CERES models was ammonium sulfate.

fertilizer can be made directly to the soil without dilution in the water. The costs for the pre-plant applications include the cost of operating the spreader equipment (a fixed cost) plus the material cost. Post-plant fertilization costs include labor to connect and disconnect the fertilizer pump (a fixed cost) and the variable materials costs. Since post-plant fertilization is applied through the irrigation system, it can only be done on irrigation days. Per kilogram fertilizer costs for pre-plant and post-plant applications can be different. The farmer's revenues are assumed equal to the price of the crop per unit weight less any per unit harvest costs (e.g., trucking and custom charges) times the yield.

The soil moisture state space is bounded by physical limits for soil moisture. On the low side, soil moisture is bounded by the 'permanent wilting point' or -15 bars of pressure[43]. On the high side, soil moisture is bounded by the saturation point[44]. Any water applied beyond the saturation point will run off the field. As a practical matter, a farmer would not intentionally allow soil moisture to fall close to -15 bars because of the potential for large yield losses. To reflect this, the lower bound on the state space is set at a higher moisture level than -15 bars. On the other hand, because percolation is high when soil moisture approaches the saturation point (especially in the sandy soils used in this study), the farmer cannot pump enough water (without

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[43]Beyond this level, crops can not extract water from the soil. Thus, the crops will die from water stress.

[44]The saturation point is simply the point at which all air space in soil is filled by water. This measure does <u>not</u> have specific pressure units associated with it.

supplemental rainfall) to maintain soil moisture even near the saturation point at any time during the growing seasons. For example, on a sandy soil the daily loss of soil moisture, above field capacity, to percolation can range from 20 to 60 percent. Furthermore, percolation of water has no economic benefit to the problem, assuming soil salinity is not a problem. Thus, the upper bounds on the soil moisture state space reflects the upper bounds of current cultural practices for a given soil and crop.

The bounds on the nitrogen state space do not result from physical limits on the soil, as they do for soil moisture. Clearly, optimal soil nitrogen levels must be non-negative and cannot reach the 100 percent level. Therefore, reasonable management bounds based on current cultural practices are used to define the range of the state space. The upper bound is set such that the nitrogen levels do not reach stage III of the <u>true</u> production surface since it is not economically efficient to do so. Because the CERES wheat and corn models do not have stage III of the production surface for nitrogen embodied in them. Thus, the system must be constrained explicitly to preclude entry into the stage III region of the surface. The lower bound is based on absolute minimum management levels for nitrogen. These levels are similar to the lower bounds on soil moisture. They are the level below which a farmer would never intentionally allow soil nitrogen levels to fall because of the potential for large yield losses. This level can vary from crop to crop. Basically, this bound is intended to keep the optimization model from evaluating an excessive number of candidate nodes which will reduce the crop yield to zero because of insufficient nitrogen. This minimum level is not based on current cultural practices.

Rules determining the feasible movements of the state variable within the state spaces are somewhat complex. There are physical limitations on how much soil moisture and nitrogen can change from one stage to the next. In the case of soil moisture, the system cannot increase soil moisture more than the effective pumping capacity[45] plus expected rain[46] less expected ET. The optimization model cannot reduce soil moisture by more than expected ET less expected precipitation for a given stage. Limits on the changes in soil nitrogen states are similar in structure to those on soil moisture. Increases in soil nitrogen are bounded on the high side by the quantity of irrigation water applied times a toxicity avoidance constant less expected nitrogen usage. Decreases in nitrogen state levels are bounded by expected nitrogen usage[47] in the next stage.

Simplifying assumptions are used in the computation of the groundwater nitrogen pollution constraint. It is assumed that no denitrification occurs in the profile between the defined soil layers and aquifer. Thus, once NO_3 percolates into the deep profile it will

[45]Quantity of irrigation water applied net of spray loss.

[46]Expected rainfall below a specific amount is assumed to be ignored in the farmers decision-making processes. This assumption is based on current cultural practices.

[47]This will be defined latter in this chapter.

eventually reach the aquifer at some point in the future[48]. Therefore, a simple sum of leached nitrogen is calculated for the growing season up to and including the current decision period. Then, this value is compared to the specified pollution level in the policy constraint. If the sum for a given node does not violate the constraint, it is allowed to enter the solution.

Techniques Used to Approximate Continuous State Variables

Although the true state space faced by the farmer is continuous, the dynamic optimization model can only handle a finite number of states within a stage. Further, solution time typically goes up rapidly with the number of states per stage. On the other hand, reducing the number of states used to approximate a continuous state space increases round-off error. With more traditional DP formulations, one can use interpolation to minimize the effect of this form of error (Burt, 1982). The structure of this problem, however, precludes the use of interpolation. The highly non-linear nature of the production relationships requires movement only between 'pre-defined' nodes in the network. Furthermore, the use of interpolation techniques would more than double computing time, because it would not allow the use of optimization techniques which exploit certain features of the dynamic optimization model. This point is discussed later in this chapter. Therefore, an alternative method must

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[48]This is a reasonable assumption because the deep profile of the study area is sand and has minimal carbon content below the defined soil layers. Therefore, there is minimal denitrification in the deep profile.

be used to reduce round-off error while keeping the number of states levels at a manageable level.

The method used here is known as discrete storage of continuous variables (Brodie and Kao, 1979). The technique involves defining a neighborhood around a given node in the state spaces. This neighborhood can be thought of as a box within a given state space (e.g., moisture or nitrogen) with a node at the center of the box. Figure 2.4 illustrates this technique. If it is feasible for a candidate state to move from the previous stage into any part of the box, then it is considered feasible to move to the node in the center of the state neighborhood box. If this feasible state from the previous stage is optimal among the candidate states, then the true state value, for the current stage, would be stored in the location associated with the reference state in the center of the box. This true value would, in turn, be used for feasibility calculations in the next stage. For example, assuming a root depth of 1.2 meters, an effective pumping capacity of 12 mm/ha/day, expected ET of 4 mm/day, no rainfall, and an increment between soil moisture states of 5 mm/m for a field; it would be possible for the network to move from 51 mm/m of soil moisture, stored at location 50 mm/m, to the node associated with 60 mm/m through the use of irrigation. This movement would occur even though expected soil moisture, for the current stage, would only be 57.7.

The size of the increment between levels of the state space must be small enough to allow smooth movement between different levels of the state vector. For upward movement in the state space, the intervals in

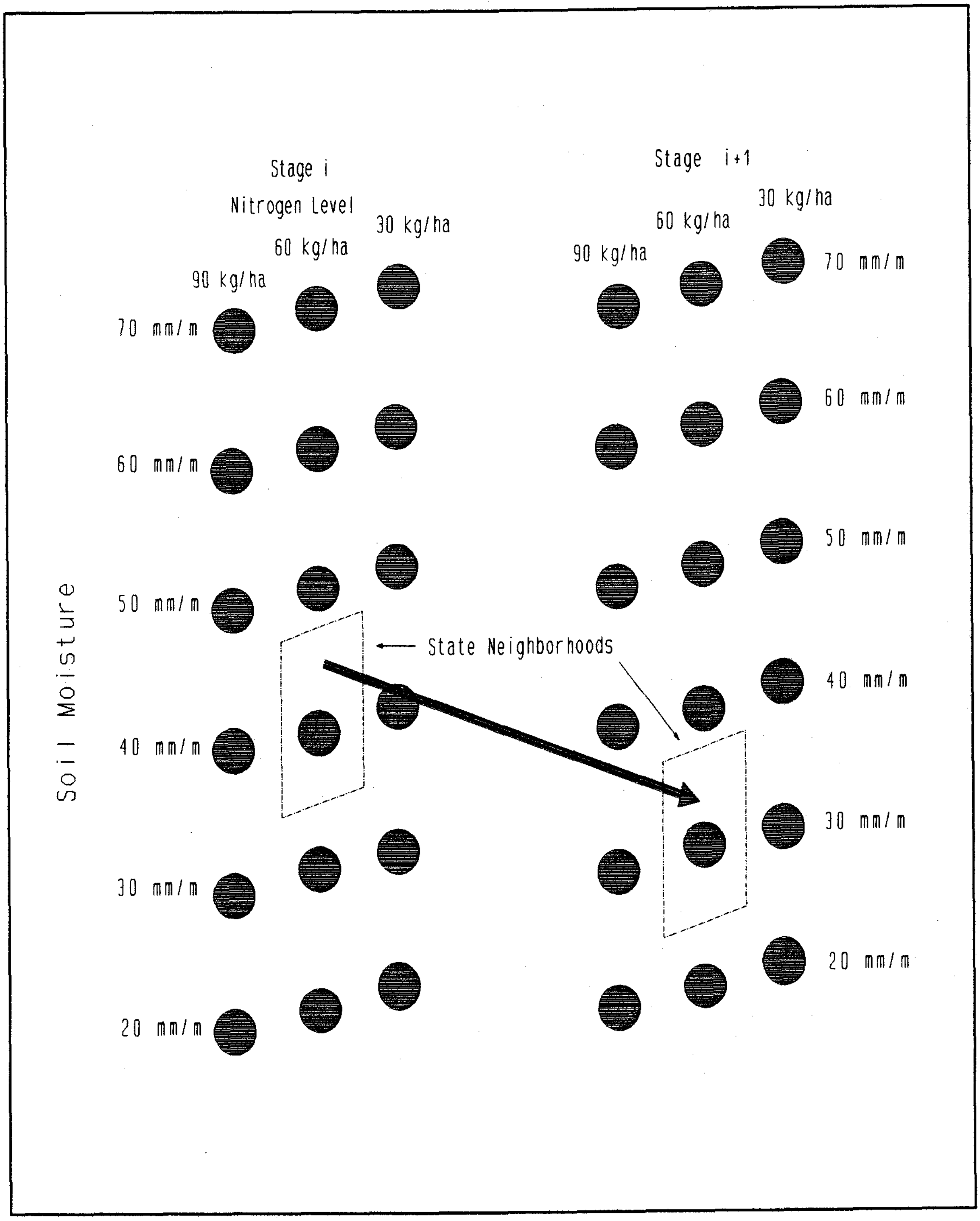

Figure 2.4. Depiction of Discrete Storage of Continuous State Variables in the Dynamic Optimization Model.

the moisture state space must be small enough reasonably to allow irrigating up from at least one lower state level[49]. For downward movement, the increment must be small enough for the soil moisture level to decrease at least one level such that no irrigation and (or) fertilization is always an option until the network reaches the lower bound on soil moisture. Pivot irrigation systems are designed to be able to deliver more water than the plants can use on the days with the highest ET levels. Thus, the maximum acceptable increment is much larger for upward than downward movement though the state space. Therefore, the minimum neighborhood size on the upper side of a given node must be larger than on the lower side. The range of the neighborhood must be at least half the distance to the next node in each direction and dimension of the state space.

As a practical matter, this was accomplished by setting the lower bound[50] on the neighborhood as the state level minus one half the increment value for that state space[51]. The upper bound[52] was set to the state level plus the increment value. This technique provides a practical means to

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[49]These issues also apply to the nitrogen state space.

[50]This lower bound on the state neighborhood defines the minimum state level that candidate states must be able to reach through irrigation and expected rainfall to be classified as a feasible movement though into a given node's neighborhood.

[51]Each dimension of the state space has a unique increment value.

[52]The largest level a state must be able to reach through ET and deep percolation and still be classified as a feasible movement into a given node's neighborhood.

reduce the dimensionality of the state spaces with a minimum of rounding error. These bounds can be expressed mathematically as:

Lower bounds:

$$Rtd(t-1)(\overline{Sa}(t) - Incr_w/2) \leq Rtd(t-1)Sa(t-1) + E(Pc(t)) + E(Ra(t)) - E(Et(t)) \quad (2.40)$$

$$Rtd(t-1)(\overline{Ntr}(t) + Incr_f/2) \leq Rtd(t-1)Ntr(t-1) + w(t)*c - E(Nu(t)) \quad (2.44)$$

Upper bounds:

$$Rtd(t-1)(\overline{Sa}(t) - Incr_w) \geq Rtd(t-1)Sa(t-1) + E(Ra(t)) - E(Et(t)) \quad (2.42)$$

$$Rtd(t-1)(\overline{Ntr}(t) + Incr_f) \geq Rtd(t-1)Ntr(t-1) - E(Nu(t)) \quad (2.43)$$

Equations (2.40) and (2.42) define the lower and upper bounds on movement with respect to a given node's soil moisture neighborhood [$\overline{Sa}(t)$], soil moisture increment [$Incr_w$], expected rainfall [E(Ra(t))], root depth [Rtd(t-1)], expected effective pumping capacity [E(Pc(t))], and expected ET [E(Et(t))]. Equations (2.41) and (2.43) describe the lower and upper bounds on movement with respect to a given node's soil nitrogen neighborhood [$\overline{Ntr}(t)$], soil nitrogen increment [$Incr_f$], irrigation amount, nitrogen concentration limit, root depth, and expected nitrogen usage [E(Nu(t))].

Values for certain state descriptors are rounded to minimize computer memory requirements of the dynamic optimization model. Rounding can introduce error into various computations. For example, water and nitrogen costs at each stage have been rounded to the nearest ten cents.

Root depth is rounded to the nearest millimeter. Soil moisture and nitrogen have been rounded to the nearest millimeter/hectare/meter of root depth and kilogram N/hectare/meter of roots depth, respectively. Deep percolation of water and nitrogen were rounded to the closest millimeter/hectare and kilogram/hectare, respectively. Daily nitrogen usage and ET have been rounded to the nearest kilogram/hectare and tenth of a millimeter/hectare, respectively. Finally, irrigation and fertilizer quantities were rounded to the closest millimeter/hectare and kilogram/hectare, respectively.

Uncertainty and Heterogeneity

The farmer must make decisions on a daily basis using 1) information on what has occurred up to a given day, and 2) expectations of what will occur for the rest of the growing season. In this study, it is assumed that the farmer has perfect information on what has occurred up to the current decision state. However, she/he only has expectations on what will occur in the current stage and for the rest of the growing season. The farmer knows the true state of soil nitrogen and water, root depth, ET, and nitrogen usage at the end of the previous stage for all nodes in the state space. The farmer is assumed to use a naive rule to forecast the nitrogen usage, water usage, and root depth for the current stage, i.e., the current period's nitrogen usage, water usage, and root depth will be the same as the previous period. Given the uniformity of climate in the study area during the irrigation season, this is a much weaker assumption than it may appear.

This formulation for incorporation of uncertainty into the optimization model introduces some aspects of the farmer's decision error caused by climatic uncertainty. However, it cannot fully overcome the ex post nature of models based on a dynamic programming solution algorithm. Therefore, the model is deterministic, in that it implicitly allows the farmer to switch input strategies in response to weather conditions in ways that would be impossible in the real world.

The farmer is also uncertain about the current stage's rainfall and spray loss[53]. For simplicity, expected rainfall is calculated using actual rainfall and assuming that any amount below a specific level is ignored in the farmer's decision-making processes. If the true rainfall is above this level, the farmer will expect only a specified percentage (less than 100 percent) of the total rainfall. This assumption seems to be a reasonable representation of farmer behavior. Expected spray loss is the mean of the seasonal spray loss, with true spray loss treated as a non-negative, truncated normally distributed random variable. To minimize complexity, true spray loss is treated as independent of weather factors such as solar radiation. General weather variables used by CERES <u>after</u> the current stage[54] are assumed equal to typical weather for each day. A

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[53]Spray loss is the quantity of water which is applied to a field but does not reach the plant or soil surfaces. This includes losses due to both mid-air evaporation and wind drift from the intended field. For a discussion of spray loss see Trimmer and Perkens (1987).

[54]The optimization algorithm must use real weather for the current stage to avoid doubling the number of times to CERES is used. The effect on the solution set of using real versus expected weather for one stage should be minimal.

general weather year simulator developed by the U.S. Department of Agriculture [WGEN] (Richardson and Wright, 1984) was used to generate a typical weather year based on historical data from the study area.

The methods used to describe these uncertainties and expectations facing a farmer are simplistic. But, farmers use simplistic rules in determining expectation (Prothero, 1988). The expected solution bias (if any) resulting from these assumptions likely would be to understate the uncertainty facing the farmer because of ex post nature of the optimization model. Furthermore, the model assumes that farmers are monitoring their fields closely, which is not always the case, especially for lower value crops.

The inclusion of these uncertainties, despite their flaws, is important in the search for an optimal decision set because unintentional nitrate leaching can result under certain sets of environmental conditions. For example, the farmer could overestimate water and nitrogen needs of the crop or underestimate rainfall. If so, deep percolation of NO_3 may occur with some positive probability if the magnitude of these uncertainties are not accounted for in the decision process.

In addition, it was recognized that no 65 hectare circle is truly homogenous. A single field's water holding capacity can vary significantly, even if the field is composed entirely of the same soil classification. Additionally, center pivot irrigation systems do not apply water uniformly across a field (James, 1982). In fact, Bernardo

(1987) found that variability in irrigation system efficiency and risk-aversion can explain a significant portion of over-irrigation on grain sorghum. These heterogeneities present special problems when applying constraints on the deep percolation of NO_3 within the dynamic optimization model. If one was solving an unconstrained model, the use of a field-wide average for the soil should give a good approximation of the field-wide average yield. However, with varying holding capacities and uneven water applications, the predicted average percolation rate using average soil may be zero when, in fact, parts of the field (with lower water holding capacity) are leaching some quantities of NO_3. Thus, the optimal decision set which appears to meet the environmental constraint using average soil and application levels does not satisfy that constraint on an actual field with heterogeneous soil and uneven applications.

To overcome this limitation of CERES, routines were developed as an interface between CERES and the dynamic optimization model to allow for the simultaneous growing of a crop on a number of different sub-fields. This interface provides the average sub-field yields, NO_3 leachate, and other variables to the optimization model. Although each of the sub-fields is treated as a homogenous unit, they can differ from other sub-fields in soil characteristics and application quantities.

The Policy Constraint

Policy constraints are used in a subset of the dynamic optimization models employed for this study. There are two types of policy constraints used. The first type restricts nitrate leachate quantity. The inclusion of a constraint on deep percolation of NO_3 in the optimization model creates a few complications for the solution process. First, CERES is employed using the irrigation and fertilization pattern from the candidate state. Next, the cumulative nitrate leachate up to and including the current stage is calculated for this candidate node. Then, the quantity of leachate is compared to the specified constraint level. If it exceeds the constraint level, the node is prohibited from entering into the solution. The second type of constraint restricts the quantity of fertilizer used. The fertilizer constraint functions exactly the way the leachate constraint does except the total quantity of fertilizer up to and including the current stage is used in determining feasibility.

Performance Optimization Techniques

Given the significant computer resources necessary to run this model, substantial effort was expended to reduce solution times. For example, the dynamic optimization model is designed only to consider making decisions on days when irrigation could be non-zero. In the case of wheat, for example, days between the fall planting date and Julian date 90 are ignored for decision-making purposes because farmers do not apply either water or nitrogen during this period. Similarly, as harvest approaches, irrigation water and fertilizer are no longer useful to the crops. Thus, the optimization model is designed to stop irrigation and fertilization a given number of days before harvest, reducing the dimensionality of the stage space.

The ability to limit the number of stages also allows for efficient testing and debugging by optimizing over small subsets of the growing season. To minimize the computer time spent each time CERES is used, computer routines save all information necessary to restart CERES from each node in the state spaces at any stage of the growing season. Since CERES is a daily-based model, this avoids repeating calculations in CERES that simulate plant growth up to the current stage. The technique exploits the sequential nature of the forward recursion in the dynamic optimization model to cut computation resources spent in the CERES by one half for corn and potatoes and by one fourth for winter wheat. Additionally, the optimization model periodically saves the current solution to mass storage to provide starting values for restarting the optimization model, in the case of computer failure.

Solution Properties

Although the solutions for DP formulations satisfying Bellman's Optimality Principle are globally optimal (Bellman, 1968), the formulation used in this thesis does not fully meet Bellman's criteria. Ideally, to solve problems based on a DP solution algorithm one would use the 'true' marginal productivities from a given stage and state when ranking various feasible states to determine the optimal movement. Given the structure of the CERES models, however, one cannot directly link changes in final yield with changes in a given stage and state.

As discussed earlier, CERES only provides final yield when given the fertilization and irrigation schedules for the entire growing season. For example, assume the farmer irrigates and fertilizes in a given stage such that soil moisture and nitrogen are well above the yield limiting levels. It would then take several stages for moisture and (or) nitrogen stress to occur. However, the dynamic optimization model could incorrectly rank the nodes when comparing the above state with a state which may only avoid stress for the current stage. This can occur because of the discretization process used for the continuous state variable. In this example, the prior state might only be able to move to the upper edge of the neighborhood whereas the latter state might only be able to move to the lower edge of the neighborhood. When calculating the predicted marginal productivity of the former state, the dynamic optimization model cannot distinguish between yield contributions resulting from stress avoidance in the current stage and stress avoidance in subsequent stages. Also, because of this flaw in calculating the predicted marginal productivities, the optimal path for the dynamic optimization model may not have the highest objective function value among the various states at some intermediate stages.

Another violation of Bellman's principle is that yields are influenced by the path the system moves to a given state. This stage interdependence occurs because of the compression in the number of state spaces. CERES has approximately 29-33 potential state variables[55] which

[55]This number varies from crop to crop. If soil variables were broken down by layer the range would be approximately 66 for corn and wheat and approximately 51 for potatoes.

were not used in the state space computations. These include such items as root biomass, leaf area index, stem biomass, plants per square meter, and stem nitrogen concentration. Using even a significant subset of these would be computationally impractical. This reduction in the dimensionality (or state compression) also may affect model solution performance if the relative ranking of the nodes is changed. The above limitations in the dynamic optimization model are expected to be sufficiently small that they are unlikely to cause solutions to differ in structure from the 'true' solutions. More importantly, direction and order of magnitude of change should be accurate.

The Linear Programming Model: A Crop Mix Model of a Diversified Farm

The farmer wishing to decrease nitrate leachate can alter crop mix as well as management strategies for a given field. To allow for this strategy, a simple linear programming (LP) model was formulated for a representative farm in the study area. The purpose of the model is to forecast optimal crop mix decisions under several policy options with respect to improving groundwater quality. Numerous studies use farm-level crop mix models. For example, Perry et al. (1989) analyzes both government program participation and crop mix decisions for a Texas farm using mixed integer programing. El-Nazer and McCarl (1986) examines crop mix decisions available to a large Eastern Oregon farm. The LP model used in this study, unlike Perry et al., is similar to that formulated by El-Nazer and McCarl.

The LP formulation used here includes basic federal farm program provisions including acreage set asides and deficiency payments. The model's objective is to find the optimal crop mix within the context of the various groundwater policy options. It is that assumed base acreage for government programs does not limit acreage planted to any program crop[56]. The assumption is made that the representative farm contains one Agricultural Stabilization and Conservation Service (ASCS) farm unit. The policy options modeled include the base scenario and restrictions on nitrate leachate. The LP is restricted to seven rotation strategies: wheat-corn-wheat-potatoes (WCWP), corn-alfalfa-alfalfa-alfalfa-potatoes (CAAAP), wheat-alfalfa-alfalfa-alfalfa-potatoes (WAAAP), corn-alfalfa-alfalfa-alfalfa-alfalfa-potatoes (CAAAAP), alfalfa-alfalfa-alfalfa-potatoes (AAAP), alfalfa-alfalfa-alfalfa-alfalfa-potatoes (AAAAP), and wheat-alfalfa-alfalfa-alfalfa-alfalfa-potatoes (WAAAP). All rotations have been used in the area and reflect the biological need to plant potatoes no more than one out of four years, to avoid disease and pest problems.

A tableau version of the crop mix model employed is given in Table 2.1 for a nitrate restriction case; the definitions and the notation used are contained in Table 2.2. This tableau provides all of the basic structures used for the other policy options. The model maximizes undiscounted-net-farm income for a given year. The first 20 activities

[56]In the long-run models, it is assumed farmers will reach a stable crop mix which will be used forever. In this case, base acreage (which is an average of historical acreage) will have time to adjust to and be the same as actual acreage.

Table 2.1. Tableau of Crop Mix Model

	N Constraint Level:	w Corn A	w/o Corn A	w Corn G	w/o Corn G	w Wheat A	w/o Wheat A	w Wheat G1	w/o Wheat G1	w Wheat G2	w/o Wheat G2	w Potato G	w/o Potato G	w Potato 3	w/o Potato 3	w Potato 4	w/o Potato 4
	Objective Function	-CC	-CC	-CC	-CC	-CW	-CW	-CW	-CW	-CW	-CW	-CP	-CP	-CP	-CP	-CP	-CP
	Land:																
(R1)	Acreage Planted	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
	Input usage:																
(R2)	Water use	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu
(R3)	N Fertilizer use	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu	-fu
	Input cost:																
(R4)	Water cost	-wcc	-wcc	-wcc	-wcc	-wcw	-wcw	-wcw	-wcw	-wcw	-wcw	-wcpg	-wcpg	-wcpa	-wcpa	-wcpa	-wcpa
(R5)	N Fertilizer Cost	-fcc	-fcc	-fcc	-fcc	-fcw	-fcw	-fcw	-fcw	-fcw	-fcw	-fcpg	-fcpg	-fcpa	-fcpa	-fcpa	-fcpa
	Production:																
(R6)	Corn	-cy1	-cy2	-cy1	-cy2												
(R7)	Wheat					-wy1	-wy2	-wy1	-wy2	-wy1	-wy2						
(R8)	Potatoes											-pyg	-pyg	-pya	-pya	-pya	-pya
(R9)	Alfalfa																
	Policy Constraint:																
(R10)	Quan. NO3 Leachate	-lc1	-lc2	-lc1	-lc2	-lw1	-lw2	-lw1	-lw2	-lw1	-lw2	-lpg1	-lpg2	-lp1	-lp2	-lp1	-lp2
(R11)	NO3 Restriction																
	Rotation:																
(R12)	A1:A2																
(R13)	A2:A3																
(R14)	A3:A4,P3													+1	+1		
(R15)	A4:P4															+1	+1
(R16)	P3,P4:W,C	+1	+1			+1	+1							-1	-1	-1	-1
(R17)	P3,P4,W,C:A1	-1	-1			-1	-1										
(R18)	PG:W1							+1	+1			-1	-1				
(R19)	W1:C			+1	+1			-1	-1								
(R20)	C:W2			-1	-1					+1	+1						
(R21)	W2:PG									-1	-1	+1	+1				
	Set Aside:																
(R22)	Corn Alf.	+1	+1														
(R23)	Corn Grain			+1	+1												
(R24)	Wheat Alf.					+1	+1										
(R25)	Wheat Grain 1							+1	+1								
(R26)	Wheat Grain 2									+1	+1						

Table 2.1. (Continued) Tableau of Crop Mix Model.

	w Potato A3	w/o Potato A3	w Potato A4	w/o Potato A4	Alfalfa 1	Alfalfa 2	Alfalfa 3	Alfalfa 4	Corn Idlement Alf	Corn Idlement Grn	Wheat Idlement Alf	Wheat Idlement Grn1	Wheat Idlement Grn2	Total Input Usage Water	Total Input Usage Nitrogen	Total Input Cost N Leached	Total Input Cost Water	Total Input Cost Nitrogen
	-CP	-CP	-CP	-CP	-CA1*	-CA2	-CA2	-CA2									-1	-1
(R1)	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1					
(R2)	-wu	-wu	-wu	-wu	-wu	-wu	-wu	-wu						+1				
(R3)	-fu	-fu	-fu	-fu	-fu										+1			
												+1						
(R4)	-wcpa	-wcpa	-wcpaa	-wcpaa	-wca1	-wca2	-wca2	-wca2										+1
(R5)	-fcpa	-fcpa	-fcpaa	-fcpaa	-fca													
(R6)																		
(R7)																		
(R8)	-pya	-pya	-pya	-pya														
(R9)					-ay1	-ay2	-ay3	-ay4										
(R10)	-lp1	-lp2	-lp1	-lp2												+1		
(R11)										+1								
(R12)					-1	+1												
(R13)		-1	+1															
(R14)	+1	+1			-1	+1												
(R15)			+1	+1				-1										
(R16)									+1		+1							
(R17)	-1	-1	-1	-1	+1				-1		-1							
(R18)							+1											
(R19)						+1	-1											
(R20)						-1		+1										
(R21)								-1										
(R22)					-sc													
(R23)						-sc												
(R24)											-sw							
(R25)							-sw											
(R26)													-sw					

* Includes fall establishment costs

Table 2.1. (Continued) Tableau of Crop Mix Model

	Total Returns					
	Corn	Wheat	Potatoes	Alfalfa		RHS
	+PC	+PW	+PP	+PA		
(R1)					≤	QL
(R2)					≤	0
(R3)					≤	0
(R4)					≤	0
(R5)					≤	0
(R6)	+1				≤	0
(R7)		+1			≤	0
(R8)			+1		≤	0
(R9)				+1	≤	0
(R10)					≤	0
(R11)					≤	QNLH
(R12)					≤	0
(R13)					≤	0
(R14)					≤	0
(R15)					≤	0
(R16)					≤	0
(R17)					≤	0
(R18)					≤	0
(R19)					≤	0
(R20)					≤	0
(R21)					≤	0
(R22)					≤	0
(R23)					≤	0
(R24)					≤	0
(R25)					≤	0
(R26)					≤	0

Table 2.2. Description of the Constraints and Activities Presented in Tableau.

ACTIVITIES:

Corn A - w/o - Acreage of corn planted in an alfalfa rotation without leachate constraint

Corn A - w - Acreage of corn planted in an alfalfa rotation with leachate constraint

Corn G - w/o - Acreage of corn planted in a grain rotation without leachate constraint

Corn G - w - Acreage of corn planted in a grain rotation with leachate constraint

Wheat A - w/o - Acreage of wheat planted in an alfalfa rotation without leachate constraint

Wheat A - w - Acreage of wheat planted in an alfalfa rotation with leachate constraint

Wheat G1 - w/o - Acreage of wheat planted in the first year of a grain rotation without leachate constraint

Wheat G1 - w - Acreage of wheat planted in the first year of a grain rotation with leachate constraint

Wheat G2 - w/o - Acreage of wheat planted in the third year of a grain rotation without leachate constraint

Wheat G2 - w - Acreage of wheat planted in the third year of a grain rotation with leachate constraint

Potato 3 - w/o - Acreage of corn planted in a five year alfalfa-grain rotation without leachate constraint

Potato 3 - w - Acreage of corn planted in a five year alfalfa-grain rotation with leachate constraint

Potato 4 - w/o - Acreage of corn planted in a six year alfalfa-grain rotation without leachate constraint

Potato 4 - w - Acreage of corn planted in a six year alfalfa-grain rotation with leachate constraint

Potato 3 - w/o - Acreage of corn planted in a four year alfalfa rotation without leachate constraint

Table 2.2. (Continued) Description of the Constraints and Activities Presented in Tableau.

ACTIVITIES:

Potato 3 - w - Acreage of corn planted in a four year alfalfa rotation with leachate constraint

Potato 4 - w/o - Acreage of corn planted in a five year alfalfa rotation without leachate constraint

Potato 4 - w - Acreage of corn planted in a five year alfalfa rotation with leachate constraint

Potato G - w/o - Acreage of corn planted in a grain rotation without leachate constraint

Potato G - w - Acreage of corn planted in a grain rotation with leachate constraint

Alfalfa 1 - Acreage of one year old alfalfa

Alfalfa 2 - Acreage of two year old alfalfa

Alfalfa 3 - Acreage of three year old alfalfa

Alfalfa 4 - Acreage of four year old alfalfa

Idle Corn Alf - Acreage of land taken out of production to comply with farm program provisions related to corn in an alfalfa rotation.

Idle Corn Grn - Acreage of land taken out of production to comply with farm program provisions related to corn in a grain rotation.

Idle Wheat Alf - Acreage of land taken out of production to comply with farm program provisions related to wheat in an alfalfa rotation.

Idle Wheat Grn1 - Acreage of land taken out of production to comply with farm program provisions related to wheat in a grain rotation.

Idle Wheat Grn2 - Acreage of land taken out of production to comply with farm program provisions related to wheat in a grain rotation.

Water - Millimeters of irrigation water applied across the entire farm

Nitrogen - Kilograms of nitrogen based fertilizer applied the entire farm

N Leachate - Kilograms of Nitrates leached below the root zone

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Table 2.2. (Continued) Description of the Constraints and Activities Presented in Tableau.

ACTIVITIES:

Water Costs - Total variable cost of water for the farm.

Nitrogen Costs - Total variable cost of nitrogen fertilizer for the farm.

Corn - Gross profits from the sale of corn.

Wheat - Gross profits from the sale of wheat.

Potatoes - Gross profits from the sale of potatoes.

Alfalfa - Gross profits from the sale of alfalfa.

CONSTRAINTS:

R1 - Insures That total acreage planted or set aside does not exceed the available land (QL).

R2 - Accounts for total hectare-millimeters of water applied

R3 - Accounts for total kilograms of nitrogen fertilizer applied

R4 - Accounts for total expenditures on irrigation water

R5 - Accounts for total expenditures on nitrogen fertilizer

R6 - Sums the production in corn

R7 - Sums the production in wheat

R8 - Sums the production in potatoes

R9 - Sums the production in alfalfa

R10 - Sums the nitrate leachate generated by production of corn, wheat, and potatoes

R11 - Constrains the nitrate leachate to be less than a given level (QNLH)

R12 - Links acreage in one year old alfalfa to acreage in two year alfalfa

R13 - Links acreage in two year old alfalfa to acreage in three year alfalfa

R14 - Links acreage in three year old alfalfa to acreage in four year alfalfa or potatoes

Table 2.2. (Continued) Description of the Constraints and Activities Presented in Tableau.

CONSTRAINTS:

R15 - Links acreage in four year old alfalfa to acreage in potatoes

R16 - Links acreage in potatoes with acreage in corn or wheat

R17 - Links acreage in potato, wheat, and corn with acreage in one year old alfalfa

R18 - Links acreage in potatoes in a grain rotation with acreage in first year wheat

R19 - Links acreage in first year wheat with acreage in corn

R20 - Links acreage in corn with acreage in third year wheat

R21 - Links acreage in third year wheat with potatoes in a grain rotation

R22 - Ratio constraint to ensure proper amount of acreage is idled for set aside for corn in an alfalfa rotation.

R23 - Ratio constraint to ensure proper amount of acreage is idled for set aside for corn in a grain rotation.

R24 - Ratio constraint to ensure proper amount of acreage is idled for set aside for wheat in an alfalfa rotation.

R25 - Ratio constraint to ensure proper amount of acreage is idled for set aside for wheat in the first year of a grain rotation.

R26 - Ratio constraint to ensure proper amount of acreage is idled for set aside for wheat in the third year of a grain rotation.

represent crop production activities in seven rotations. The technical coefficients for these 20 activities are based on results from the dynamic optimization model. The dynamic optimization coefficients include water and fertilizer costs and quantities, yield, and leachate quantities. These coefficients are optimal for a given crop and leachate constraint level, a characteristic that is different from most LP crop-mix models. Also note that the only yield differences resulting from rotational effects are for potatoes following grain versus potatoes following alfalfa.

The next four activities represent one through four year old alfalfa crops. Note that no yield difference is assumed for potatoes following three year old alfalfa versus four year old alfalfa. The alfalfa yield coefficients are based on average yield data from representative farms in the region. It is assumed that no nitrates leach from the alfalfa fields. Thus, the farmer can lower total farm nitrate pollution, for example, by shifting from WAAAP to WAAAAP. The next five activities are set aside acreage for corn and wheat. The succeeding five activities are primarily for accounting purposes of input costs and usage and nitrogen leachate. The last four activities provide a breakdown of gross returns by crop.

Constraint R1 limits acreage to the land available on the farm. Constraints R2-R5 account for water and fertilizer costs and usage, based on data from the dynamic optimization model. Constraints R6-R9 calculate total production for each crop based on data from the dynamic optimization model. Constraint R10 sums the nitrate leachate across the entire farm.

Constraint R11 restricts total farm nitrate leachate to be less than a given level. Formulations for the other policy options do not include this constraint. Constraints R12-R21 are used to manage the various rotations. An explanation of how such rotational constraints work is provided in El-Nazer and McCarl (1986). Constraints R22-R26 insure that appropriate acreage set asides are made for corn and wheat.

Summary

This chapter has provided both the theoretical framework for the study and a detailed description of the models used in the analysis. The first models discussed were the CERES crop simulators which act as production functions to relate the quantities and timing of water and nitrogen applications to plant yields. Next, a simple mass balance model for an aquifer was described. The aquifer model links nitrate leachate from the root zone with nitrate concentrations in the aquifer. Third, a dynamic optimization model was presented which maximizes undiscounted-net-field level income with respect to the timing and quantities of irrigation water and nitrogen fertilizer. Finally, an LP model was described which is used to maximize undiscounted-net-farm income with respect to crop mix given any policy constraint. The next chapter discusses the data used to implement these various components of the assessment framework.

CHAPTER 3: DATA SOURCES

Introduction

An extensive data set was necessary to fully utilize the models described in Chapter 2. The CERES models require detailed information on crop and environmental conditions throughout the growing season, including residue levels, soil, weather, cultivar, and management practices. The dynamic optimization model requires information on crop and input prices and labor costs associated with fertilizer and irrigation applications. The solution parameters used to generate each analysis of the optimization model are reviewed. In addition, the LP model requires per hectare production costs for each crop for all potential rotations. The LP model also requires average yield data for alfalfa since no CERES model is available for alfalfa.

Data Used for the CERES models

Source of Actual Weather

The "real" weather data used for the study area were collected from several sources (Prothero, 1988; Redmond, 1988; and Solar Monitoring Lab, 1987). For 1979-86, the weather data were from the Hermiston, Oregon weather station, while for 1987-88, data was from an on-farm weather station in Echo, Oregon (which is about 8 miles from Hermiston) except for two short periods in the winter when the station were inoperative; during these periods, Hermiston weather data were used. The Echo data were used because the actual farm crop data used in validating the corn and wheat models is located in Echo. These data were used for all three CERES crop models.

These data sets had a significant number of missing observations (104 of 3393 days, or three percent) for global solar radiation because of equipment break downs. Having a complete data set was necessary before any CERES model could be used because the model requires daily data to simulate growth. Econometric forecasting techniques were used to fill these missing data points using the SHAZAM software package (White, 1978). The econometric model formulation is dependent on the availability of other data for a missing day or days. Complete data sets were available for daily temperature and precipitation. Some of the days missing global solar radiation data did have data on diffuse and/or direct solar radiation. Furthermore, when only a single day's data was missing, leads and lags on global solar radiation could be used. The following were the general forms of the regressions used:

Linear model:

$$GR = b_0 + b_1\, DFR + b_2\, DR + b_3\, TD + b_4\, TM + b_5\, PD + b_6\, GR_{t-1} + b_7\, GR_{t+1} + E_t \quad (3.1)$$

Log-Linear model:

$$\ln(GR) = b_0 + b_1 \ln(DFR) + b_2 \ln(DR) + b_3 \ln(TD) + b_4 \ln(TM) + b_5\, PD + b_6 \ln(GR_{t-1}) + b_7 \ln(GR_{t+1}) + E_t \quad (3.2)$$

Equation (1) is the general form of the linear model used and equation (2) is the general form of log-linear model used[57]. The dependent variable is global solar radiation (GR), which needs predicted values to fill in for the missing data. The independent variables include contemporaneous values of: diffuse solar radiation (DFR), direct solar radiation (DR), mean temperature (TM), temperature differential (TD) (the difference between maximum and minimum temperatures for that day), and a dummy variable for precipitation (with 1 indicating a day with measurable rain), as well as both the previous day's global solar radiation (GR_{t-1}) and the next day's global solar radiation (GR_{t+1}). The log-likelihood criteria were used to select between the linear and log model for a given missing point or group of points. Each missing point or group of points required a separate regression; therefore, it was necessary to run 41 sets of regressions. The sample for the regression was set at 20 days before and 20 days after the missing data point(s). An example of the SHAZAM source code and output used for one of the missing groups of global radiation data points can be found in the Appendix B.

Given the computer resources required to run the dynamic optimization model, only three weather years were selected for use in the analysis. The 1987-88 data were used in the base analysis because of data limitations on grower production and management behavior. The other two years were selected based on growing degree days (base 10 degrees Celsius)

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[57]The subscript t is implied for all the variables except the lag and lead variables.

for the primary portion of the growing season (Julian day 152 to Julian day 242). These growing degree days were calculated using a simple FORTRAN program (DTT, provided in Appendix A). The years were ranked based on the growing degree days with the highest and lowest years used to preform sensitivity analysis on the effect of weather year choice. Table 3.1 provides a growing degree day ranking of the weather years. Data from these three real weather years are provided in Appendix B. Based on this ranking, 1980 was selected as the low growing degree day year and 1986 as the high growing degree day year.

Expected Weather Year Generation

The expected weather files were generated using a slightly modified version of WGEN (Richerson and Wright, 1984)[58]. The real weather files from 1980-88 were used as inputs to the parameter generator for WGEN named WGENPAR[59]. WGENPAR calculates aggregate statistics from a set of actual weather including monthly amplitude, mean, and standard deviations for rainfall, maximum temperatures, and minimum temperatures. It also estimates the parameters for a gamma function which is used by WGEN to describe the probability of rainfall occurring on a given day.

Using these parameters, WGEN generated 21 years of random weather. From these random weather years, the year with the median number of

[58]The modifications were limited to the input and output routines therefore no source listing is provided.

[59]The parameters generated by WGENPAR can be found in Appendix B.

Table 3.1. Ranking of Weather Years in Terms of Growing Degree Days for June, July, and August.

Year	Growing Degree Days (Base 10 C°)	Rank
1980	879.75	1
1981	930.70	3
1982	1028.10	7
1983	910.55	2
1984	943.30	4
1985	1038.85	8
1986	1093.25	9
1987	1002.85	5
1988	1017.85	6

growing degree days was used as expected weather for the corn and wheat model using the, DTT, program. Table 3.2 provides the ranking of the random weather years in terms of growing degree days. The corn model uses just this median year while the wheat model also uses portions of the previous random weather year because planting occurs in the previous fall. The potato model requires that no frost occur after emergence to avoid killing the crop. Thus, an expected weather year was selected from the subset of years in which frost did not occur between emergence and harvest. The basis for the selection was the closeness to the median year in terms of growing degree days. Data from all three of these expected weather years are provided in the Appendix B.

Soil Used for CERES

As discussed in the introduction, the aquifers of interest for this study are the sedimentary units. These units are generally overlaid with well drained to excessively drained alluvial soils. There are several soils with high nitrate pollution potential, including Quincy (56,056 hectares in Morrow and Umatilla counties), Sagehill (20,733 hectares), and Winchester (7,224 hectares) sands and loamy sands. The dominate soil series in the study area are Quincy sands (Harper, 1948; Johnson and Makinson, 1988; and Hosler, 1983). This is the soil series used for this study. Figures 3.1 and 3.2 depict the soils in the northern part of Umatillia county and the northern part of Morrow county. It was assumed that a field irrigated by a center pivot system contained equal portions of three different types of soils within the Quincy series. Table 3.3

Table 3.2. Ranking of Random Weather Years in Terms of Growing Degree Days for June, July, and August.

Year	Growing Degree Days (Base 10 C°)	Rank
1	966.10	11
2	915.40	3
3	938.75	6
4	912.50	2
5	1113.20	21
6	991.30	16
7	1060.85	19
8	949.75	8
9	986.70	14
10	1071.70	20
11	869.85	1
12	992.25	17
13	962.60	10
14	968.95	12
15	1034.70	18
16	948.40	7
17	953.60	9
18	920.20	4
19	933.60	5
20	975.65	13
21	989.70	15

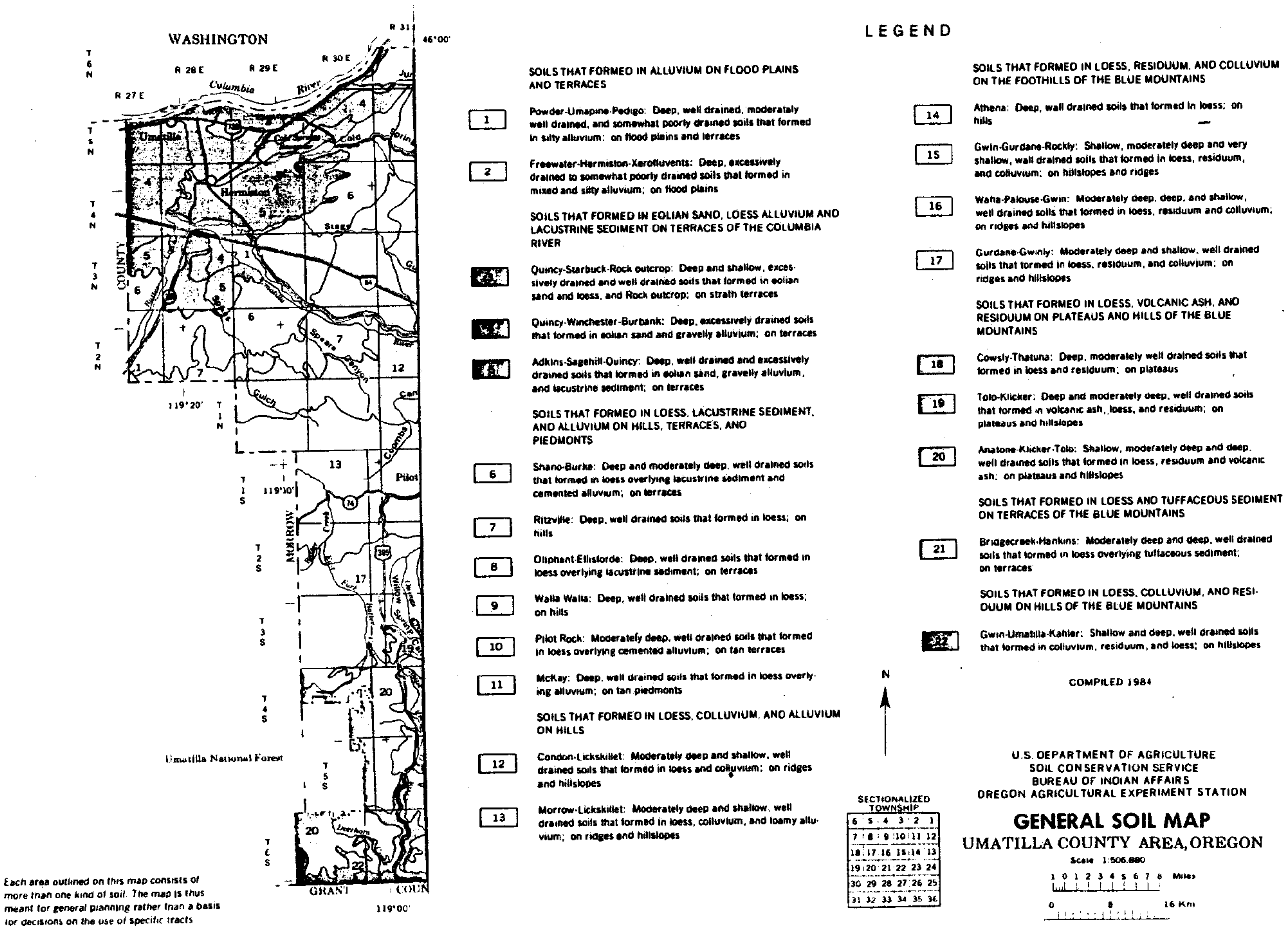

Figure 3.1. General Soil Map for Western Umatilla County, Oregon.
Source: Johnson and Makinson, 1988.

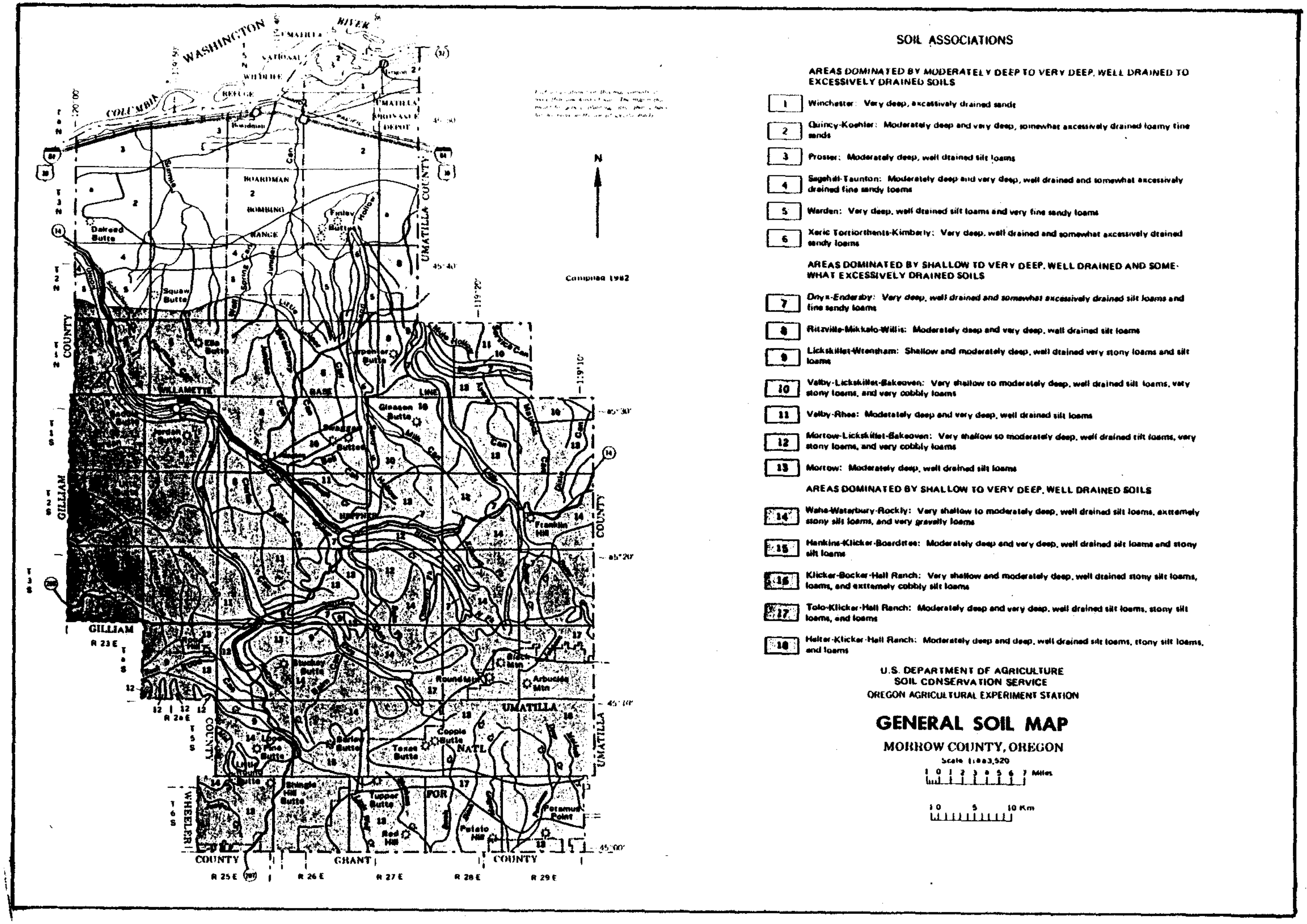

Figure 3.2. General Soil Map for Morrow County, Oregon.
Source: Hosier, 1983.

Table 3.3. Characteristics for the Three Types of Quincy Sands Used for this Study.

Layer Thickness (cm)	-15 Bars (%)	-0.5 Bars (%)	Saturation (%)	Soil Water (%)	Root Weight Index	Bulk Density (g/cm^2)	Org. Cont. (%)	NH_4 (ppm)	NO_3 (ppm)	pH
Quincy Sand - High Flow										
15.	.200	.260	.355	.260	1.000	1.40	.30	1.2	1.2	6.8
15.	.200	.260	.355	.260	0.638	1.40	.30	1.2	1.2	6.8
30.	.200	.260	.355	.260	0.407	1.40	.30	1.2	1.2	6.8
40.	.200	.260	.355	.260	0.202	1.40	.30	1.2	1.2	6.8
Quincy Sand - Low Flow										
15.	.250	.330	.360	.330	1.000	1.60	.80	1.2	1.2	7.4
15.	.250	.330	.360	.330	0.638	1.60	.80	1.2	1.2	7.4
30.	.250	.330	.360	.330	0.407	1.60	.80	1.2	1.2	7.4
40.	.250	.330	.360	.330	0.202	1.60	.80	1.2	1.2	7.4
Quincy Sand - Medium flow										
15.	.225	.295	.358	.295	1.000	1.50	.55	1.2	1.2	7.1
15.	.225	.295	.358	.295	0.638	1.50	.55	1.2	1.2	7.1
30.	.225	.295	.358	.295	0.407	1.50	.55	1.2	1.2	7.1
40.	.225	.295	.358	.295	0.202	1.50	.55	1.2	1.2	7.1

defines the characteristics, by layer, of the three soils. The major differences between these three soils are in their water holding capacity and porosity. Note also that the soils used for the potato model exclude the fourth sub-layer shown in the table. Table 3.4 provides general soil parameters used in all of the dynamic optimization models[60].

Genetics Used in CERES

Each of the CERES models requires selected genetic information about the cultivar used by the simulation model. These values will vary somewhat from region to region owing to differences in the climate and soils. No genetic coefficients have, to date, been specifically developed for the crops in the study area. Proper estimation of these coefficients would require a large number of trial plots over several years with detailed data collection, a task beyond the scope of this study.

To approximate these coefficients, farm records were used along with genetic coefficients from other regions (Ritchie, Godwin, and Otter-Nacke, 1986; Ritchie, Morgusson, and Hodges, 1987; Jones and Kiniry, 1986; Prothero, 1988; and English, 1988). The farm records included seeding rates, planting and harvest dates, weekly irrigation and fertilizer quantities, yields, and limited soil tests. Because of limitations on farm-level data, the genetic coefficients for corn and wheat were estimated using heavier soils (e.g., silts) than the primary soils used

[60]The calculation of the saturation percentage, root weighing index, SCS curve number, and the soil water drainage percentage was done with the assistance of a FORTRAN program.

Table 3.4. General Soil Parameters used in all the CERES models.

Parameter Name	Parameter Value
Bare Soil Albedo:	0.25 (unitless)
Upper Limit of Layer #1 Evaporation:	6.0 (mm)
SCS Curve Number:	67
Annual Average Ambient Temperature:	11.4 C°
Annual Amplitude in mean monthly Temperature:	20.8 C°
Soil Water Drainage Constant:	
High Flow Soil:	0.45 (%/day)
Medium Flow Soil:	0.32 (%/day)
Low Flow Soil:	0.17 (%/day)

for this thesis. Based on this limited information, the various genetics coefficients were estimated by trying various values and selecting the values which best approximated reality. Specifically, the genetic values were selected on the basis of how closely they mirrored the current yields and harvest dates and were not based on field measurements of items such as growth rates or thermal time between various stages of development. The resulting yields and phenology are approximately correct for each crop, based on comparisons with the limited farm-level records provided by the growers. The coefficients for a given crop were calibrated to a single field, then validated with a second field. Table 3.5 provides a comparison of several predicted characteristics with observed data. The genetic coefficients for each crop were validated with a second field. The result of the validation simulations can also be found in Table 3.5. Table 3.6 provides the estimated genetic coefficients for each crop.

General Parameters used in CERES

CERES has several simulation parameters which are independent of the cultivar, including the date which the simulation begins[61], planting date, net planting rate (i.e., germination rate), harvest date (for potatoes), average irrigation system efficiency, and seeding depth. Values for these parameters were chosen primarily on the basis of current practices in the region (Prothero, 1988; and English, 1988). Table 3.7 provides the

[61]This date must be at least one day before the planting date for the CERES models to function correctly.

Table 3.5. Estimates by CERES of Yields and Maturity Date with Actual Data for Corn, Wheat, and Potatoes.

Characteristics	Predicted	Observed	Units
Corn:			
End of Grain Fill	257	259**	Julian Day
Yield	11,424	11,460	kg/ha
Soil: Shano Silt			
Validation Run:			
End of Grain Fill	257	259**	Julian Day
Yield	10,520	10,337	kg/ha
Soil: Taunton Loam			
Wheat:			
End of Grain Fill	196	196**	Julian Day
Yield	8,779	9,076	kg/ha
Soil: Shano Silt			
Validation Run:			
End of Grain Fill	196	196**	Julian Day
Yield	8,938	9,407	kg/ha
Soil: Shano Silt			
Potatoes:			
End of Tuber Growth	229	229	Julian Day
Yield	58,986	58,651	kg/ha
Soil: Quincy Sand			
Validation Run:			
End of Tuber Growth	274	274	Julian Day
Yield	65,701	66,056	kg/ha
Soil: Shano Silt			

** Estimated based on last day of irrigation.

Table 3.6. Estimated Genetic Coefficients for Corn, Wheat, and Potatoes.

Type of Coefficient	Value	Unit
Corn:		
Thermal Time from Seeding to Emergence:	180	GDD base 8 C°
Photoperiod Sensitivity:	0.3	(0,1) index
Thermal Time from Silking to Maturity:	800	GDD base 8 C°
Potential Number of Kernels:	650	kernels/ear
Potential Kernel Growth Rate:	8.1	mg/kernel/day
Potential Leaf Growth Rate:	3.5	cm^2/plant/day
Wheat:		
Phyllochron Interval:	120	GDD base 2 C°
Day Length Sensitivity:	0.007	(unitless)
Vernalization Sensitivity:	0.033	(unitless)
Thermal Time from Beginning of Grain Fill to Maturity:	546	GDD base 2 C°
Potential Number of Grains:	27.5	grains/gm stem wt.
Potential Grain Fill Rate:	4.08	mg/kernel/day
Constant for Determination of Tiller Number:	0.94	(unitless)
Potatoes:		
Potential Leaf Growth Rate:	1600	cm^2/plant/day
Potential Tuber Growth Rate:	8.0	gm/plant/day
Determinacy Index:	0.0	(0,1) index

Table 3.7. General Parameters Used for CERES Corn, Wheat, and Potatoes.

Type of Coefficient	Value	Unit
General:		
Mean Irrigation Efficiency:	0.90	percent
Standard Deviation of Irrigation Efficiency:	0.025	percent
Maximum Irrigation Efficiency:	1.00	percent
Minimum Irrigation Efficiency:	0.75	percent
Corn:		
First Day of Simulation:	120	Julian Day
Planting Date:	121	Julian Day
Seeding Depth:	2	cm
Net Planting Rate:	10.9	Plants/m^2
Initial Soil Nitrogen for Current Practices Analysis:	73*	kg N/ha/m
Wheat:		
First Day of Simulation:	300	Julian Day
Planting Date:	301	Julian Day
Seeding Depth:	4	cm
Net Planting Rate:	229	Plants/m^2
Initial Soil Nitrogen for Current Practices Analysis:	112**	kg N/ha/m
Potatoes:		
First Day of Simulation:	74	Julian Day
Planting Date:	75	Julian Day
Seeding Depth:	10	cm
Planting Rate:	3.5	Plants/m^2
Initial Soil Nitrogen for Current Practices Analysis:	138*	kg N/ha/m
Reserve Carbohydrates in Seed:	20	gm/plant
Sprout Length:	10	cm/plant
Emergence Date:	98	Julian Day
Termination Date:	229	Julian Day

* Estimated for the entire root zone based on soil tests conducted in the first foot of soil.
** Typical values used given no pre-plant soil test was available.

general simulation parameters used for each crop in the analyses conducted for this study.

Irrigation and Fertilizer Treatment Data Used in Base Analysis

This study compares current water and nitrogen management strategies with various constrained strategies for these inputs. Weekly farmer records of water and nitrogen applications were used to define current practices. Because CERES requires irrigation quantities on a daily basis, a FORTRAN program (LAMB, provided in Appendix A along with sample input files found in Appendix B) was developed to spread the weekly quantities, found in the farm-level records, over the previous week. This spreading technique distributes the water relatively evenly over the week based on irrigation set length[62] and irrigation equipment capacity. Tables 3.8A-3.8C provide the irrigation dates and quantities used in the base analyses for potatoes, wheat, and corn. The irrigation system capacity used for both the simulations and the dynamic optimization models were set at 11 millimeters per day. The fertilizer applications were assumed to occur on the closest irrigation day prior to the date of the weekly fertilizer records provided by participating farmers (Prothero, 1988). Table 3.9 provides all of the fertilization dates and quantities used in the base analyses for potatoes, wheat, and corn. All nitrogen fertilizer applications in this study were assumed to be in some form of NH_4 such as ammonium sulfate and that all fertilization had a mixing depth of 15 cm.

[62]Irrigation set length means the average number of hours a farmer will operate the center-pivot to make a single rotation around the field.

Table 3.8A. Irrigation Dates and Quantities Used in the Base Simulation for Potatoes.

Julian Date	Amount (mm)
110	4.0
111	11.0
112	11.0
113	11.0
114	11.0
121	10.0
127	1.0
128	6.0
129	11.0
134	2.0
135	6.0
136	11.0
139	10.0
140	11.0
141	11.0
142	6.0
143	11.0
145	5.0
146	11.0
147	11.0
148	11.0
149	11.0
150	11.0
154	8.0
155	11.0
156	6.0
157	11.0
162	9.0
163	6.0
164	11.0
169	8.0
170	11.0
171	11.0
172	6.0
173	11.0
174	11.0
175	11.0
176	11.0
178	7.0
179	11.0
180	11.0
181	11.0
182	11.0

Table 3.8A. (Continued) Irrigation Dates and Quantities Used in the Base Simulation for Potatoes.

Julian Date	Amount (mm)
183	11.0
184	11.0
185	11.0
187	6.0
188	11.0
189	11.0
190	11.0
191	11.0
192	11.0
193	1.0
194	11.0
195	11.0
196	11.0
197	11.0
198	11.0
199	11.0
202	4.0
203	11.0
204	11.0
205	6.0
206	11.0
208	1.0
209	11.0
210	11.0
211	11.0
212	11.0
213	11.0
216	9.0
217	11.0
218	11.0
219	6.0
220	11.0

Table 3.8B. Irrigation Dates and Quantities Used in the Base Simulation for Corn.

Julian Date	Amount (mm)
90	10.0
102	11.0
103	6.0
104	11.0
110	6.0
111	11.0
125	4.0
132	8.0
144	4.0
145	6.0
146	11.0
165	5.0
166	6.0
167	11.0
171	10.0
172	11.0
173	6.0
174	11.0
177	11.0
178	11.0
179	11.0
180	11.0
181	11.0
183	7.0
184	11.0
185	11.0
186	11.0
187	11.0
188	11.0
191	10.0
192	11.0
193	11.0
194	11.0
195	11.0
197	4.0
198	11.0
199	11.0
200	11.0
201	11.0
202	11.0
203	11.0
204	11.0
205	11.0
206	11.0

Table 3.8B. (Continued) Irrigation Dates and Quantities Used in the Base Simulation for Corn.

Julian Date	Amount (mm)
207	11.0
208	11.0
209	11.0
211	8.0
212	11.0
213	11.0
214	11.0
215	11.0
216	11.0
217	1.0
218	11.0
219	11.0
220	11.0
221	11.0
222	11.0
223	11.0
231	1.0
232	11.0
233	11.0
234	6.0
235	11.0
236	6.0
237	11.0
239	2.0
240	11.0
241	11.0
242	11.0
243	11.0
244	11.0
256	4.0
257	6.0
258	11.0

Table 3.8C. Irrigation Dates and Quantities Used in the Base Simulation for Wheat.

Julian Date	Amount (mm)
89	6.0
90	11.0
101	3.0
102	11.0
103	6.0
104	11.0
109	8.0
110	6.0
111	11.0
118	10.0
121	2.0
122	11.0
123	11.0
124	6.0
125	11.0
127	2.0
128	11.0
129	11.0
130	11.0
131	11.0
132	11.0
135	10.0
136	11.0
137	11.0
138	11.0
139	11.0
140	3.0
141	11.0
142	11.0
143	11.0
144	11.0
145	11.0
146	11.0
149	9.0
150	11.0
151	11.0
152	6.0
153	11.0
160	10.0
163	6.0
164	11.0
165	11.0
166	11.0
167	11.0

Table 3.8C. (Continued) Irrigation Dates and Quantities Used in the Base Simulation for Wheat.

Julian Date	Amount (mm)
170	10.0
171	11.0
172	11.0
173	11.0
174	11.0
175	2.0
176	11.0
177	11.0
178	11.0
179	11.0
180	11.0
181	11.0
185	7.0
186	11.0
187	6.0
188	11.0
192	8.0
193	11.0
194	6.0
195	11.0

Table 3.9. Fertilization Dates and Quantities Used in the Base Analyses for Corn, Wheat, and Potatoes.

Julian Date	Amount (kg/ha)
Corn:	
123	79.0
183	40.0
189	36.0
196	34.0
211	40.0
217	36.0
Wheat:	
300	165.0
98	42.0
125	42.0
133	28.0
140	6.6
Potatoes:	
75	127.0
127	22.5
131	22.5
138	22.5
145	28.1
152	28.1
166	33.7
158	33.7
173	33.7
180	28.1
187	28.1
194	25.8

Residue Data used in CERES

CERES requires an estimate of the top and root residue quantities left from the previous crop, along with the carbon-nitrogen ratio for this residue. In this study, only two residues levels are used (Table 3.10). Level 1 has a high carbon-nitrogen ratio and minimal quantities of carryover straw and root biomass, a result typical after harvests of corn, wheat, and potatoes. The data in this first level are based on data provided with the wheat CERES model (Ritchie, Godwin, Otter-Nacke, 1986) and is used to simulate the carryover effects of non-leguminous crops. Level 1 was assumed for all wheat and corn analyses. It is also used for the potato grain rotation scenarios.

Residue level 2 has a low carbon-nitrogen ratio and significant quantities of carryover straw and root biomass. Data for this second residue level are based on a previous study of carryover effects for alfalfa on sandy soil with multiple cuts per year (Hesterman, et. al., 1986)[63]. The purpose of this second level is to simulate the carryover effects after several years of alfalfa and is used for potatoes following alfalfa[64].

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[63]The estimates of the carryover effects for alfalfa are widely divergent in the agronomy literature. They range from 35 kg/ha to 305 kg/ha (Hesterman, et. al., 1986) depending on local conditions and the alfalfa management strategy. No further sensitivity analysis was conducted to determine what effects different residues would have on the model results.

[64]The root residue routines in CERES potatoes were altered for runs which used an alfalfa residue file. This involved replacing a constant carbon to nitrogen ratio of 100.0 in the code with the parameterized carbon-to-nitrogen ratio used originally for straw residue (e.g., 35.5 in this study).

Table 3.10. Root and Straw Residues Data Used.

Previous Crop	Straw Biomass (kg/ha)	Root Biomass (kg/ha)	Carbon/ Nitrogen Ratio	Straw Mixing Depth (cm)
Wheat, Corn, and Potatoes	500	300	180.0	15
3 or 4 Year Old Alfalfa	500	3700	35.5	15

Price Levels Used for the Dynamic Optimization Model

The dynamic optimization model requires information on the market price of each crop, labor costs, and irrigation water and nitrogen fertilizer costs. Table 3.11 displays all assumed prices and costs used in the optimization model. These items include: market prices for each crop, labor costs to turn on and off irrigation systems, to hook and unhook fertilizer tanks, custom charges to apply pre-plant nitrogen fertilizer, irrigation water costs, nitrogen fertilizer prices, and market prices for each crop. The commodity and input price data are based on typical values faced by farmers in the study area (Prothero, 1988). The irrigation labor cost were calculated based on irrigation labor hours from a previous study (Hinman, Wright, and Willett, 1982) and assuming a $5.50 per hour wage rate. The fertigation[65] labor costs were arbitrarily set at half the per hectare costs for each irrigation day. The application costs for pre-plant nitrogen fertilizer costs were assumed to be 55% of typical application cost because other amendments are being applied jointly with the nitrogen.

Dynamic Optimization Model Parameters

The dynamic optimization model requires a number of the parameters in the solution process. As noted in Chapter 2, selection of state nodes

[65]Fertigation is the application of fertilizer through the irrigation system.

Table 3.11. Assumed Prices and Costs Used in the Dynamic Optimization Model.

Item	Price or Cost	Units
Expenses:		
Irrigation Water	0.16	$/ha/mm
Irrigation Labor	0.13	$/ha/application
Nitrogen Fertilizer	0.34	$/kg N
Fertigation Labor	0.065	$/ha/application
Pre-Plant Fertilizer	0.34	$/kg N
Pre-Plant Application of Fertilizer	6.17	$/ha/application
Output Prices:		
Potatoes (Russet)	0.074	$/kg
Winter Wheat (Stephens)	0.16	$/kg
Field Corn (Pioneer 3732)	0.11	$/kg

in the optimization model involves a tradeoff between accuracy and solution time. In addition, the maximum and minimum state nodes should be outside the set of desireable state nodes, recognizing that smaller distances between minimum and maximum values may result in decreased solution accuracy. Extensive experimentation with different boundary conditions for water and nitrogen state spaces resulted in identification of extreme state levels and node intervals that provided an acceptable balance of accuracy and solution time. These parameter values are reported in Table 3.12.

Table 3.12 also provides the boundary values for the decision variables. The upper bounds on daily irrigation quantities were based on typical values for the region (Prothero, 1988). The upper bounds on fertilizer concentrations through the water system was based on the maximum rates recommended by OSU extension agents. The lower bounds for daily irrigation quantities were determined through farmer interviews on maximum reasonable speed for a circle. The lower bound for minimum fertilizer application rates were based on farmer records (Prothero, 1988).

Farm-Level Enterprise Budgets

The farm-level LP model requires estimated total production costs on a per-hectare basis for the objective function coefficients. However, the dynamic optimization model only provides estimates of the cost per

Table 3.12. Solution Parameters for Dynamic Optimization Model.

Parameter	Value	Units
Soil Moisture State Space Step Size	5	mm/m
Soil Nitrogen State Space Step Size	20	kg N/ha/m
Lower Bound on Moisture State Space	20	mm/m
Lower Bound on Nitrogen State Space	20	kg N/ha/m
Upper Bound on Moisture State Space, Wheat	100	mm/m
Upper Bound on Moisture State Space, Corn	110	mm/m
Upper Bound on Moisture State Space, Potatoes	110	mm/m
Upper Bound on Nitrogen State Space, Wheat	120	kg N/ha/m
Upper Bound on Nitrogen State Space, Corn	160	kg N/ha/m
Upper Bound on Nitrogen State Space, Potatoes (Grain)	160	kg N/ha/m
Upper Bound on Nitrogen State Space, Potatoes (Alfalfa)	260	kg N/ha/m
Minimum Irrigation Application	4	mm
Minimum Fertigation Application	5	kg N/ha
Maximum Fertigation Application	4	kg N/mm/ha water
Minimum Rainfall Required Before Accounted for in Irrigation Decisions	4	mm
Percentage of Rainfall Used in Irrigation Decisions	0.75	percent

hectare for variable costs associated with irrigation and nitrogen fertilization and estimates of total revenue because (as already explained) other costs become essentially fixed after planting. To estimate the other costs of production for the representative farm, a simple enterprise budget was developed on a computerized worksheet program (QUATTRO). Figures 3.3A-3.3G provide a source listing of the main budget elements in the worksheet[66]. Figure 3.4 provides a general map indicating which portions of the worksheet are represented in each figure[67]. The enterprise budgets are based a fixed crop mix, input usage levels (e.g., irrigation and nitrogen fertilizer quantities), and yields. Using these budgets the non-per unit production costs calculated for each crop and each rotation. These the costs were then average across rotations because they varied less than one percent. The per-hectare costs used for alfalfa establishment, alfalfa, corn, wheat, and potatoes (excluding irrigation, nitrogen, and per unit costs) were $513.95, 1,219.23, 939.09, 749.78, and 2,940.53. The alfalfa yields in Figure 3.3B is the yield used for all of the LP analyses conducted in this study. These yields are based on reported yields on center-pivot irrigated fields in the study area (Prothero, 1988). Thus, the budgets shown in Figures 3.3A-3.3G represent only one of many scenarios investigated in this study.

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[66]A copy of this computerized worksheet is available on request from the author.

[67]The worksheet, unlike the rest of this study, uses English units of measure (i.e. acres, pounds, etc.) because the base data for this worksheet were all reported in English units. The total per-acre costs were then converted to metric units for the LP model.

Look Up #	Complement	Total Hours	Cost	Quantity	Cost per hour Fixed	Variable	Total	Age (hr)	Life (hr)	RV	Deprec.	RV(i+1)	CFC/hr	hpr/hp	hp	Repair	Rf1	Rf2
1.00	Wheel tractor, 80 hp <Not Used	0.00	$21,000.00	1.00				4000	8000				5.29	1.00	80.00	0.00	0.01	2.00
2.00	Wheel Tractor (JD 4650), 165 hp	1770.75	$85,000.00	2.00	$12.17	$14.52	$26.69	4000	8000	52605.05	4208.40	48396.65	5.46	1.00	165.00	8024.23	0.01	2.00
3.00	MB Plow, 4-16, 2-way <Not Used>	0.00	$6,500.00	1.00				1000	2000							0.00	0.43	1.80
4.00	Rotary Cult., 8-Row	17.50	$4,000.00	1.00	$0.03	$0.90	$0.93	1000	2000	2.23	0.26	1.97				15.73	0.16	1.40
5.00	Packer, 36 ft.	291.50	$2,100.00	1.00	$0.68	$0.45	$1.13	1000	2000	828.62	95.29	733.33				132.56	0.16	1.30
6.00	Rotary Cult., 4-Row <Not Used>	0.00	$3,500.00	1.00				750	1500							0.00	0.36	1.40
7.00	Potato Planter, 6-row	108.75	$16,000.00	1.00	$10.69	$3.59	$14.28	600	1200	4892.65	562.66	4330.00				390.52	0.19	1.40
8.00	Offset Disc, 36 ft.	275.00	$20,000.00	1.00	$6.65	$6.69	$13.34	1000	2000	7695.69	885.00	6810.69				1840.89	0.18	1.70
9.00	Potato Harvester 2-row	375.00	$26,000.00	1.00	$6.58	$7.99	$14.57	1250	2500	10381.71	1193.90	9187.81				2996.63	0.19	1.40
10.00	Granular Applicator	127.50	$1,400.00	1.00	$0.88	$1.53	$2.41	600	1200	472.72	54.36	418.35				194.88	0.95	1.30
11.00	Combine, 20 ft.	86.25	$60,000.00	1.00	$25.65	$24.31	$49.96	1000	2000	9314.95	1071.22	8243.73	8.47	1.00	128.00	1366.14	0.12	2.10
12.00	Corn Header, 6-ft.	28.75	$7,000.00	1.00	$0.50	$2.30	$2.79	1000	2000	59.95	6.89	53.06				66.02	0.14	2.30
13.00	Rotary Cult., 6-row	133.75	$3,800.00	1.00	$2.04	$1.77	$3.81	750	1500	1149.27	132.17	1017.10				236.19	0.36	1.40
14.00	Corn Planter, 8-Row	15.63	$10,000.00	1.00	$0.84	$6.56	$7.39	600	1200	55.05	6.33	48.72				102.47	0.54	2.10
15.00	Grain Drill, 30-ft.	54.00	$10,000.00	1.00	$6.79	$6.79	$13.58	600	1200	1543.95	177.55	1366.39				366.45	0.54	2.10
16.00	Truck, 2 ton **	187.50	$20,000.00	1.00	$8.34	$8.84	$17.18	5000	10000	461.67	53.09	408.58		1.00				
17.00	Truck, 2 ton (used) ** <not used>	0.00	$6,500.00	1.00	$6.26	$8.12	$14.38	5000	10000					1.00				
18.00	Pickup, 3/4 ton **	862.50	$11,000.00	1.00	$3.82	$8.99	$12.81	5000	10000	3250.64	373.82	2876.82		1.00				
19.00	Windrower, 65 hp, 14 ft.	798.75	$34,000.00	1.00	$5.34	$15.24	$20.59	1250	2500	17973.31	2066.93	15906.38	4.30	1.00	65.00	8740.05	0.12	1.80
20.00	Rake or Fluffer	686.25	$6,500.00	1.00	$1.13	$3.88	$5.01	1000	2000	3264.00	375.36	2888.64				2663.19	0.38	1.40
21.00	PTO Baler	1035.00	$11,000.00	1.00	$1.26	$6.34	$7.59	1000	2000	5474.17	629.53	4844.64				6559.43	0.23	1.80
22.00	Center Pivot **		$57,500.00	1.00	$74.80	$1.67												
23.00	Wheel Tractor(JD 2355),55hp	1042.50	$20,000.00	2.00	$4.55	$4.66	$9.21	4000	8000	11589.56	927.17	10662.40	3.64	1.00	55.00	1066.01	0.01	2.00
24.00	Wheel Tractor (JD 8750),250 hp	350.00	$123,000.00	1.00	$18.87	$20.59	$39.47	4000	8000	32252.29	2580.18	29672.11	8.27	1.00	250.00	4313.61	0.01	2.00
25.00	Marker Bar 17'	31.13	$3,500.00	1.00	$0.32	$1.48	$1.80	1000	2000	41.46	4.77	36.69				46.04	0.30	1.40
26.00	Harrow 34'	18.75	$1,200.00	1.00	$0.07	$0.45	$0.52	750	1500	5.43	0.62	4.81				8.46	0.30	1.40
27.00	Vine Cutting Bar 17'	56.25	$1,000.00	1.00	$0.29	$0.33	$0.61	1000	2000	68.38	7.86	60.52				18.31	0.23	1.40
28.00	Ripping Bar 15'	75.00	$6,000.00	1.00	$2.24	$1.96	$4.20	1000	2000	706.12	81.20	624.92				147.04	0.23	1.40

** => Non-standard Variable and (or) Capital Cost Computational Method

Figure 3.3A. Computerized Enterprise Budget for an Irrigated Eastern Oregon Farm: Equipment Table.

Percentage Age:	0.50
Interest Rate:	0.12
Depreciation Rate:	0.07
Diesel/gal:	0.80
Gasoline/gal:	0.90
Land lease/acre:	100.00

	Acres	Per lb. Seed Cost	Fudge Factor Land Multiple	Per Acre Yield	Price	Gross Revenue	Less Variable Cost	Returns over VC	Less Equip Depr	Returns Ld & Man	less Overhead	Returns Land	Less Ld Lease	Net Ret. Ld
Potatoes (tons):	375.00	$8.00	1.00	30.00	$85.00	$2,550.00	$1,462.55	$1,087.45	$117.00	$970.45	$178.50	$791.95	$325.00	$466.95
Field Corn (bu):	125.00	$1.35	1.00	195.00	$3.10	$604.50	$306.35	$298.15	$93.80	$204.35	$42.32	$162.03	$175.00	($12.97)
Winter Wheat (bu):	250.00	$0.11	1.00	120.00	$4.20	$504.00	$169.27	$334.73	$85.60	$249.13	$35.28	$213.85	$175.00	$38.85
Alfalfa (tons):	1125.00	$2.00	1.00	6.50	$82.50	$536.25	$287.27	$248.98	$125.82	$123.16	$37.54	$85.62	$175.00	($89.38)
Years of Alfalfa:	3.00													
						$4,194.75	$2,225.44	$1,969.31	$422.22	$1,547.09	$293.63	$1,253.46	$850.00	$403.46

Machine labor/hr:	5.50
Custom Fert./acre:	4.50
General Overhead:	0.07
Seed Cutting Cost/	1.25
Insurance Rate (%)	0.01

Type Fertilizer	Price (lb.)	Pre-plant fertilizer quantity Potatoes	Corn	Wheat	Alfalfa
Nitrogen-solid:	0.17	100.00	130.00	60.00	20.00
Nitrogen-irr.:	0.17				
Phosphate:	0.32	150.00	100.00	30.00	50.00
Potash:	0.16	150.00	60.00		
Zinc:	0.50	10.00	3.00		
Boron:	2.15	1.00			1.00
Sulfur:	0.28	25.00			
Total:		$104.15	$67.35	$21.95	$22.55

Figure 3.3B. Computerized Enterprise Budget for an Irrigated Eastern Oregon Farm: Income Statement and Parameters.

	Operations Potatoes:	Equip.		Month	Machine Hours	Labor hours	Machine Fixed	Variable Cost Fuel etc	Variable Cost Machine Labor	Service	Materials	Variable Cost	Total Cost
	Tractor-Ripping (2X)	24.00	24	MAR	0.20	0.22	3.77	4.12	1.21			5.33	9.10
	Ripping	28.00	28/w above	MAR	0.20		0.45	0.39				0.39	0.84
	Tractor Disc. (2X)	24.00	2	MAR	0.20	0.22	3.77	4.12	1.21			5.33	9.10
	Disc. (2X)	8.00	8/w above	MAR	0.20		1.33	1.34				1.34	2.67
	Pack (2x)	5.00	5/w above	MAR	0.20		0.14	0.09				0.09	0.23
	Fumigation		C	MAR					0.00	250.00		250.00	250.00
100.00	Fertilize		C	MAR					0.00	4.50	104.15	108.65	108.65
	Pre-Plant Soil testing		C	MAR						0.50		0.50	0.50
	Nematicide Appl.		C	APR						4.00	81.00	85.00	85.00
38.00	Irrigate* 38"		22	APR-AUG		0.84	74.80	63.46	4.62			68.08	142.88
	Tractor-Mark Out	2.00	2	APR	0.08	0.09	1.01	1.21	0.47			1.68	2.69
	Mark Out	25.00	25/w above	APR	0.08		0.03	0.12				0.12	0.15
20.00	Cut Seed (by plant quantity)		C	APR						25.00		25.00	25.00
20.00	Tractor - Plant	2.00	2	APR	0.29	0.65	3.53	4.21	3.58		160.00	167.79	171.31
	Plant	7.00	7/w above	APR	0.29		3.10	1.04				1.04	4.14
	Haul Seed	16.00	16	APR	0.50	0.55	4.17	4.42	3.03			7.45	11.62
	Tractor-Cultivate	2.00	1	MAY	0.14	0.16	1.70	2.03	0.88			2.91	4.62
	Cultivate	13.00	13/w above	MAY	0.14		0.29	0.25				0.25	0.53
	Granular Application (insectic	10.00	10/w above	MAY	0.34		0.30	0.52	0.00		46.00	46.52	46.82
	Tractor-Cultivate	2.00	1	MAY	0.14	0.16	1.70	2.03	0.88			2.91	4.62
	Cultivate	13.00	13/w above	MAY	0.14		0.29	0.25				0.25	0.53
	Tractor-Harrowing	23.00	23	MAY	0.05	0.06	0.23	0.23	0.30			0.54	0.76
	Harrowing	26.00	26/w above	MAY	0.05		0.00	0.02				0.02	0.03
	Soil testing & tissue Analysis		C	APR-SEPT						7.25		7.25	7.25
	Aerial Photography		C	APR-SEPT						3.50		3.50	3.50
	Herbigation		C	MAY					0.00	3.50	24.00	27.50	27.50
125.00	Nitrogation #100		n/a	JUNE					0.00		21.25	21.25	21.25
100.00	Nitrogation #100		n/a	JULY					0.00		17.00	17.00	17.00
	Cover Sprays- Fungicide & Insecticide		C	JULY					0.00	4.50	20.00	24.50	24.50
0.00	Nitrogation #50		n/a	AUG					0.00		0.00	0.00	0.00
	Cover Sprays- Fungicide		C	AUG					0.00	4.50	2.00	6.50	6.50
	Cover Sprays- Fungicide		C	SEPT					0.00	4.50	2.00	6.50	6.50
	Growth Regulator Appl.		C	JUNE						4.00	20.00	24.00	24.00
	Defoliate		C	SEPT					0.00	4.00	12.00	16.00	16.00
	Tractor-Vine Cutting	23.00	23	SEPT	0.15	0.16	0.68	0.70	0.88			1.58	2.26
	Vine Cutting	27.00	27	SEPT	0.15		0.04	0.05				0.05	0.09
30.00	Tractor - Digging (by yield)	2.00	2,9	SEPT	1.00	3.09	12.17	14.52	16.99			31.52	43.68
30.00	Digging (3 people by yield)	9.00	9/w above	SEPT	1.00		6.58	7.99				7.99	14.57
4.25	Hauling (by yield)		C	SEPT						127.50		127.50	127.50
	Pick-up	18.00	18	MAR-SEP	0.30	0.32	1.15	2.70	1.76			4.46	5.60
12.00	Storage (by yield)									360.00		360.00	360.00
					0.00								
									34.60	807.25	509.40	1462.55	1579.55

Figure 3.3C. Computerized Enterprise Budget for an Irrigated Eastern Oregon Farm: Production Activities for Potatoes.

	Operations Corn:		Equip.	Month	Machine Hours	Labor hours	Machine Fixed	Fuel etc	Machine Labor	Service	Materials	Variable Cost	Total Cost
40.00	Irrigation* 40"		21	APR-SEP		0.88	74.80	66.80	4.84			71.64	146.44
	Tractor - Disc (2x)	24.00	24	APR	0.20	0.22	3.77	4.12	1.21			5.33	9.10
	Disc (2x)	8.00	8/w above	APR	0.20		1.33	1.34				1.34	2.67
	Pack (2x)	5.00	5/w above	APR	0.20		0.14	0.09				0.09	0.23
130.00	fertilize		C	APR						4.50	67.35	71.85	71.85
6.60	Herbigation		C	MAY						3.50	22.00	25.50	25.50
18.00	Tractor - Plant	2.00	2	MAY	0.13	0.13	1.52	1.82	0.70		24.30	26.82	28.34
	Plant	14.00	14/w above	MAY	0.13		0.10	0.82				0.82	0.92
	Tractor - Cultivate	2.00	2	MAY	0.14	0.16	1.70	2.03	0.88			2.91	4.62
	Cultivate	4.00	4/w above	MAY	0.14		0.00	0.13				0.13	0.13
75.00	Nitrogation		n/a	JUNE					0.00		12.75	12.75	12.75
	Tractor - Cultivation	2.00	2	JUNE	0.23	0.25	2.80	3.34	1.38			4.71	7.51
	Cultivation	13.00	13/w above	JUNE	0.23		0.47	0.41				0.41	0.88
75.00	Nitrogation		n/a	JULY					0.00		12.75	12.75	12.75
	Combine	11.00	11	OCT	0.23	0.25	5.90	5.59	1.38			6.97	12.87
	Combine	12.00	12/w above	OCT	0.23		0.11	0.53	0.00			0.53	0.64
2.50	Hauling (by yield)		C	OCT						13.66		13.66	13.66
8.00	Drying		C	OCT					0.00	43.70		43.70	43.70
	Pick-up	18.00	18		0.30	0.32	1.15	2.70	1.76			4.46	5.60
									12.14	65.35	139.15	306.35	400.15

Figure 3.3D. Computerized Enterprise Budget for an Irrigated Eastern Oregon Farm: Production Activities for Corn.

	Operations Winter Wheat:		Equip.	Month	Machine Hours	Labor hours	Machine Fixed	Fuel etc	Machine Labor	Service	Materials	Variable Cost	Total Cost
60.00	Pre-Plant Fertilize		C	SEPT					0.00	4.50	21.95	26.45	26.45
	Tractor - Disc	24.00	24	SEPT	0.10	0.13	1.89	2.06	0.72			2.77	4.66
	Disc	8.00	8/w above	SEPT	0.10		0.66	0.67				0.67	1.33
	Pack	5.00	5/w above	SEPT	0.10		0.07	0.05	0.00			0.05	0.11
80.00	Planting	2.00	2	SEPT	0.06	0.06	0.73	0.87	0.33		8.80	10.00	10.73
	Planting	15.00	15/w above	SEPT	0.06		0.41	0.41				0.41	0.81
	Insecticide (wheat aphid)		C	MAR						4.50	5.50	10.00	10.00
	Herbicide		C	MAR						4.50	3.50	8.00	8.00
28.00	Irrigation		n/a	MAR-SEPT		0.75	74.80	46.76	4.13			50.88	125.69
80.00	Nitrogation #80		n/a	APR-MAY					0.00		13.60	13.60	13.60
100.00	Tractor Applied Fertilizer		n/a	MAR						4.50	17.00	21.50	21.50
	Harvest	11.00	11	JULY	0.23	0.25	5.90	5.59	1.38			6.97	12.87
3.75	Hauling (by yield)		C	JULY						13.51		13.51	13.51
	Pick-up	18.00	18		0.30	0.32	1.15	2.70	1.76			4.46	5.60
									8.30	31.51	70.35	169.27	254.87

Figure 3.3E. Computerized Enterprise Budget for an Irrigated Eastern Oregon Farm: Production Activities for Wheat.

	Operations Alfalfa Establishment		Equip.	Month	Machine Hours	Labor hours	Machine Fixed	Fuel etc	Machine Labor	Service	Materials	Variable Cost	Total Cost
	Tractor - Disc (2x)	24.00	2	AUG	0.20	0.22	3.77	4.12	1.21			5.33	9.10
	Disc (2x)	8.00	8/w above	AUG	0.20		1.33	1.34					
	Pack (2x)	5.00	5	AUG	0.20		0.14	0.09				0.09	0.23
	Fertilization		C	AUG						22.55	4.50	27.05	27.05
	Herbicide		C	AUG						17.84	4.50	22.34	22.34
	Tractor - Disc (2x)	24.00	2	AUG	0.20	0.22	3.77	4.12	1.21			5.33	9.10
	Disc (2x)	8.00	8/w above	AUG	0.20		1.33	1.34					
	Pack (2x)	5.00	5	AUG	0.20		0.14	0.09	0.00			0.09	0.23
1.00	Tractor - Planting cover of Wh	2.00	2	AUG	0.06	0.06	0.73	0.87	0.33	4.20		5.40	6.13
	Planting cover of Wheat	15.00	15/w above	AUG	0.06		0.41	0.41				0.41	0.81
	Tractor - Planting	2.00	2	AUG	0.04	0.05	0.54	0.64	0.26	34.40		35.30	35.84
	Planting	15.00	15/w above	AUG	0.04		0.30	0.30					
	Pack	5.00	5	AUG	0.04		0.03	0.02				0.02	0.05
8.00	Irrigation 8"		n/a	AUG-OCT		0.95	74.80	13.36	5.22			18.59	93.38
	Pick-up	18.00	18		0.20	0.22	0.76	1.80	1.21			3.01	3.77
									9.45	78.99	9.00	122.95	208.04

Figure 3.3F. Computerized Enterprise Budget for an Irrigated Eastern Oregon Farm: Production Activities for Alfalfa Establishment.

	Operations Producing Alfalfa:		Equip.	Month	Machine Hours	Labor hours	Machine Fixed	Fuel etc	Machine Labor	Service	Materials	Variable Cost	Total Cost
	Gopher Control	23.00	23,H	NOV	0.25	0.28	1.14	1.17	1.54	0.25	0.88	3.84	4.97
	Fertilization		C	NOV					0.00	4.50	34.15	38.65	38.65
	Weed Control		C	FEB					0.00	4.50	24.04	28.54	28.54
35.00	Irrigation 35"		n/a	APR-OCT		3.40	74.80	58.45	18.70			77.15	151.95
	Swathing	19.00	19	MAY	0.28	0.31	1.50	4.27	1.71			5.97	7.47
	Tractor - Rake & Turn	23.00	2	MAY	0.24	0.27	1.09	1.12	1.49			2.60	3.70
	Rake & Turn	20.00	20/w above	MAY	0.24		0.27	0.93				0.93	1.20
	Tractor - Bale	2.00	2	MAY	0.37	0.40	4.50	5.37	2.20		4.25	11.82	16.32
	Bale	21.00	21/w above	MAY	0.37		0.46	2.34				2.34	2.81
	Remove & Stack		C	MAY					0.00	15.00		15.00	15.00
	Swathing	19.00	19	JULY	0.17	0.19	0.91	2.59	1.04			3.64	4.54
	Tractor - Rake & Turn	23.00	2	JULY	0.15	0.16	0.68	0.70	0.88			1.58	2.26
	Rake & Turn	20.00	20/w above	JULY	0.15		0.17	0.58				0.58	0.75
	Tractor - Bale	2.00	2	JULY	0.22	0.24	2.68	3.19	1.32		2.25	6.76	9.44
	Bale	21.00	21/w above	JULY	0.22		0.28	1.39				1.39	1.67
	Remove & Stack		C	JULY					0.00	7.50		7.50	7.50
	Swathing	19.00	19	AUG	0.17	0.19	0.91	2.59	1.04			3.64	4.54
	Tractor - Rake & Turn	23.00	2	AUG	0.15	0.16	0.68	0.70	0.88			1.58	2.26
	Rake & Turn	20.00	20/w above	AUG	0.15		0.17	0.58				0.58	0.75
	Tractor - Bale	2.00	2	AUG	0.22	0.24	2.68	3.19	1.32		2.25	6.76	9.44
	Bale	21.00	21/w above	AUG	0.22		0.28	1.39				1.39	1.67
	Remove & Stack		C	AUG					0.00	7.50		7.50	7.50
	Swathing	19.00	19	SEP	0.09	0.09	0.48	1.37	0.49			1.87	2.35
	Tractor - Rake & Turn	23.00	2	SEP	0.07	0.08	0.32	0.33	0.44			0.77	1.09
	Rake & Turn	20.00	20/w above	SEP	0.07		0.08	0.27				0.27	0.35
	Tractor - Bale	2.00	2	SEP	0.11	0.12	1.34	1.60	0.66		0.75	3.01	4.35
	Bale	21.00	21/w above	SEP	0.11		0.14	0.70				0.70	0.84
	Remove & Stack		C	SEP					0.00	2.50		2.50	2.50
	Pick-up	18.00	18		0.50	0.53	1.91	4.50	2.92			7.41	9.32
									36.63	41.75	68.57	246.28	343.74

Figure 3.3G. Computerized Enterprise Budget for an Irrigated Eastern Oregon Farm: Production Activities for Alfalfa.

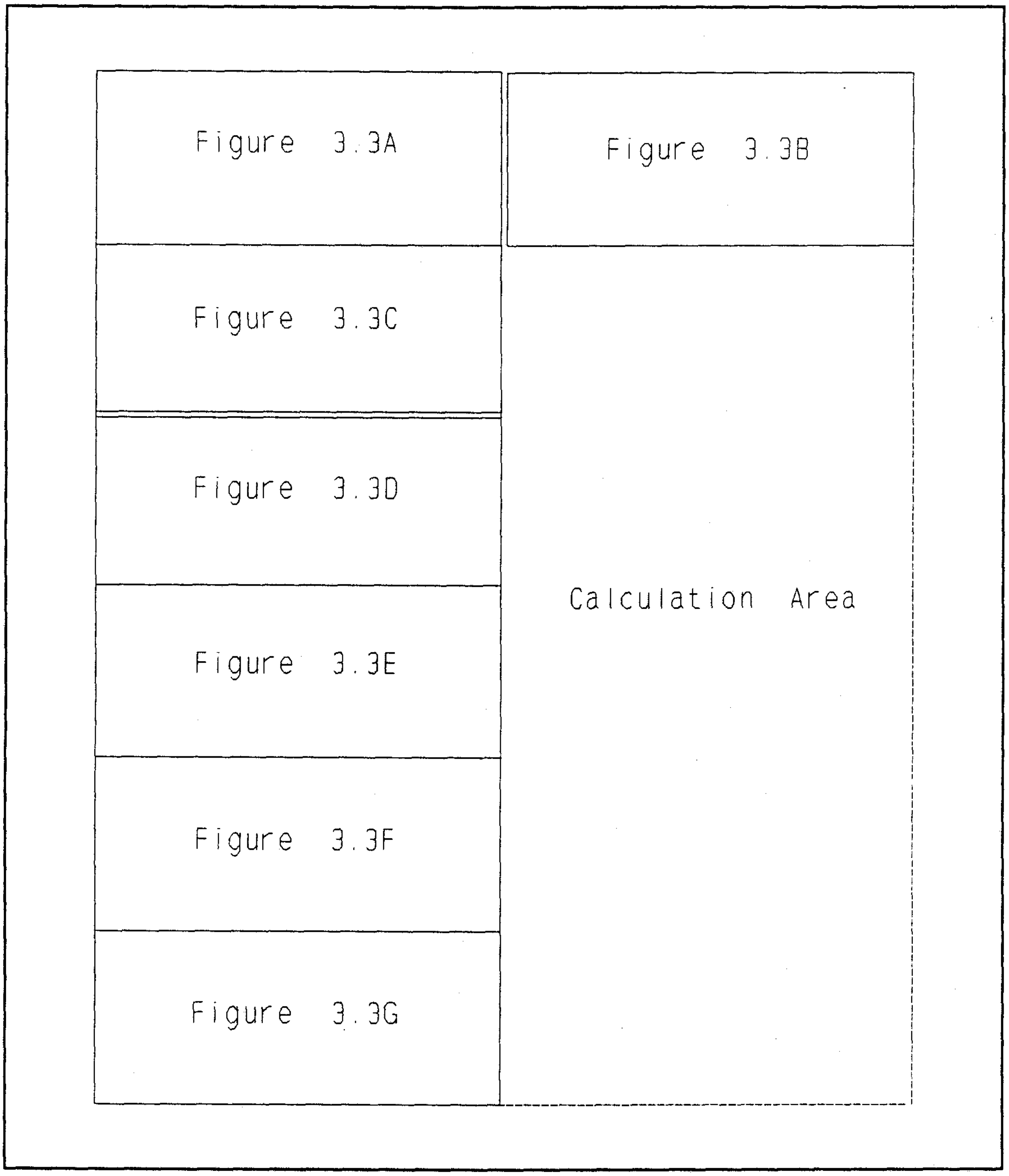

Figure 3.4. Schematic of Computerized Enterprise Budget Worksheet.

The budgets assume a fixed equipment complement (Figure 3.3A). The hours per machine in the complement table of the worksheet are linked to the sums of machine time of individual production activities associated with each crop. The fixed costs are:

$$FC = ((RV_i + RV_{i+1})/2)(r + ins) + DPR \quad (3.3)$$

Where:

$$DPR = RV_i - RV_{i+1} \quad (3.4)$$

$$RV_{i+1} = P * F1\ (F2)^{((BH/H)+1)} \quad (3.5)$$

$$RV_i = P * F1\ (F2)^{(BH/H)} \quad (3.6)$$

$$H = TH/NE \quad (3.7)$$

The fixed cost per hour of an operation [FC] is equal to this year's depreciation [DPR] plus the average value of a piece of equipment times an interest rate [r] and insurance rate [ins]. The average value is equal to the average of remaining value at the beginning [RV_i] and the end [RV_{i+1}] of the current year. Depreciation is equal to the remaining value at the beginning of the year less the remaining value at the end of the current year. Remaining value [RV] at a given point in time (i or i+1) is a function of the age, current purchase price [P], and scaling parameters [F1 and F2] (American Society of Agricultural Engineers, 1986). Age in years is determined by dividing total hours up to the current period [BH] (i or i+1) by the hours per year per piece of equipment [H]. The number of hours per piece of equipment is simply equal to the total hours per year a given type of equipment [TH] is used on the farm divided by quantity of that type of equipment available [NE]. The capital costs for the center-pivot irrigation system are based on previously estimated fixed values and do not use the above formulation for depreciation estimates (Hinman, Wright, and Willett, 1982). These center-pivot fixed costs are on a per acre basis.

Variable costs are calculated as follows:

$$VC = CFC + RC/H \quad (3.8)$$

Where:

$$CFC = GP*hp\ (0.52*lf + 0.77 - 0.04\ (738*lf*173)^{0.5})/2 \quad (3.9)$$

$$RC = P*rf1\ (((H + BH)/1000)^{rf2} - (BH/1000)^{rf2}) \quad (3.10)$$

The variable costs per hour [VC] are equal to calculated fuel costs per hour [CFC] plus total calculated repair costs [RC] divided by the hours of operation in the current year. Calculated fuel costs are a function of the price of diesel fuel [GP], horsepower [hp], and a load factor [lf] (which is set to one for this study) (American Society of Agricultural Engineers, 1986). This formula is used for all self-powered equipment except for the trucks. Calculated repair cost are a function of the original purchase price, machine-specific scaling parameters [rf1 and rf2], and the hours of use at the beginning and end of year (American Society of Agricultural Engineers, 1986). The operating costs for the trucks are based on previous of estimated fixed values (Hinman, Wright, and Willett, 1982). Note also that truck time is in hours per acre, rather than miles per acre. The operating costs for the center-pivot irrigation system is a fixed value equal to that used in the dynamic optimization model ($0.16 ha/mm or $20 acre/ft).

The crop budgets (Figures 3.3C-3.3G) provide a complete list of all cultural activities assumed for each crop (i.e. wheat, corn, potatoes, and alfalfa). The crop budgets are based, in part, on farmer interviews in the study area and together with previously developed crop budgets for the Columbia Basin (Hinman, Wright, and Willett, 1982). Basically, farmers were shown the old enterprise budgets for Washington and asked how and where their operations differed.

Time requirements for most production activities were calculated on a per-acre basis. The exceptions included all harvest-related costs for potatoes, hauling and drying costs for corn, and hauling costs for wheat, which were based on crop yields.

The fixed and variable machine costs in these crop budgets are functions of per-hour costs of the appropriate items in the equipment complement. The per-acre labor costs for each activity are linked to the wage rate cell of the parameter table (Figure 3.3B) in the worksheet. A "C" in the equipment number column of these budgets indicates the activity is being provided by a custom service of some type. Custom service costs are listed in the "Service" column of each budget table of the worksheet. The materials column lists the cost of any materials used in an activity, such as pesticides or herbicides. Most of the values are constants, but some are calculated. For example, the portion of the worksheet (see Figure 3.3B) which calculates the costs of pre-plant fertilizer mixes for all crops is linked to one cell of this column in each budget. Also, the values in the input quantity/cost column of each budget (see the first column of each crop budget) hold several types of data which vary from line item to line item. This column provides a general purpose parameter cell for each line item. The values in these cells are generally used to calculate the cost of certain materials, such as seed costs and nitrogen fertigation. This column contains, in other cases, per unit costs for custom services such a hauling.

The income statement of the worksheet (see Figure 3.3B) provides a summary of the costs and returns for the production of each crop. This income statement provides various pieces of information by crop, including gross receipts, total variable cost, total capital costs, overhead costs (which are a fixed percentage of gross receipts), and land costs[68].

Summary

This chapter discusses the data used to implement the various models defined in Chapter 2. Sources for all data are provided. Formulas used in calculating some of the parameters are also reported. Data requirements for the CERES crop simulators are discussed including weather, soils, genetics, and base management practices. Next, the input costs and price data used in the dynamic optimization model are supplied. Finally, the procedure and data used to generate and enterprise budget for

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[68]One feature of this table is that it can display the item on a per acre basis, by circle, or by farm depending on the value placed the "Display Acres" column. This is accomplished by setting the acres parameter to 1 for a per acre display, to 125 for a per circle display, or to total acres of in a given crop for across farm display.

a diversified irrigated farm in the study area are discussed. The next chapter discusses the results of this study.

CHAPTER 4: RESULTS AND IMPLICATIONS

Introduction

Previous chapters of this dissertation present the problem setting, the methodological approach, and a description of the data used to implement that methodology. The current chapter focuses on the empirical results arising from this application. Specifically, the base solutions from the dynamic optimization model for all three crops are presented, followed by results from various policy scenarios. Several sensitivity analyses are also presented to test the general robustness of the optimal solutions.

Following the discussion of crop-specific analyses, results of the farm-level LP model are discussed that reflect the effects of farm-level restrictions on total nitrate leachate are compared to optimal management practices. The farm-level model accounts for adjustments in crop mix as a possible mitigation strategy for changes in farm-level nitrate restrictions. Finally, effects of optimal farm irrigation and fertilization practices on nitrate levels in the aquifer are briefly explored though a series of multi-year simulations with the geohydrology model.

Computational Issues Related to the Dynamic Optimization Model

Before proceeding with a discussion of the optimization results, it is important to understand the conditions under which these numeric estimates were generated. There are several computational issues associated with models such as the dynamic optimization/CERES model used here. First, a post-decision period decision rule must be selected. Two post-decision period irrigation rules for soil moisture[69] were tested for each crop to determine which rule resulted in the highest net returns. The first rule maintained the current state level from the day after the decision period through harvest; the second rule maintained a fixed level of soil moisture independent of the state level and varied from crop to crop. The rule that resulted in the largest net profit for a given crop was selected for use as the base analysis.

Second, because of the computational time required to obtain an optimal solution, the dynamic optimization models were solved on three different type of computers. The computers used for this study were a VAX 8700, a Definicon 785, and a FPS 164/264. To test for the potential effect of differences in numeric precision across computers, the same test models for potatoes (in a grain rotation) and wheat were solved on different systems. The results of these optimization analyses, which are given in Table 4.1, indicating trivial differences in yields and net returns, minor differences in water and nitrogen usage, but substantial

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[69]The importance of providing CERES a post-decision period irrigation rule to calculating final yields was discussed in Chapter 2.

Table 4.1. Differences in the Dynamic Optimization Model Estimates Across Computer Systems.

Computer Systems	Net Returns ($/ha)	Yields (kg/ha)	N Leachate (kg/ha)	N Usage (kg/ha)
Wheat:				
Definicon 785:	1,253	9,102	0.92	280
Vax 8700 (VMS):	1,254	9,041	1.41	269
Percent Difference:	0.008	0.7	66	3.9
Potatoes:				
FPS 264:	4,438	63,861	1.76	403
Vax 8700 (VMS):	4,247	61,400	2.90	423
Percent Difference:	0.7	0.2	34	3.2

relative (but not absolute) difference in nitrate leachate levels (of 66 and 34 percent for wheat and potato). This variability in numeric precision of leachate levels occurs largely because of the numerous discontinuous relationships embedded within the CERES models, allowing very small differences in precision to lead to substantially different results. To minimize the problem of varying numeric precision, all solutions for a given crop in a given rotation were solved on the same operating system (except where indicated).

Third, differences in precision between computers may also cause differences in simulation results. For example, test solutions indicated that yield could vary by up to three percent and predicted nitrate leachate rates could vary by nearly five percent. Therefore, all results are reported from each machine without normalization to a common computer. Comparisons of numeric results between different crops and/or computers should be done only where values differ significantly. These differences in precision were not considered serious enough to alter the qualitative implications of the results.

Fourth, the computational costs of each dynamic optimization analysis were significant. For comparison purposes, the computational times on a Cray X-MP would be approximately 0.9, 2.5, 2.8, and 3.1 hours for wheat, potatoes after grain, corn, and potatoes after alfalfa. The basic dynamic optimization analyses required approximately 30, 80, 90, and 98 hours of computer time for wheat, potatoes after grain, potatoes after alfalfa, and corn on a Definicon 785[70]. The computational time for the wheat sensitivity analyses ranged from 8.8 hours to 221 hours. Therefore, the number of analyses examined in this dissertation was kept to a minimum.

Dynamic Optimization Results

The dynamic optimization model identified optimal irrigation and fertilization patterns for all crops. In addition, a number of policy options were considered, including 1) restricting total fertilizer quantities at 25 percent less than the optimal quantity, 2) a tax on nitrogen fertilizer equal to its cost (i.e., a 100 percent tax), 3) Pigovian taxes on nitrate pollution levels, and 4) direct controls on pollution quantities. Sensitivity analyses were then performed with the wheat model because it was the simplest model to solve. Sensitivity analyses included 1) alternative post-decision period irrigation rules for soil moisture, 2) decreases in output prices, 3) use of homogenous soils, 4) alternative weather years, 6) alternative state space step sizes, and 6) a tax on irrigation water equal to its cost. In addition, stand-alone simulations were done with CERES for each crop using current irrigation and fertilizer practices, along with simulations that reduced nitrogen

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[70]The computational times are provided for comparative purpose only. To compute these timing statistics, benchmarks for each system used in this study were done using a version of the CERES simulator. Then, the actual solution times for the base optimization models were computed on the original computers used for each crop. These values were then normalized to the Cray and the 785.

applications 25 percent across the board from optimal levels. Table 4.2 provides a summary of the major analyses conducted for this dissertation.

A summary of the dynamic optimization model results are presented in Tables 4.3A-4.3D for wheat, corn, potatoes after grain, and potatoes after alfalfa. This tables shows the effects on optimal irrigation and fertilization strategies arising from changes in input and output prices, from weather patterns, soil homogeneity, pollution taxes, restrictions on quantity of nitrogen fertilizer applied, and restrictions on pollution rates. The profits shown in these tables are returns after irrigation, nitrogen, and per unit costs (e.g., hauling costs) are subtracted. Figures 4.1 and 4.3-4.10 provide a graphic depiction of the differences in average soil moisture levels, average soil nitrogen levels, irrigation patterns and fertigation patterns between the base optimization models and selected policy and sensitivity models. Table 4.4 presents the Julian dates for each stage of each CERES crop. The agronomy literature lacks a clear consensus concerning the definitions of many intermediate growth stages; therefore, one should refer to CERES's documentation for the definitions used for each stage (Ritchie, Godwin, and Otter-Nacke, 1986; and Jones and Kiniry, 1986). Complete listings of optimal irrigation and fertilization patterns for each crop's base scenario can be found in Appendix B.

Table 4.2. Summary of Major Dynamic Optimization Analyses.

Abbreviated Titles*	Summaries
Current Practices	Actual irrigation and nitrogen fertilization practices observed in the study area for the 1987-8 crop year with the CERES crop simulators.
Base Model	Dynamic optimization models to maximize net farm income with respect to irrigation and fertilization application.
Base Model w/25% Fixed N Reduction	Imposed a 25 percent across the board reduction in nitrogen fertilizer applications to the solutions of the base dynamic optimization models using the CERES simulators.
25% N Restriction	Dynamic optimization with constraints restricting nitrogen fertilizer to be 25 percent less than the base models.
XX% Leachate Restriction	Dynamic optimization with constraints restricting nitrate leachate to be XX percent less than the base models.
N Tax	Dynamic optimization with a 100 percent tax applied to nitrogen fertilizer ($0.37 per kilogram elemental N).
Pollution Tax	Dynamic optimization with a $26.42 per kilogram tax applied to nitrate which leaches below the root zone.

* These abbreviated titles are the same titles used in subsequent tables of results.

Table 4.3A. Results of the Wheat Dynamic Optimization Models.

Type of Analysis	Pred. Yield (kg/ha)	Profit ($)	Quant. Water Appl. (mm)	Quant. Nitr. Appl. (kg/ha)	Quant. Water Leach (mm)	Quant. NO_3 Leach (kg/ha)
Definicon 785 Runs:						
Current* Practices	8,779	1,207	605	298	66	1.53
Base Model w/Shano Soil	9,176	1,280	394	303	11	0.92
Base Model w/Quincy Sand	9,102	1,253	531	280	45	3.17
Base Model:						
Sub-Field#1	9,080	-	531	280	52	3.70
Sub-field#2	9,127	-	531	280	43	3.00
Sub-field#3	9,099	-	531	280	41	2.81
Base Model w/25% Fixed N Reduction**	8,156	1,128	531	210	50	3.44
25% N Restriction	8,620	1,210	484	209	16	1.70
50% Leachate Restriction	9,087	1,259	493	277	17	1.50
70% Leachate Restriction	8,190	1,159	430	203	10	0.98
N Tax	8,603	1,107	468	244	10	1.00
Water Tax	9,091	1,182	474	288	12	1.12
Pollution Tax	8,870	1,208	485	260	10	1.01
25% Reduction in Output Price	9,039	883	514	283	21	1.86
State Space Steps:						
2 mm/m & 10 kg/ha/m	9,050	1,246	574	273	26	1.76
2 mm/m & 20 kg/ha/m	9,026	1243	545	269	47	2.64
1980 Weather	9,511	1,332	461	276	30	3.08
1986 Weather	8,552	1,139	549	342	48	4.39
Homogenous Soil	9,039	1,300	514	283	22	1.71
Vax 8700 (VMS) Runs:						
Base Model	9,041	1,254	496	269	17	1.41
Alternative Post-Decision Period Irrigation Rule	8,780	1,208	515	268	33	1.86

*This simulation run is presented to provide a reference point; it used a different soil type (Shano silt) than the majority of the optimization analyses.
** Simulation Run

Table 4.3B. Results of the Corn Dynamic Optimization Models.

Type of Analysis	Pred. Yield (kg/ha)	Profit ($)	Quant. Water Appl. (mm)	Quant. Nitr. Appl. (kg/ha)	Quant. Water Leach (mm)	Quant. NO_3 Leach (kg/ha)
Floating Point Systems 164 & 264 Runs:						
Current* Practices	11,424	1,010	665	320	42	2.37
Base Model w/Shano Soil	12,019	1,100	456	383	0	0.00
Base Model w/Quincy Sand	11,992	1,067	605	391	24	2.07
Base Model:						
Sub-Field#1	12,176	-	605	391	31	2.84
Sub-field#2	11,878	-	605	391	22	1.85
Sub-field#3	11,923	-	605	391	20	1.52
Base Model w/25% Fixed N Reduction**	10,342	858	605	293	25	1.98
25% N Restriction	11,882	1,093	599	291	17	1.55
50% Leachate Restriction	11,589	1,044	559	334	8	0.69
89% Leachate Restriction	11,723	1,055	556	369	2	0.23
95% Leachate Restriction	6,355	532	529	240	1	0.11
N Tax	12,004	929	613	382	45	3.71
Pollution Tax	11,987	1,049	636	392	9	0.81
Alternative Post-Decision Period Irrigation Rule	11,715	1,042	586	387	14	1.09

*This simulation run is presented to provide a reference point; it used a different soil type (Shano silt) than the majority of the optimization analyses.
** Simulation Run.

Table 4.3C. Results of the Potatoes (after alfalfa) Dynamic Optimization Models.

Type of Analysis	Pred. Yield (kg/ha)	Profit ($)	Quant. Water Appl. (mm)	Quant. Nitr. Appl. (kg/ha)	Quant. Water Leach (mm)	Quant. NO_3 Leach (kg/ha)
<u>Vax 8700 (VMS) Runs:</u>						
Current* Practices	58,986	4,081	711	434	18	5.11
Base Model w/Quincy Sand	61,007	4,224	799	400	14	2.30
Base Model:						
Sub-Field#1	61,258	-	799	400	26	4.33
Sub-field#2	64,047	-	799	400	10	1.76
Sub-field#3	57,715	-	799	400	6	0.82
Base Model w/25% Fixed N Reduction*	47,504	3,262	799	300	14	2.25
25% N Restriction	53,370	3,698	728	300	14	2.30
50% Leachate Restriction	58,473	4,052	719	396	7	1.24
97% Leachate Restriction	58,499	4,062	686	387	0.4	0.06
N Tax	60,241	4,038	728	390	15	3.09
Pollution Tax	59,798	4,120	724	407	6	1.12
Homogenous Soil	62,970	4,370	753	420	22	4.80
Alternative Post-Decision Period Irrigation Rule	59,549	4,118	791	397	25	5.87

* Simulation Run

Table 4.3D. Results of the Potatoes (after grain) Dynamic Optimization Models.

Type of Analysis	Pred. Yield (kg/ha)	Profit ($)	Quant. Water Appl. (mm)	Quant. Nitr. Appl. (kg/ha)	Quant. Water Leach (mm)	Quant. NO_3 Leach (kg/ha)
Floating Point Systems 164/264 Runs:						
Base Model w/Quincy Sand	63,861	4,438	767	403	15	1.76
Base Model:						
Sub-Field#1	71,019	-	767	403	21	2.66
Sub-field#2	59,804	-	767	403	15	1.68
Sub-field#3	60,546	-	767	403	8	0.95
Base Model w/25% Fixed N Reduction*	44,595	3,081	767	305	15	1.70
25% N Restriction	51,202	3,536	795	300	20	2.22
50% Leachate Restriction	57,098	3,961	710	369	8	0.87
96% Leachate Restriction	58,831	4,092	644	394	0.6	0.07
N Tax	58,379	3,762	768	403	21	2.51
Pollution Tax	58,913	3,915	738	444	11	1.11

* Simulation Run

Table 4.4. Julian Date for Various Phenological Stages in Each CERES Model.

CERES Stage Label	Beginning Julian Date
CERES Wheat:	
Germination	300
Emergence	301
Vernalization	313
Early Ear Growth	115
Pre-Anthesis (pre-flowering) Ear Growth	142
Flowering	158
Grain Filling	169
Maturity	196
CERES Corn:	
Germination	121
Emergence	123
Juvenile	133
Vegetative	146
Tassel Initiation	152
Early Grain Filling	196
Effective Grain Filling	208
Maturity	256
CERES Potatoes:	
Germination	75
Emergence	76
Vegetative	99
Early Tuber Growth	163
Linear Tuber Growth	189
Dominant Tuber Growth	n/a
Maturity	229

n/a - not applicable

Current Versus Optimal Crop Production and Base Analyses

A comparison between current and optimal practices suggests only modest increases in yields and profits if farmers had the same flexibility of choices available to the optimization model. Wheat yields would, on a silty soil, increase from 8,779 kg/ha to 9,176 kg/ha (five percent) with an eight percent improvement in profits. Corn yields, on the same soil, registered about the same relative increase from 11,424 to 12,019 kg/ha (five percent), with a nine percent increase in profits. Note that nitrate pollution was eliminated using the optimization model because of improvements in water management. Potato yields following alfalfa on a sandy soil increased approximately three percent under optimal practices (to 61,007 kg/ha), with a four percent improvement in profits. The base optimization model for potatoes following grain predicted yields of 63,861 kg/ha. Note that no current practices data were available for potatoes following grain on a sandy soil. Although the base optimization models suggest lower potato yields following alfalfa than if following grain, farmers in the study area find the opposite was true. This discrepancy can be attributed to shortcomings in CERES-Potatoes, specifically 1) failure to recognize the benefits of tilth on yields and 2) the large yield penalties for excessive quantities of mineralized soil nitrogen in the potatoes following alfalfa rotation.

The percentage changes in the net returns for moving from the current-practice models to the optimization models (discussed above) were modest. However, the percentages understate the change in net profits faced by the farmer because fixed production costs have not been subtracted. For example, if the fixed production costs are deducted, the increase in profits for potatoes following alfalfa would triple to 13 percent[71].

In each model, alternative post-decision period irrigation rules were tested. The results for corn and potatoes suggest that maintaining a fixed soil moisture yields a higher net return than maintaining the current state of soil moisture. The fixed levels used in the decision rules for corn and potatoes were 70 mm/m and 45 mm/m. However, the opposite was true for wheat. Therefore, the fixed decision rule was used for all subsequent corn and potato analyses, and the current state rule was used for wheat analyses. The differences between the two rules were modest, with differences in net returns ranging from only two to four percent. It should be noted that the selection of these two rules for respective crops was based on tests of numerous other rules, most whose performance were substantially below the two rules selected for formal testing. Thus, the selection of a post decision period rule can have serious impacts on the results of the analysis.

Figures 4.1A-4.1C depict how the optimization models respond relative to the current practices models. No comparison between optimal and current practices was conducted for potatoes following grain because

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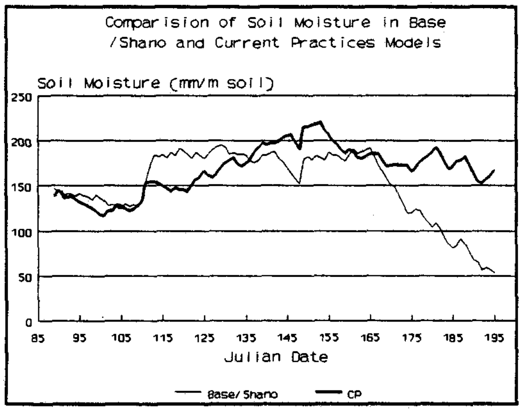
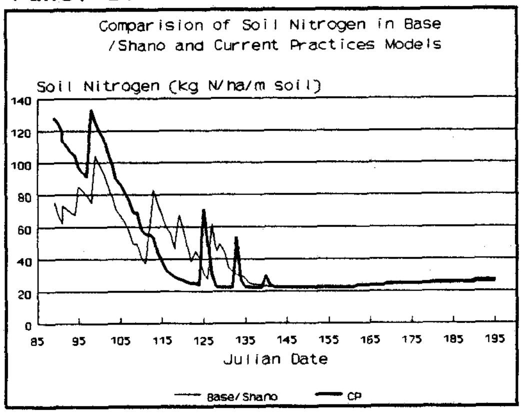
[71]The assumed per hectare fixed production costs for wheat, corn, and potatoes are 750, 939, and 2,941 dollars.

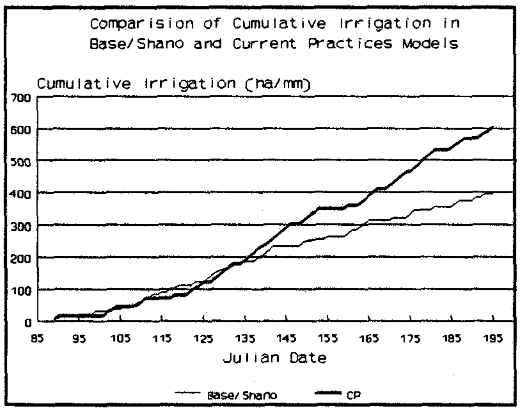
Panel 1.



Panel 2.



Panel 3.



Panel 4.

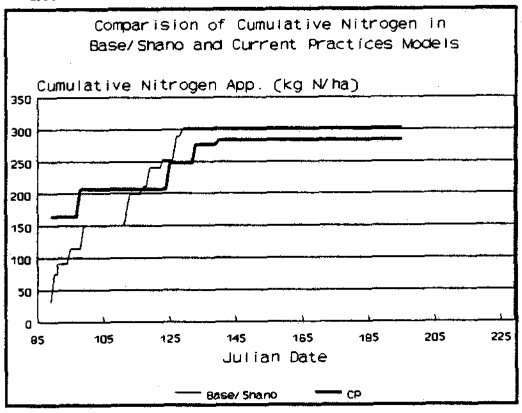


Figure 4.1A. Depiction of Differences in Base and Current Practices Models for Winter Wheat.

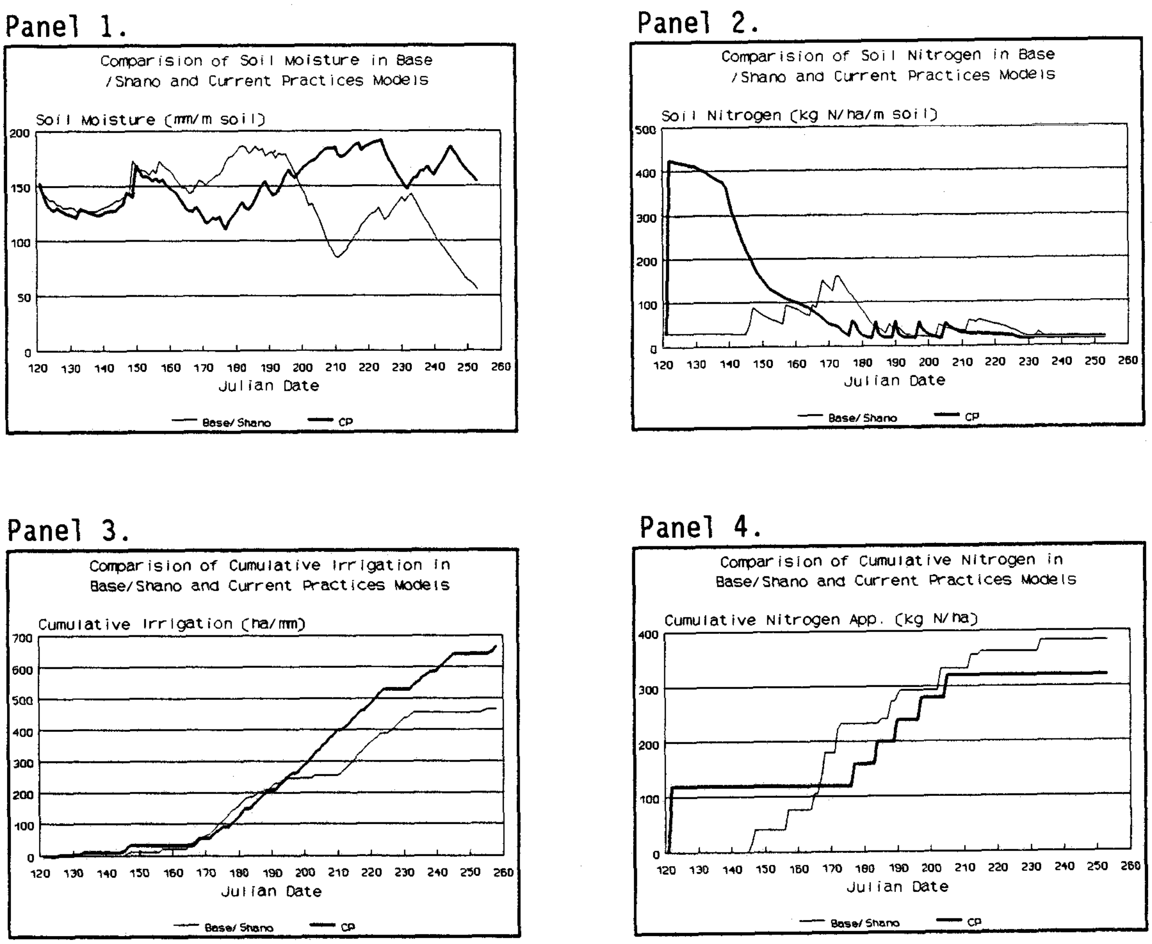


Figure 4.1B. Depiction of Differences in Base and Current Practices Models for Corn.

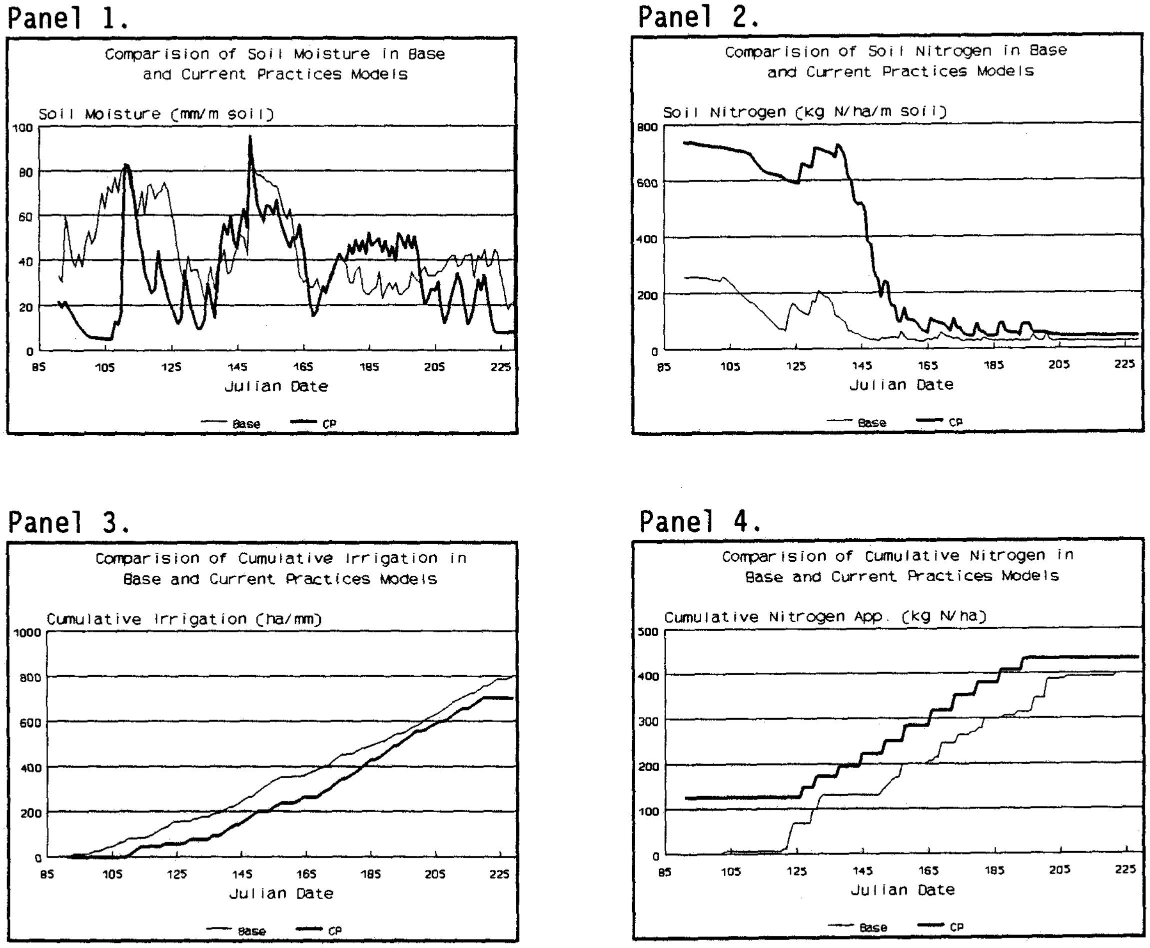


Figure 4.1C. Depiction of Differences in Base and Current Practices Models for Potatoes (following alfalfa).

no data were available for potatoes following grain on sands. Panels 1 and 3 in Figure 4.1A indicate that the wheat optimization model reduces soil moisture and irrigation levels prior to a storm on Julian date 149 (May 28) and during the grain filling stage compared to the current practices model. Panel 4 in Figure 4.1A suggests that pre-plant fertilizer quantities were reduced in the optimization model to 88 kg N/ha from 165 kg N/ha for the current practices model[72]. However, the differential in cumulative applications was made up in the first few weeks of the irrigation season and the optimization model ends up applying significantly more fertilizer (than current practices) by the beginning of the early ear growth stage through the end of the growing season. In summary, the results suggest that farmers are applying too much pre-plant fertilizer, are under-fertilizing in the irrigation season, and are over-watering during grain fill.

Panels 1 and 3 in Figure 4.1B suggest that soil moisture and irrigation levels for the corn optimization model were modestly higher during a period of high evapotranspiration and were lower during the early grain filling stage in comparison to the current practices model. Panels 2 and 4 in Figure 4.1B indicate an elimination of the pre-plant application of fertilizer in the optimization model. The figures also suggest modestly increased fertigation rates spread throughout the growing season. The major implications from this comparison are that farmers should decrease irrigation during early grain fill, increase soil moisture

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[72]Note, as discussed in Chapter 3, that the nitrogen carryover levels used are extremely low; therefore, the pre-plant fertilizer application rate are higher than one would normally expect in the study area.

on high evapotranspiration days during tasseling and pollination, eliminate pre-plant nitrogen applications, and increase fertigation rates.

Panels 1 and 3 in Figure 4.1C imply higher soil moisture and irrigation levels in the first 40 days of the irrigation season for the optimization model for potatoes following alfalfa when compared to the current practices model and only minor differences thereafter. Panels 2 and 4 in Figure 4.1C suggest elimination of the pre-plant application of nitrogen fertilizer. Additionally, they suggest that the fertigation rates should be moderately higher through the season. Consequently, the results of the optimization model imply increased irrigation rates early in the growing season, elimination of the pre-plant application of fertilizer, and increased fertigation applications. The results also suggest current management of potatoes is closest to the optimal of the three crops examined. The common theme when comparing these three optimization models and their respective current practices models is a reduction or elimination in pre-plant fertilization and increased dependance on fertigation.

Comparisons between optimization and current practices models suggest modest changes for overall input usage, profits, and yields. For example, the increase in profits for the optimization models ranged from three to eight percent. Therefore, the optimization models appear to be reasonably valid.

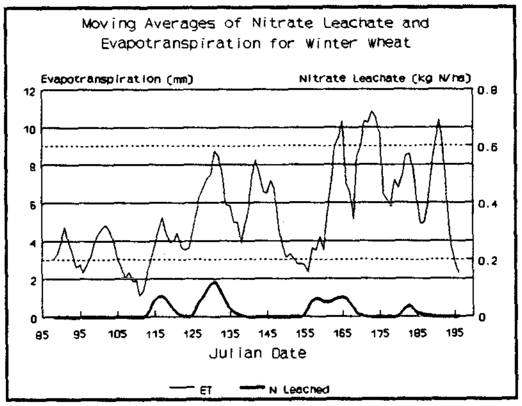
The base optimization models for corn and wheat were redone using Quincy sands, assuming the farming operation being analyzed contained only this type of soil. Quincy Sands are also the dominant soil in the area overlying the wells with the highest nitrate levels. Because of their composition, Quincy Sands have significantly higher leachate potential than Shano Silts. The base analyses for wheat and corn suggests profit maximizing yields of 9,102 kg/ha and 11,992 kg/ha with an associated nitrate leachate levels of 3.17 kg N/ha and 2.07 kg N/ha.

Figure 4.2 provides a graphic depiction of nitrate leachate and evapotranspiration patterns for each base optimization model averaged across sub-fields[73]. The graphs in this figure are smoothed using a simple three day moving average technique so the values in the figure do not exactly reflect actual numeric results. Also, because of the layered structure of soil assumed in the CERES models, leachate events may have lag with respect to the initiating weather water application. Figure 4.2 suggests that periods of nitrate leachate in each crop were associated with periods of either high evapotranspiration or major storm events (e.g., Julian date 149). However, leaching events do not occur during all periods of high evapotranspiration.

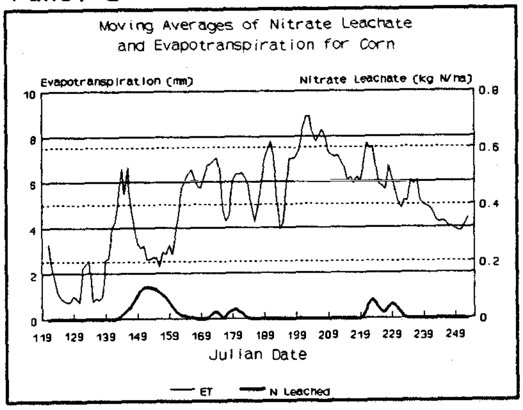
The absolute differences between current and optimal practices were generally small for nitrate leachate levels. In a relative sense, however, the differences can be quite dramatic. For example, the quantity

[73]A listing of the raw evapotranspiration and leachate levels used to generate this graph can be found in Appendix B within the output files for the base analysis of each crop.

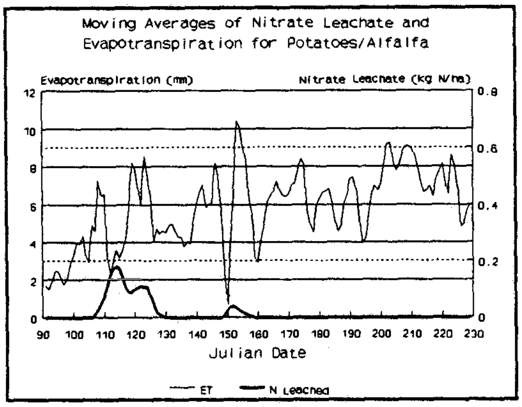
Panel 1.



Panel 2.



Panel 3.



Panel 4.

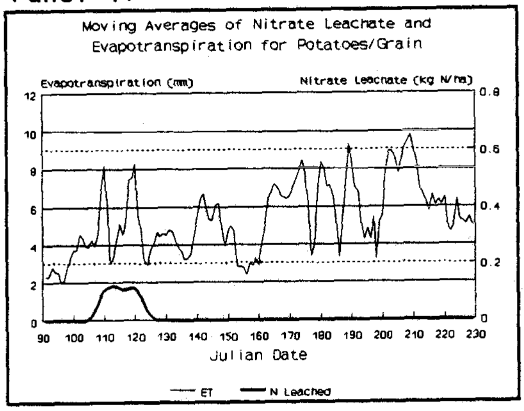


Figure 4.2. Depiction of Three Day Moving Averages of Nitrate Leachate and Evapotranspiration for Winter Wheat, Field Corn, Potatoes Following Alfalfa, and Potatoes Following Grain.

of NO_3 leached under optimal irrigation and fertilization strategies for potatoes following alfalfa was predicted to be only 2.81 kg N/ha less than under current practices. However, the relative difference (55 percent), indicating a major reduction in leachate.

As noted earlier, the optimal solutions use information about weather events that may not be available to farmers. However, movement from current management strategies closer to those identified as optimal is possible even if farmers are unable to obtain perfect information about future weather events. The primary change in management concerns the number of fertilizer applications. Specifically, the number of nitrogen applications was typically two to three times higher under the optimal solutions than for current practices[74]. As might be expected, quantities of nitrogen per application were smaller under the optimal solution. In effect, higher profits and lower nitrate leachate levels can be achieved if farmers time applications to coincide more closely with plant needs.

Some variability exists between sub-fields in terms of yield and pollution rates for each of the crops. The coefficients of variation for yields in the sub-fields of wheat, corn, potatoes following alfalfa and potatoes following grain were 0.3, 1.3, 5.2, and 9.8. The coefficients of variation for nitrate leachate in the sub-fields of wheat, corn, potatoes following alfalfa and potatoes following grain were 14.8, 33.3,

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[74]The number of nitrogen applications for the current practices verses the base optimization model was 5 verses 10 for wheat, 6 verse 24 for corn, 12 verse 24 for potatoes following alfalfa, and 12 verses 32 for potatoes following grain.

78.3, and 48.9. The magnitude of the leachate variability emphasizes the importance of including heterogenous soils in the model to help understand some of the reasons for nitrate pollution. Additionally, the results indicate that heterogeneity is more important when dealing with potatoes than with grains.

Leachate levels modeled under current practices were unexpectedly low for all three crops, with the highest concentration being approximately five kg N/ha for potatoes following alfalfa. By comparison, Hergert (1986) found that leaching rates for irrigated corn in Nebraska on sandy soil ranged from 12 to 146 kg N/ha depending on the weather year and irrigation strategy. This result is in stark contrast to the base optimum leachate levels for corn of only two kg N/ha. Hergert also identified other researchers who estimated leachate levels ranging from 20 to 157 kg N/ha. In part, the low levels predicted in this study can be attributed to 1) relatively homogeneous soils, 2) use of center pivot irrigation systems, and 3) a high level of irrigation and fertility management. Nonetheless, these results suggest CERES may understate the level of nitrates actually being leached. It seems reasonable to assume, however, that the relative ranking between different model solutions are correct for each crop. The relative differences between solutions may also be correct.

One possible explanation for CERES's apparent understatement of leachate rates may be found in the nitrogen uptake functions. Panel 2 in Figures 4.1A-C suggest extremely rapid nitrogen uptake at various points in the growing seasons of each crop. For example, potatoes following grain had daily nitrogen uptake rates[75] of as high as 33 kg N/ha. If the CERES models are not limiting daily nitrogen uptake adequately, then nitrate concentrations during periods of percolation may also be understated. Consequently, the predicted nitrate leachate will be low because it is a function of percolation rates and soil nitrate concentrations.

The Effect of Nitrogen Restrictions

Two types of nitrogen restriction were applied to the base models. The first was a 25 percent across-the-board cut in the quantity of fertilizer available for application based on each optimal solution. The second was a constraint that also reduces the total application by 25 percent, but allows the model to allocate this reduced quantity of nitrogen throughout the growing season.

The 25 percent across the board cuts in quantity of fertilizer applied to the optimal solutions, as expected, generated lower profits compared to the 25 percent nitrogen application restriction that allows flexibility in fertilizer timing. Profits were reduced for wheat, corn, potatoes following alfalfa, and potatoes following grain by 7, 22, 12, and 13 percent when comparing across the board cuts to the flexible constraints. In fact, the constrained corn model with flexible timing

[75]The daily nitrogen use includes primarily uptake of mineralized NO_3 and NH_4. It also includes small amounts of denitrification and net loss of organic nitrogen forms.

had essentially the same profits when compared to the unconstrained model, suggesting a large range of fertilizer application strategies (or combinations) with similar profit levels. It also suggests that the dynamic optimization model is not a global optimum[76].

Furthermore, across the board cuts in corn and wheat fertilizer were inferior to flexible restrictions as a means of reducing leachate. Leachate levels were reduced by 102 percent for wheat and by 22 percent for corn under the flexible constraints when compared to across the board cuts. The flexible constraint also caused a reduction in the number of nitrogen applications when compared with the base analyses. For example, the wheat model reduced the number of nitrogen applications by 30 percent (from 10 to 7 applications) and average application rates by 19 percent. These results suggest that if nitrogen restrictions are applied, they should be flexible in terms of timing because flexible restrictions perform as well or better than across the board restrictions with respect to pollution rates and significantly better with respect to profits.

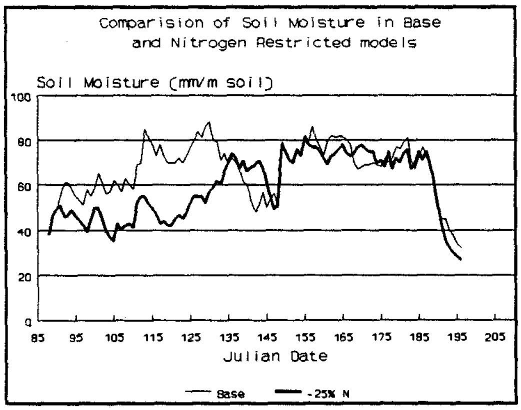
---

[76]There are a combination of likely reasons for this anomaly. First, note that if fertilizer applications after Julian date 200 in the base optimization model were eliminated (amounting to 50 kg N/ha), the yield would only fall 24 kg/ha, indicating a low marginal product for the late applications. Second, the expected weather during grain fill was substantial more favorable to corn than actual weather. Third, the nitrogen from the late fertilization was exhausted well before the end of grain fill. Therefore, the use of expected weather may have given corn optimization model false signals as to the true marginal productivity of the late nitrogen applications. Furthermore, since solutions with these late nitrogen applications quickly used up their soil nitrogen, the solutions could compete favorably with the states which maintained lower application rates to enter the solutions for the lowest nitrogen state levels.

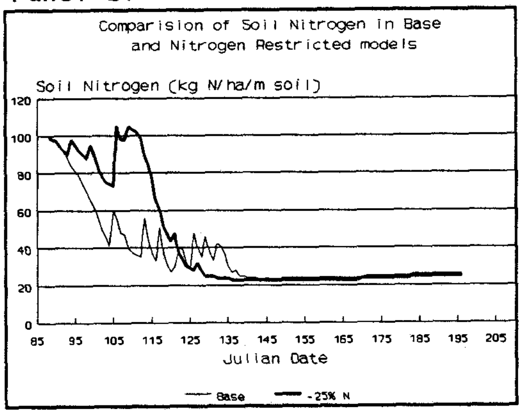
Note that the nitrate leachate levels for wheat in the fixed restriction scenario actually increase a modest amount in comparison to the base optimization model. This was caused by limitations on the wheat crop's ability to absorb nitrogen which, in turn, was caused by reduction in biomass resulting from nitrogen stress early in the growing season. This result provides a good example of why the sign of nitrate leachate is indeterminent when nitrogen restrictions are imposed in an inflexible manner.

Figures 4.3A-D illustrate how the optimization models responded to flexible nitrogen restrictions. Panel 4 in Figure 4.3A indicates that nitrogen applications for wheat were shifted somewhat toward the early part of the growing season (the vernalization and early ear growth stages). However, Panels 1 and 3 in Figure 4.3A indicate significantly lower irrigation and soil moisture levels in approximately the same period. Panels 2 and 4 in both Figures 4.3B and 4.3C indicate some minor shifts in soil nitrogen and fertigation levels in the middle of the season, until the fertilizer constraint becomes binding when corn and potatoes (following grain) are compared to the base models. Panel 3 in Figure 4.3D indicates only minor differences in irrigation patterns when the constrained corn model is compared to the base model. Panels 1 and 3 in Figures 4.3D indicate modestly higher irrigation and soil moisture levels in the middle of the season and lower levels during the linear tuber growth stage for potatoes (following grain). An indication that the fertigation and irrigation patterns of the constrained potatoes (following alfalfa) were identical to the base model until the fertigation constraint

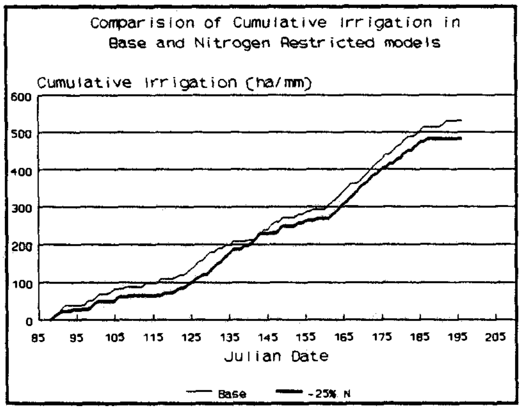
Panel 1.



Panel 2.



Panel 3.



Panel 4.

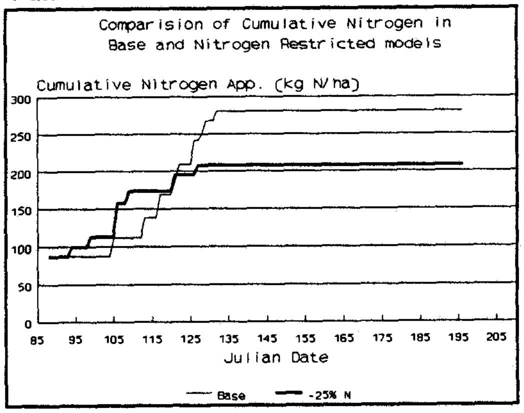
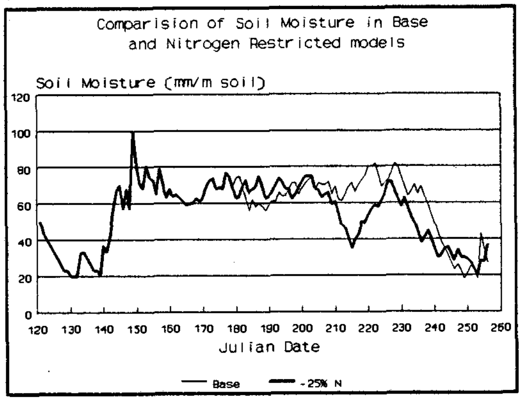
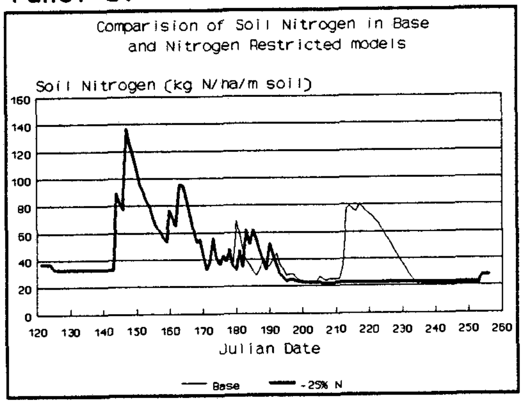


Figure 4.3A. Depiction of Differences in Base and Nitrogen Restricted Models for Winter Wheat.

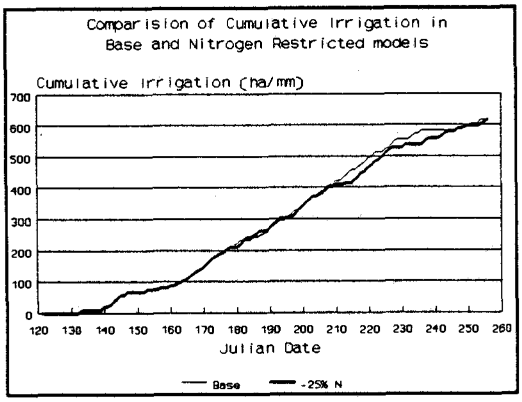
Panel 1.



Panel 2.



Panel 3.



Panel 4.

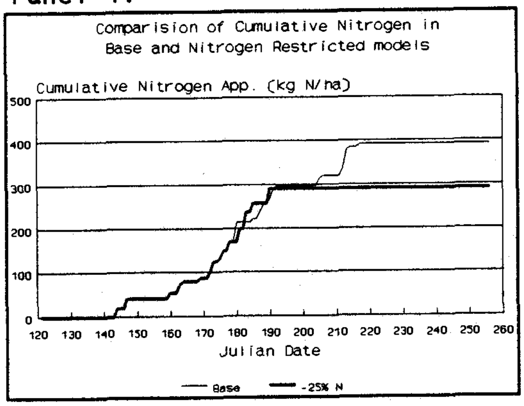
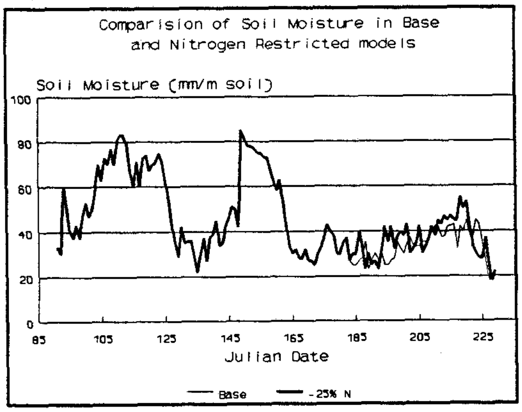
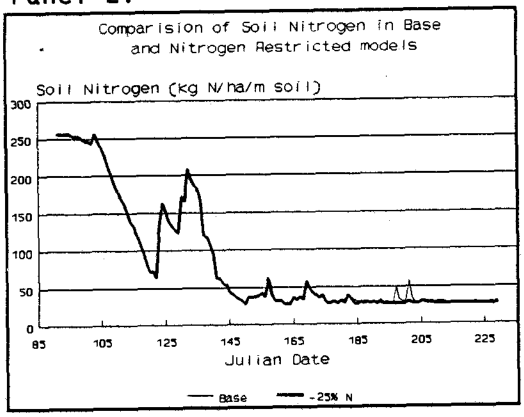


Figure 4.3B. Depiction of Differences in Base and Nitrogen Restricted Models for Corn.

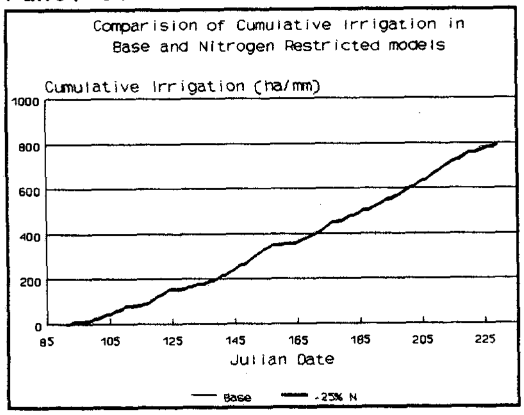
Panel 1.



Panel 2.



Panel 3.



Panel 4.

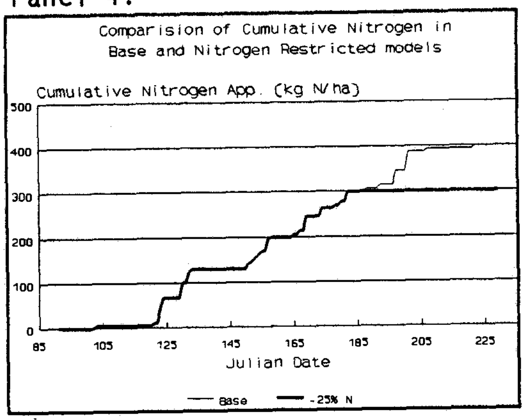
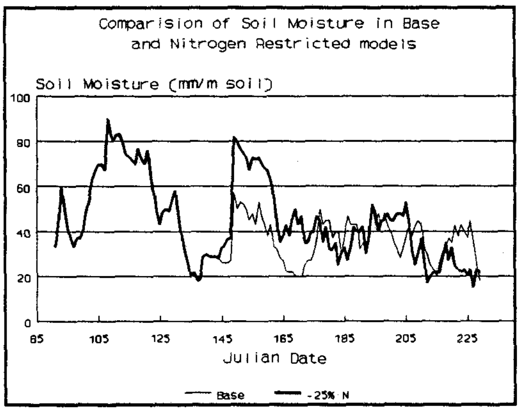
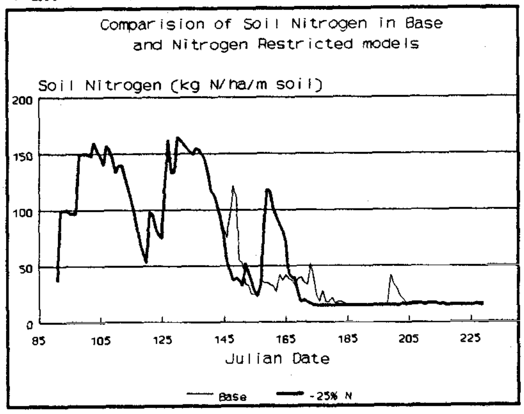


Figure 4.3C. Depiction of Differences in Base and Nitrogen Restricted Models for Potatoes (after alfalfa).

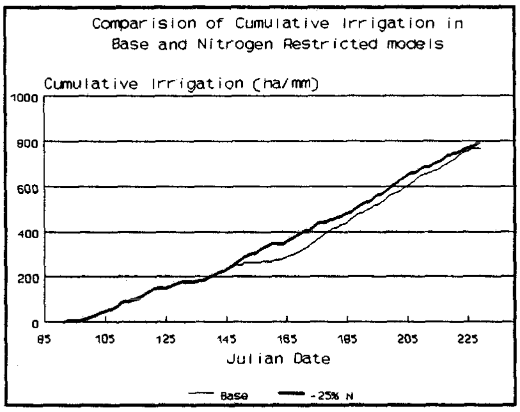
Panel 1.



Panel 2.



Panel 3.



Panel 4.

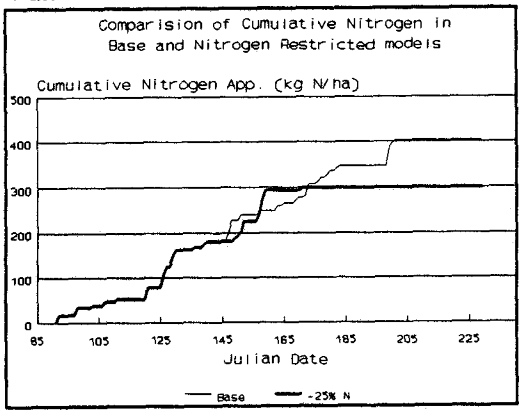


Figure 4.3D. Depiction of Differences in Base and Nitrogen Restricted Models for Potatoes (after grain).

becomes binding is shown in Panels 2 and 4 of Figure 4.3C. Even after the point where fertilizer becomes constrained irrigation quantities remain essentially the same as the base model.

All four nitrogen restricted optimization models suggest a shift in nitrogen application toward the early portion of the irrigation season. This indicates a higher marginal productivity of nitrogen earlier in the season. However, given that the nitrogen constraint uses cumulative applications up to and including the current stage, there may be a bias toward nitrogen application early in the growing season.

Nitrate Leachate Restriction

Two levels of nitrate leachate restrictions were analyzed for wheat. One analysis restricted leachate to 50 percent of the base level. This scenario results in essentially no change in yield and profits compared to the base analysis. However, Panels 1 and 3 in Figure 4.4A indicate that this leachate restriction resulted in a modest decline for irrigation quantities from the pre-anthesis ear growth stage to the end of the irrigation season. Panel 4 in Figure 4.4A implies minimal changes in the fertigation patterns. The fact that the restricted models generated slightly more profit results suggests the base analysis was not a global optimum for the given step sizes[77].

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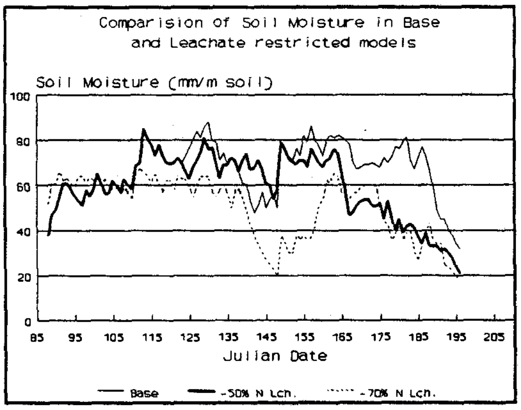
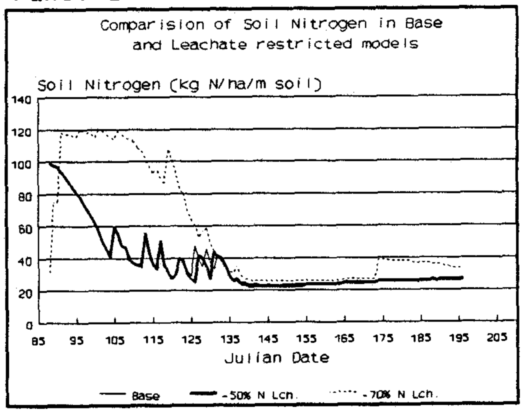
[77]To further examine the larger returns realized under a constraint model, the base analysis for wheat was repeated on a different system (VAX 8700). Table 4.4A provides a summary of the results from this alternative base run. There is only a modest difference in irrigation and fertigation patterns between the base model run on one system and the base model run

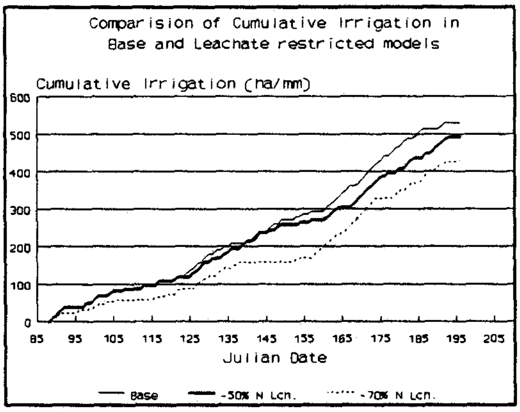
Panel 1.



Panel 2.



Panel 3.



Panel 4.

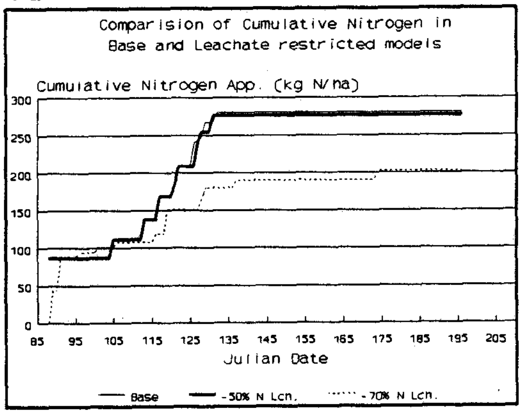


Figure 4.4A. Depiction of Differences in Base and Leachate Restricted Models for Winter Wheat.

A second analysis constrained leachate rates to 0.98 kg N/ha. This value (which represents a 69 percent restriction) was based on the quantity of leachate lost because of winter rains (with no pre-plant nitrogen application) and thus was outside the control of the farm operator. Elimination of any additional leachate throughout the irrigation season was achieved by reducing total water applications by 19 percent and reducing nitrogen applications by 27 percent. Total profits decreased by eight percent. Panels 1 and 3 of Figure 4.4A suggest the methods by which leachate during the irrigation season was eliminated. The model restricts soil moisture levels throughout the season, especially before a major rain storm in late May (Julian date 149) through the end of the pre-anthesis ear growth (Julian date 158) because the model can implicitly anticipate the storm. Panel 4 in Figure 4.4A indicates that to achieve the leachate restriction for wheat, the pre-plant application of nitrogen was eliminated and fertigations late in the irrigation season were reduced relative to the base scenario.

Three levels of nitrate leachate restrictions were identified for corn. The first restricted leachate to 50 percent of the base level. The results show minor differences in yield and profits (three percent and two percent decreases). The second scenario restricted leachate rates to 0.2 kg N/ha (an 89 percent reduction). This level was the maximum nitrate constraint level before profits and yields fall precipitously.

---

on a second system. The profits from the alternative base run are the same as the original base run. However, nitrate leaching levels are 56 percent lower indicating the possibility for a large number of solutions to be very close in terms of profit but divergent in terms of pollution rates.

The 89 percent restriction was achieved through an eight percent decrease in total water applications and a six percent decrease in total nitrogen applications, with only a two percent decrease in profits. Panels 3 and 4 in Figure 4.4B indicate modest decreases in irrigation and fertigation levels throughout the growing season for both the 50 and 89 percent leachate restrictions.

The third scenario for corn restricted leachate levels to 0.1 kg N/ha (a 95 percent reduction). This was the maximum constraint possible for corn without killing the crop. The constraint was achieved through reduction of total water applications by 13 percent, with a 39 percent decrease in total nitrogen applications. This results in a 50 percent decrease in profits. Panel 3 in Figure 4.4B indicates significantly lower irrigation levels until just prior to early grain fill and toward the end of the season relative to the base model. Panel 1 in Figure 4.4B shows that soil moisture levels were reduced markedly prior to a major rain storm early in the season. Significant reductions in fertilizer throughout the growing season are indicated by Panel 4 in Figure 4.4B. The sharp decrease in profits resulting from a small decrease in the constraint level implies a high economic cost for the marginal reduction of 0.1 kg N/ha of nitrate leachate.

Two levels of nitrate leachate restrictions were evaluated for potatoes following alfalfa. Like wheat and corn, the first restricted leachate to 50 percent of the base level. The scenario results in a seven percent decrease in total water applied, an 11 percent decrease in yields

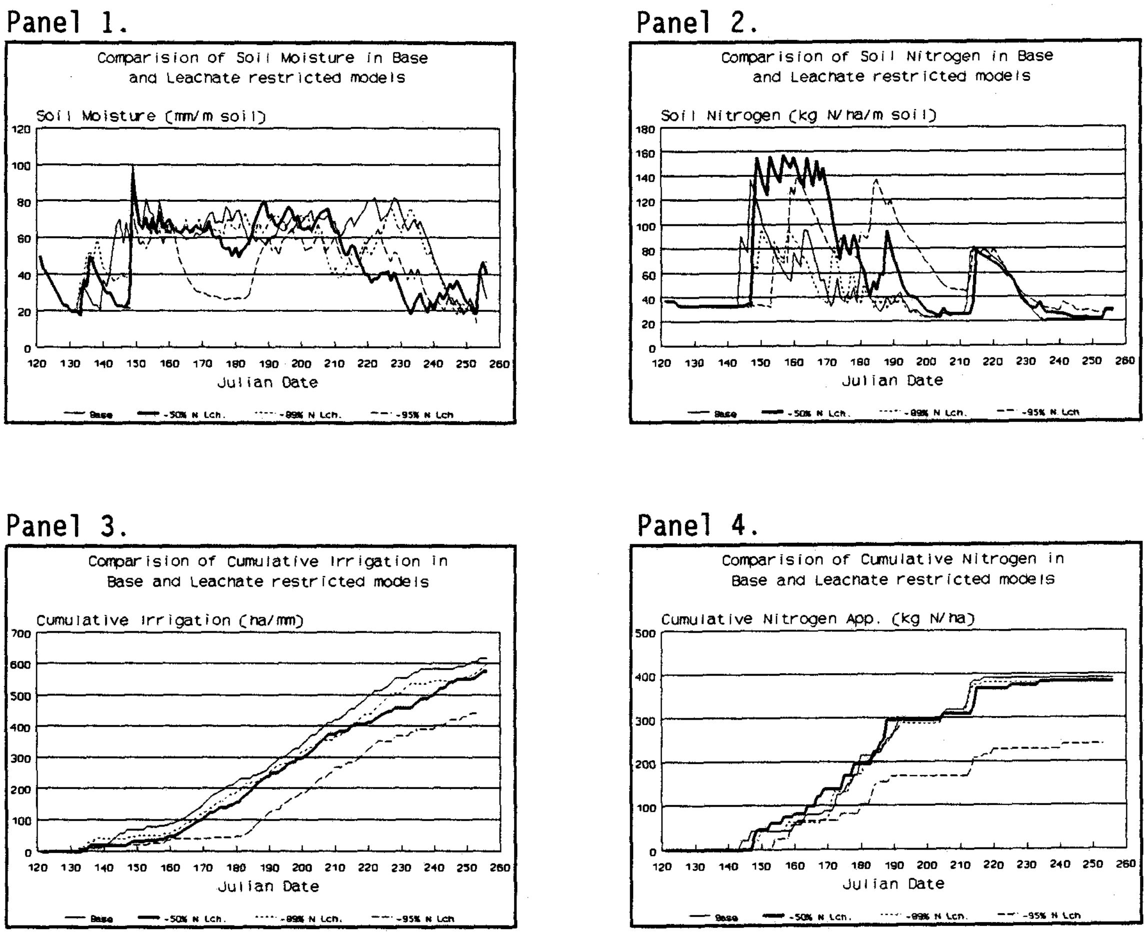
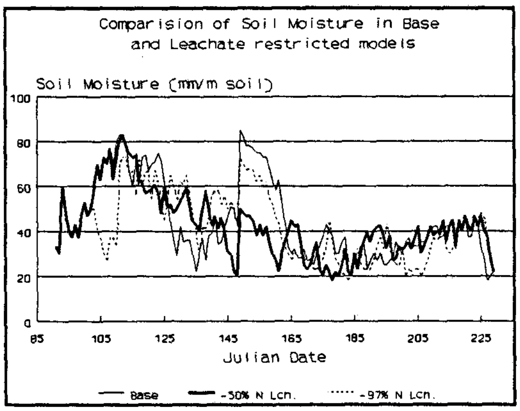


Figure 4.4B. Depiction of Differences in Base and Leachate Restricted Models for Corn.

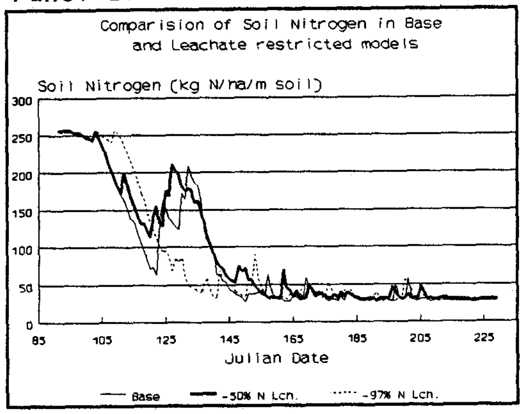
and an 11 percent decrease in profits. Panel 4 in Figure 4.4C suggests only minor shifts in fertigation patterns when compared with the base model. Panels 1 and 3 in Figure 4.4C indicate lower irrigation and soil moisture levels prior to a major mid-season storm through the beginning of early tuber growth and only minor shifts in other portions of the season. The second leachate-restricted solution decreased rates to 0.07 kg N/ha. This constraint level was the maximum possible without killing the crop due to moisture stress. This restriction was realized through a 16 percent decrease in total water application and a five percent decrease in total nitrogen, resulting in an eight percent decrease in profits. Panels 1 and 3 in Figure 4.4C indicate significantly lower irrigation and soil moisture levels early in the season, especially prior to a major mid-season storm through the beginning of the early tuber growth stage, with only minor shifts in other portions of the season. Panel 4 in Figure 4.4C suggests a significant decrease in fertigation levels during much of the vegetative stage and only minor shifts in fertigation patterns thereafter.

Two levels of nitrate leachate restrictions were identified for potatoes following grain. Again, the first restricted leachate to 50 percent of the base level. The analysis resulted in modest decreases in yields and profits (four percent in each). Panels 1 and 3 in Figures 4.4D indicate a small decrease in irrigation and soil moisture levels from the beginning of early tuber growth to the end of the growing season. Panel 4 in Figure 4.4D shows a decrease in fertigation levels late in the

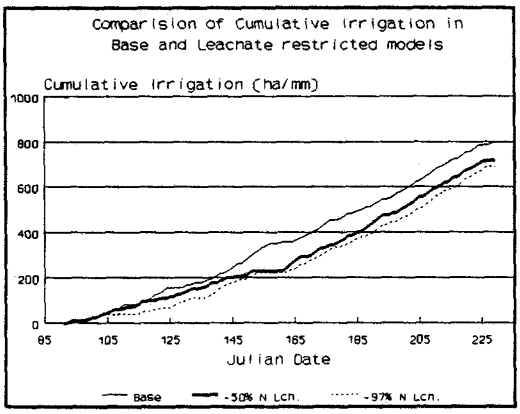
Panel 1.



Panel 2.



Panel 3.



Panel 4.

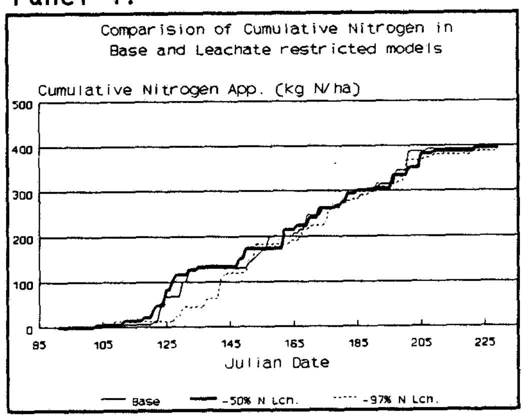


Figure 4.4C. Depiction of Differences in Base and Leachate Restricted Models for Potatoes (after alfalfa).

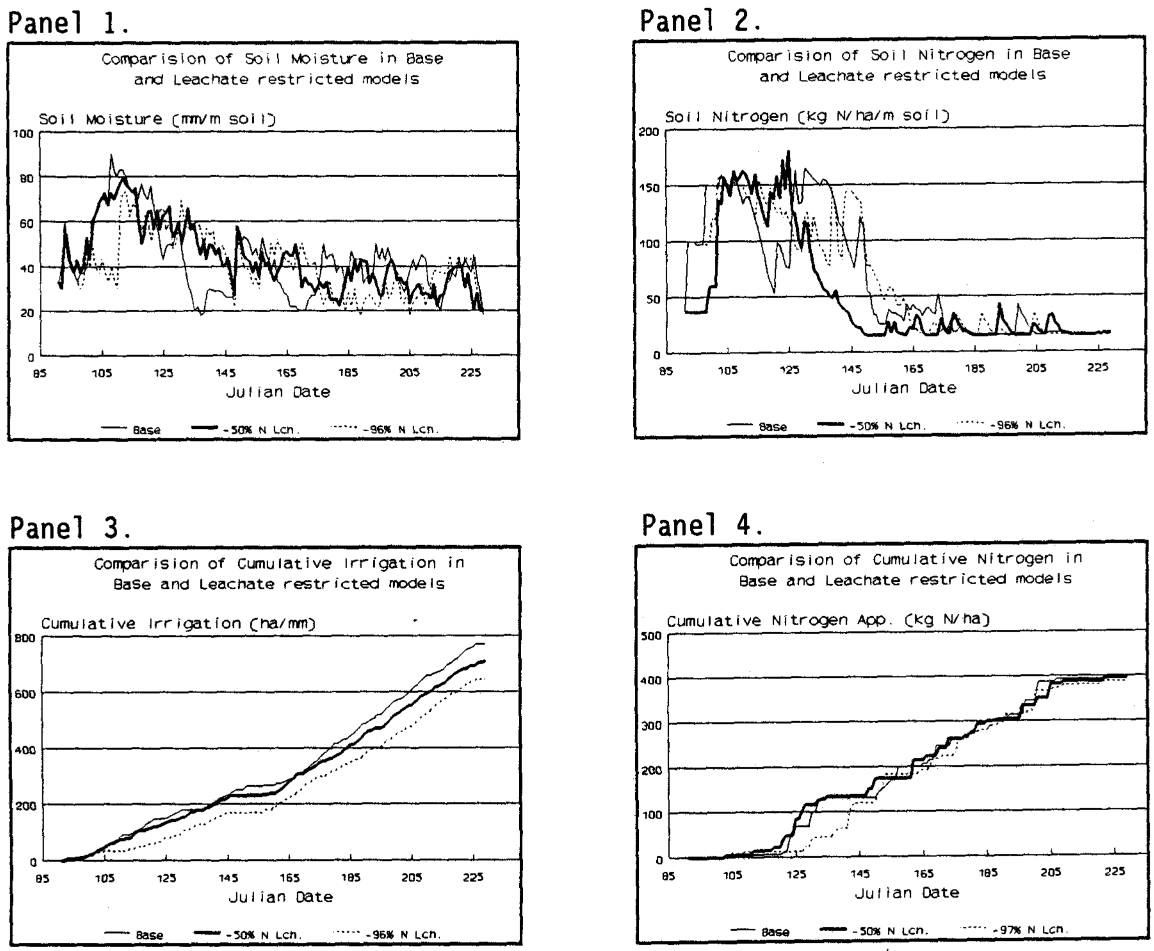


Figure 4.4D. Depiction of Differences in Base and Leachate Restricted Models for Potatoes (after grain).

vegetative stage. The second analysis restricts leachate rates to the minimum level possible without killing the crop, namely to 0.06 kg N/ha (96 percent). This restriction was achieved by reducing total water applications by 14 percent and reducing total nitrogen by three percent. This results in a four percent decrease in profits. A general decrease in both irrigation and soil moisture levels throughout the irrigation season is suggested by Panels 1 and 3 in Figure 4.4D. Panel 4 of Figure 4.4D indicates slight shifts in fertigation patterns when compared to the base model.

The leachate restricted analyses indicate it is possible to achieve a significant decrease in pollution rates with only modest reductions in profits. The reductions are achieved primarily through restrictions on irrigation levels, rather than fertilization rates. The restrictions in soil moisture occurred primarily during periods when leaching was most likely; specifically, during periods of high evapotranspiration and prior to significant storms. However, since the optimization model can implicitly anticipate weather event such as storms, the achievement of the profits discussed above under leachate constraints is highly unlikely in reality. This is because the farmer would have to cut back on soil moisture at the slightest probability of rainfall. The analysis also suggests that, despite the models ability to anticipate implicitly weather events, there are minimum levels of leachate resultant from in the production of all three crops on sandy soil. These minimum levels vary with the crop and weather conditions.

Input Taxes

A 100 percent tax on nitrogen was applied to each optimization model. The tax reduced profits for wheat, corn, potatoes (following alfalfa), and potatoes (following grain) by twelve, two, four, and fifteen percent. The tax scenarios had negligible impacts on water use in the corn and potatoes (following grain) models. The nitrogen tax had only minor impacts on nitrogen use for the corn and both potatoes models. In fact, the pollution rates actually increased slightly for corn and potatoes when compared to the base. These increases occur because of minor shifts in fertilization patterns which, in turn, caused increased nitrate concentrations at points in the growing season when water was percolating.

Conversely, application of a tax on nitrogen in the wheat model moderately reduced both water and fertilizer use (by 12 and 13 percent) when compared to the base model, which, because of these reductions, achieves a 68 percent reduction in pollution levels for wheat. The resulting (very) short-run price elasticities for nitrogen were extremely small for the corn, potatoes (following alfalfa), and potatoes (following grain) models (-0.02, -0.03, and -0.01); however, it was somewhat larger for wheat (-0.13)[10].

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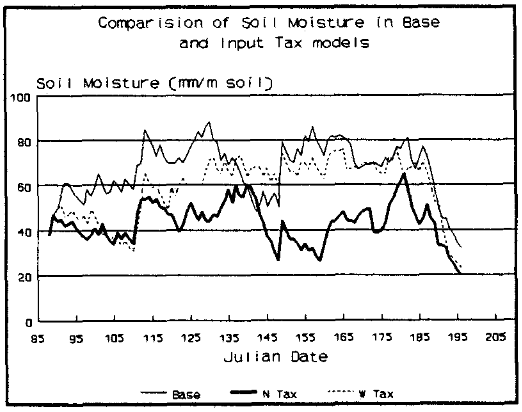
[10]The term "very short-run price elasticity" means the price elasticity for nitrogen when <u>all</u> decisions other than those related to irrigation and nitrogen fertilization are fixed.

Panel 3 of Figure 4.5A reveals a decline in demand for irrigation water late in the vernalization stage and during pre-anthesis ear growth by the nitrogen tax wheat model when compared to the base model. Panel 1 in Figure 4.5A indicates soil moisture levels that were significantly lower for nearly the entire growing season. Panel 4 of Figure 4.5A suggests somewhat increased applications of nitrogen late in the vernalization stage and decreased applications during early ear growth.

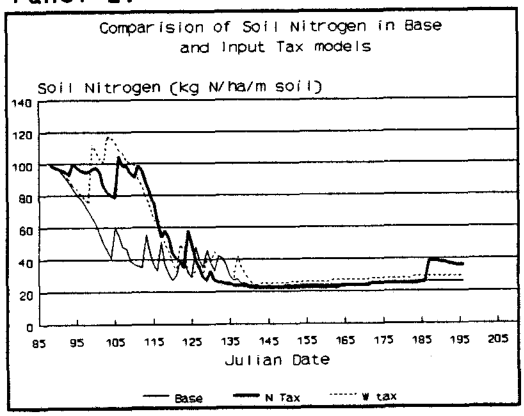
Figures 4.5B and 4.5D shows only minor shifts in irrigation and fertilization levels for the corn and potatoes (following grain) models relative to the respective base models. Panel 3 in Figure 4.5C suggests cumulative irrigation for potatoes (following alfalfa) remained approximately the same until a major rain storm occurred (Julian date 149). Irrigation was reduced by about 100 ha/mm during the last ten days of the vegetative stage, with irrigation then returning to a pattern similar to the base scenario's for the remainder of the production year. Panel 4 of Figure 4.5C indicates that the nitrogen tax model had only minor differences in nitrogen application patterns when compared to the base solution.

A 100 percent tax on water was also considered in the wheat optimization model. The effect of this tax is to reduce water use by 11 percent; this achieves a 65 percent decrease in pollution levels and six percent reduction in profits. These results imply that the very short-run price elasticity for irrigation water was -0.11. Panels 1 and 3 of

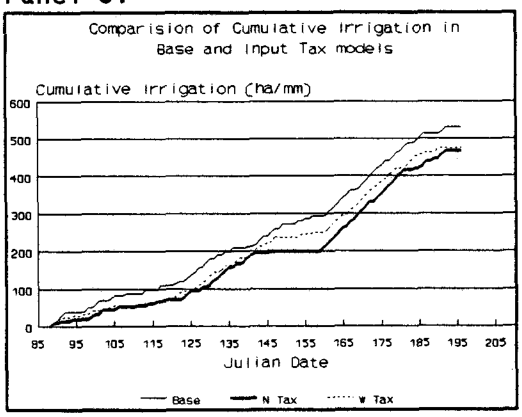
Panel I.



Panel 2.



Panel 3.



Panel 4.

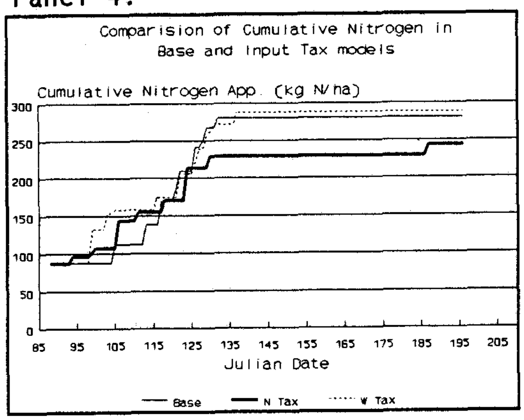


Figure 4.5A. Depiction of Differences in Base and Input Tax Models for Winter Wheat.

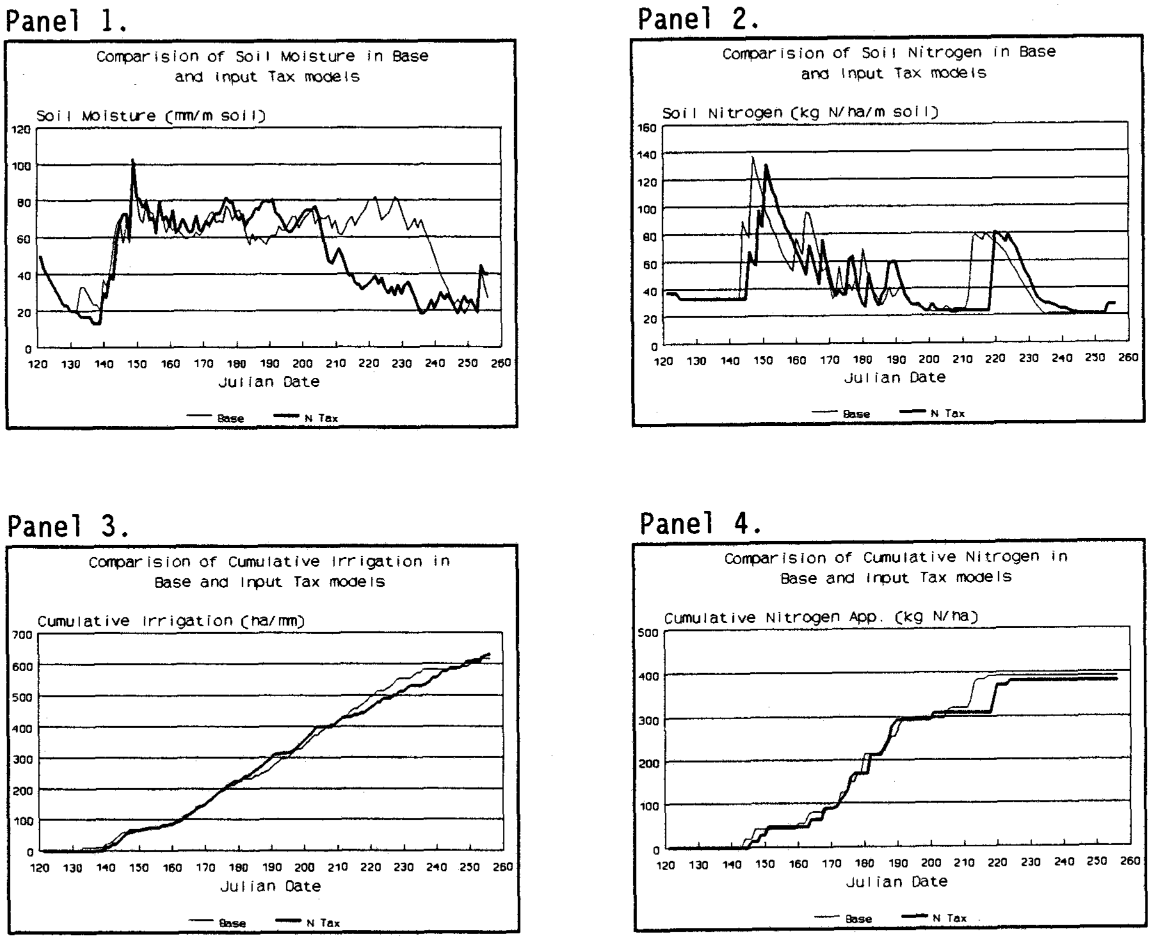
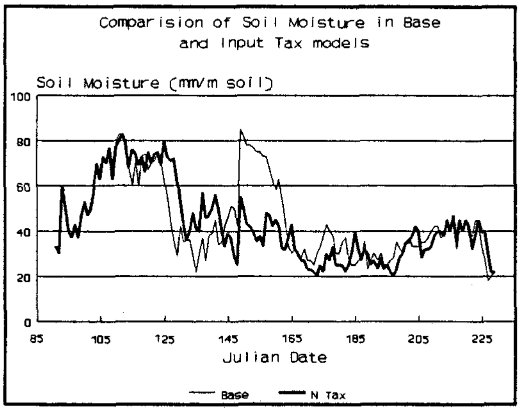
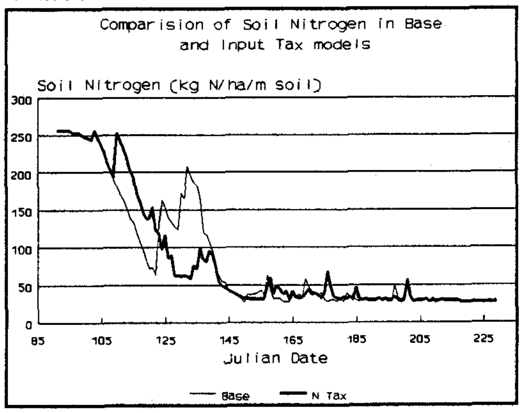


Figure 4.5B. Depiction of Differences in Base and Input Tax Models for Corn.

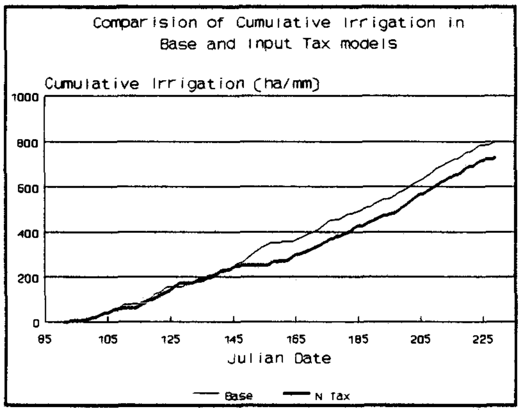
Panel 1.



Panel 2.



Panel 3.



Panel 4.

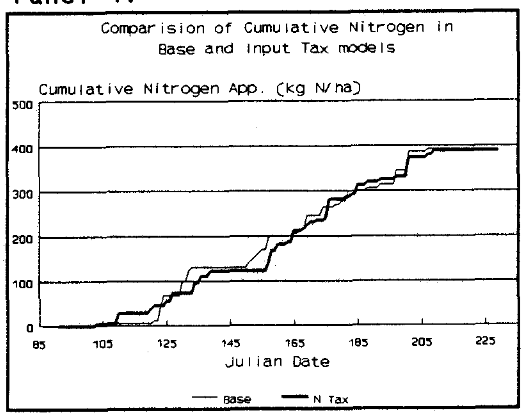
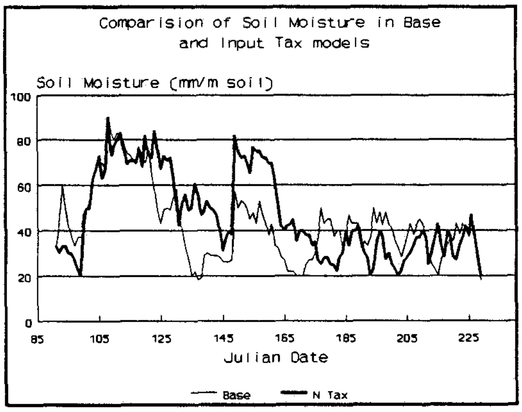
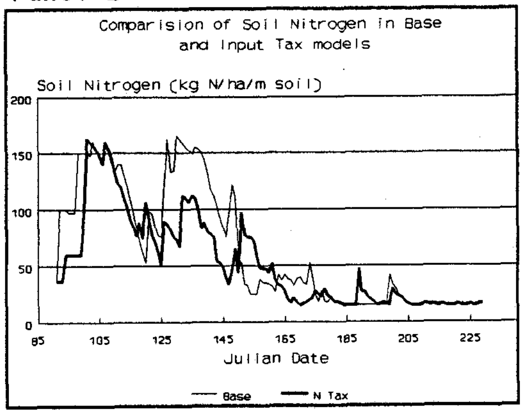


Figure 4.5C. Depiction of Differences in Base and Input Tax Models for Potatoes (after alfalfa).

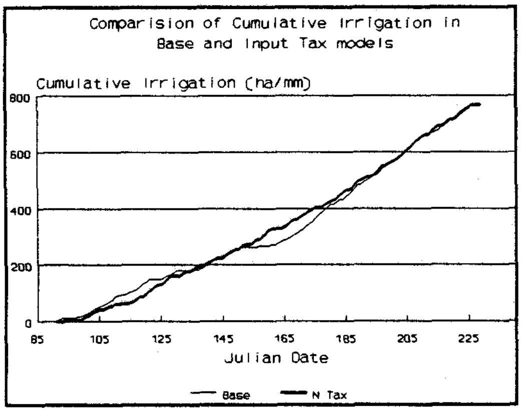
Panel 1.



Panel 2.



Panel 3.



Panel 4.

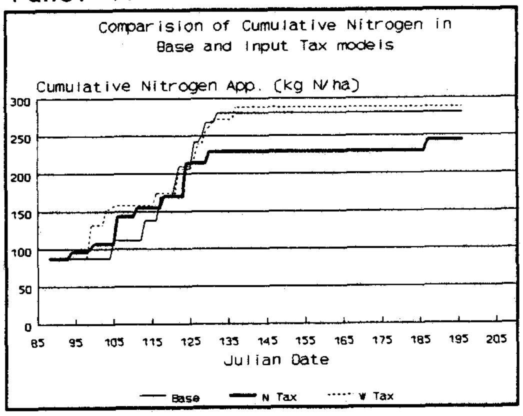


Figure 4.5D. Depiction of Differences in Base and Input Tax Models for Potatoes (after grain).

Figures 4.5A indicate a decline in irrigation and soil moisture levels during the late vernalization and portions of the early ear growth stages. Panel 4 in Figure 4.5A suggests increased nitrogen application in the late vernalization stage and only modest shifts in patterns thereafter.

The result of this set of analyses indicate that large input taxes do not assure reductions in nitrate pollution rates. The primary reason is the inelastic nature of water and nitrogen demand under the climatic and other physical conditions modeled in the study area. This inelastic demand is caused in part by the unavailability of substitutes in the model and the relatively small factor shares. For example, nitrogen costs make up only three percent of total production in the base potato (following alfalfa) model.

Leachate Taxes

A Pigovian tax (as discussed in Chapter 2), based on mitigation costs, was applied to each optimization model. The tax level used in each analysis was $26.42 per kilogram of nitrate leached into the vadose zone. The Pigovian tax results in slight to moderate reductions in profits ranging from two to twelve percent when compared to the base optimization model. The tax significantly reduces leachate levels in each model with reductions ranging from 37 to 68 percent when compared to the base.

In fact, in all cases, except wheat, the Pigovian tax caused large reductions in leachate compared to the nitrogen tax models. The Pigovian tax on wheat did not reduce leachate more than the nitrogen tax because the leachate level in the nitrogen tax analysis was already within a few percent of the minimum leachate level for wheat. The Pigovian tax analyses generally had significantly more profits than the nitrogen tax models, with increases averaging nine percent. This difference in profits between the Pigovian tax and the nitrogen tax solutions were largely due to differences in total tax payments (i.e., Pigovian and nitrogen tax payments) in the two sets of analyses. Therefore, as expected, Pigovian taxes would be a Pareto improvement for society and the farmer as compared with nitrogen taxes if they could be efficiently applied and enforced.

Panels 3 and 4 in Figure 4.6A indicate significant decreases in irrigation and soil moisture levels for wheat late in the vernalization stage and through the early ear growth stage (both periods include significant leachate) when compared to the base model. These levels were greater than the base model during a high evapotranspiration period in late May (Julian dates 140 to 148). Panel 4 of Figure 4.6A suggests increased applications of nitrogen late in the vernalization stage and decreased applications in the early ear growth stage.

Panels 1 and 3 in Figure 4.6B indicate decreased irrigation levels for corn in the early grain filling stage continuing on through much of the effective filling stage, with the later stage including significant periods of nitrate leachate. Panel 4 of Figure 4.6B suggests small shifts in fertilizer levels and patterns.

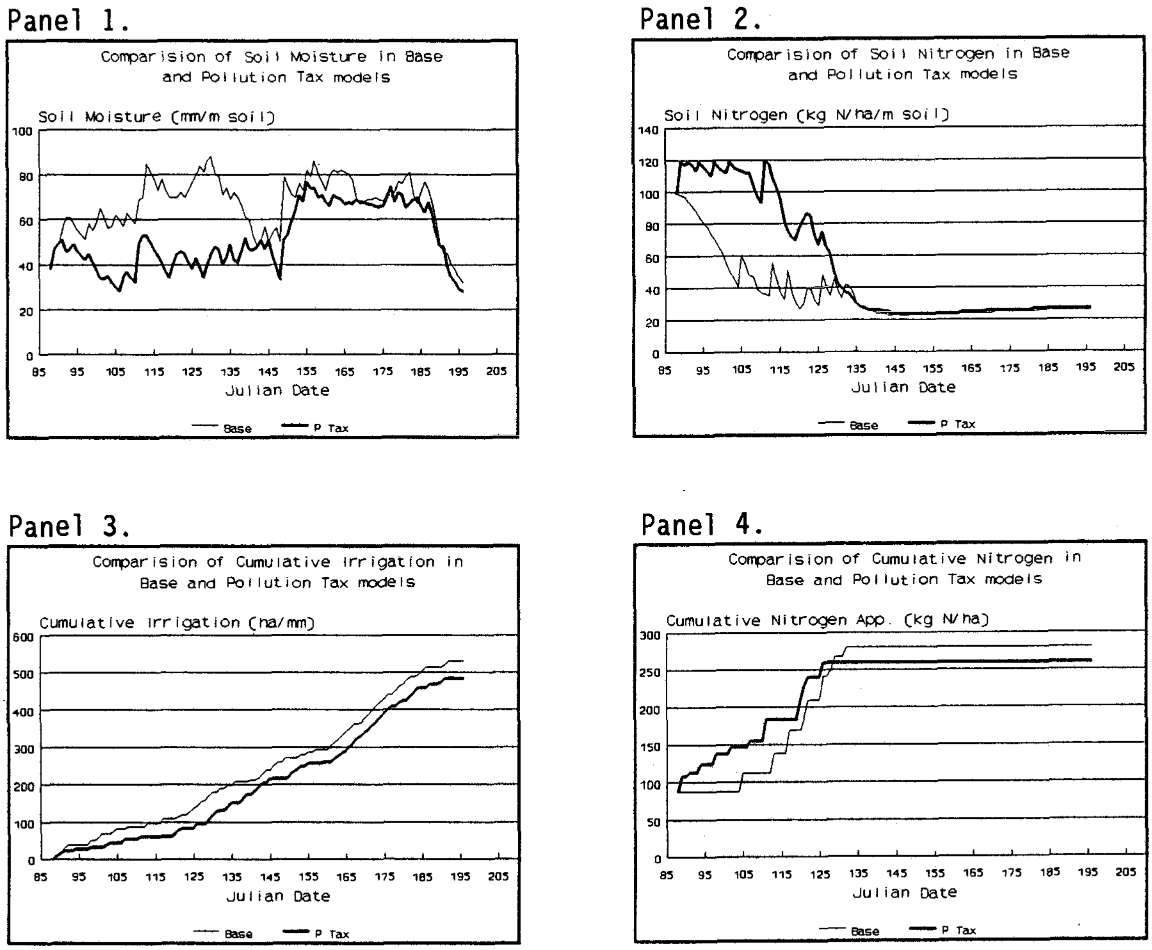
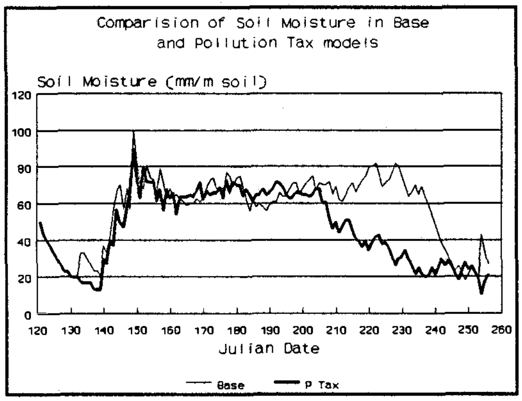
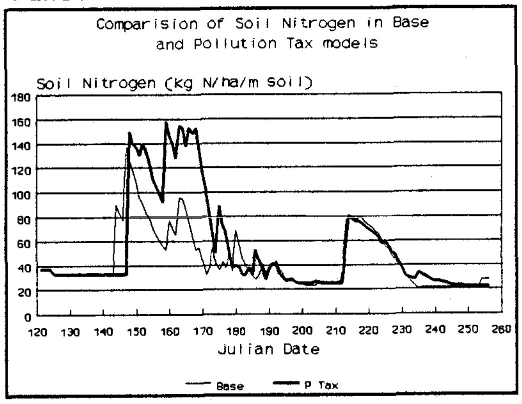


Figure 4.6A. Depiction of Differences in Base and Pigovian Tax Models for Winter Wheat.

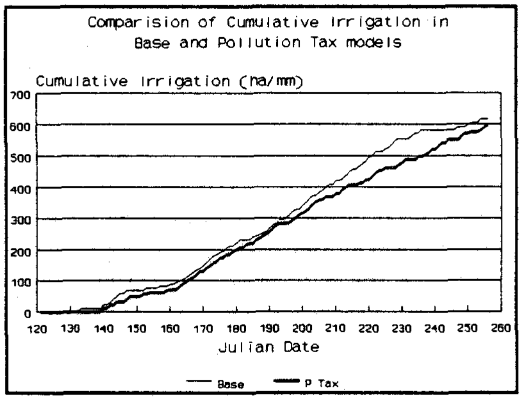
Panel 1.



Panel 2.



Panel 3.



Panel 4.

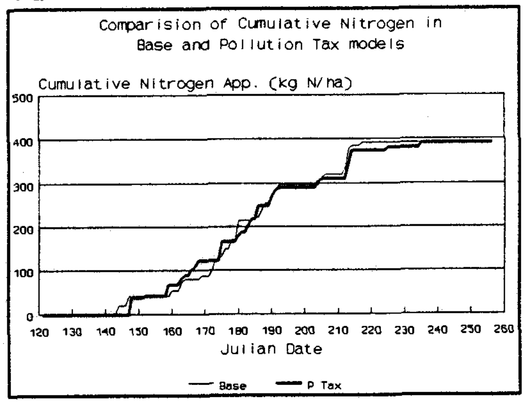


Figure 4.6B. Depiction of Differences in Base and Pigovian Tax Models for Corn.

Panels 1 and 3 in Figure 4.6C indicate decreased irrigation quantities and soil moisture levels for potatoes (following alfalfa) early in the vegetative phase (a period of high leachate) and during the early and linear tuber growth stages when compared to the base model. They also suggest increased soil moisture late in the vegetative stage. Panel 4 of Figure 4.6C implies that the Pigovian tax model identified only minor differences in nitrogen application patterns. Figure 4.6D suggests only minor shifts in fertilization and irrigation levels for the potatoes (following grain) Pigovian tax model when compared to the base model. The results of all four models imply that reduction in pollution rates in the Pigovian tax models are achieved primarily through restrictions in soil moisture during periods of significant nitrate leachate.

Sensitivity Analysis

Sensitivity analysis was done to identify potential sources of error. The analyses here include changes in weather, solution space step size, output prices, and soil homogeneity. The sensitivity analyses are also used to indicate the general robustness of the results.

Two alternative weather scenarios were examined for the base wheat model. Figure 4.7 illustrates the patterns of growing degree days (GDD) for the three weather years examined with the optimization model. The first of these looked at a high GDD year (1986). Optimizing for 1986 weather resulted in a six percent decrease in yields, a nine percent decrease in profits, a three percent increase in water use, and a 38

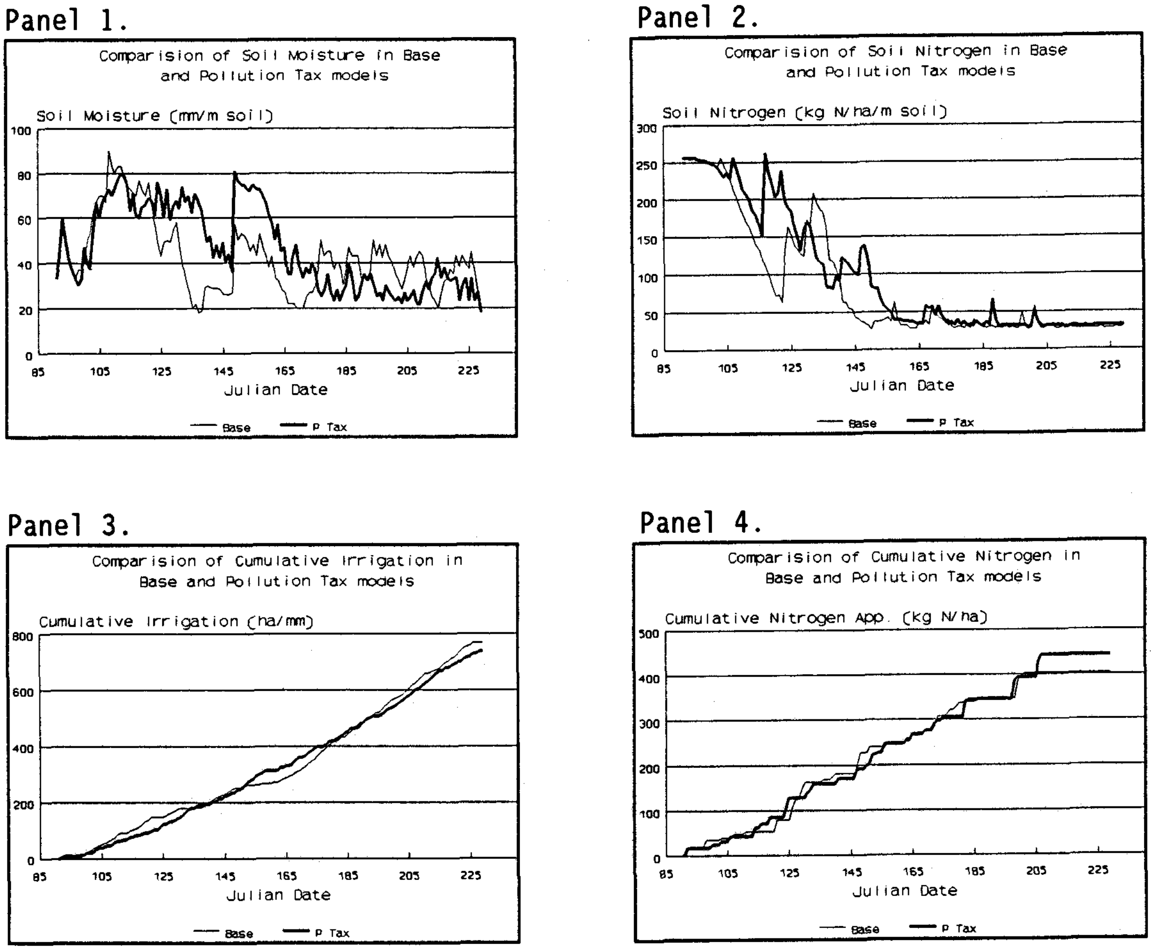
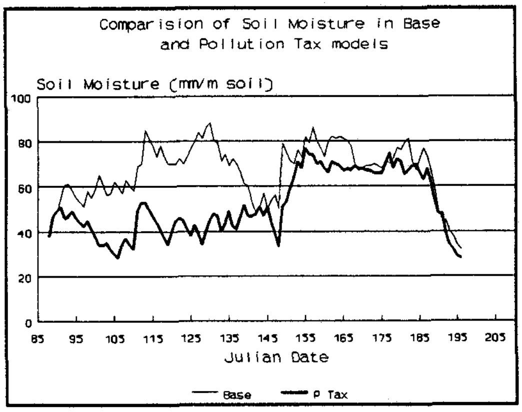
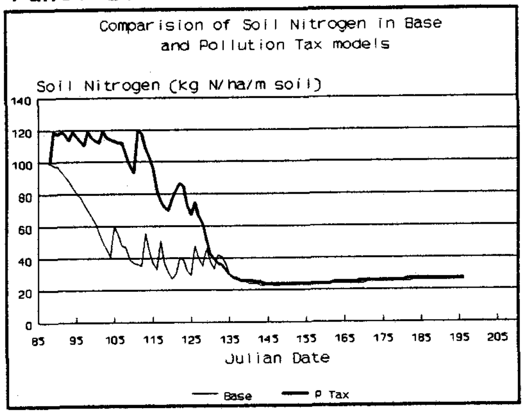


Figure 4.6C. Depiction of Differences in Base and Pigovian Tax Models for Potatoes (after alfalfa).

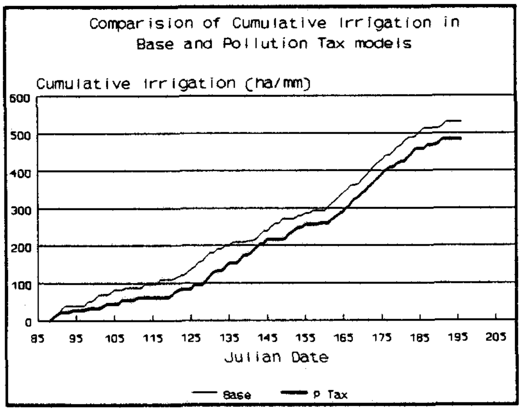
Panel 1.



Panel 2.



Panel 3.



Panel 4.

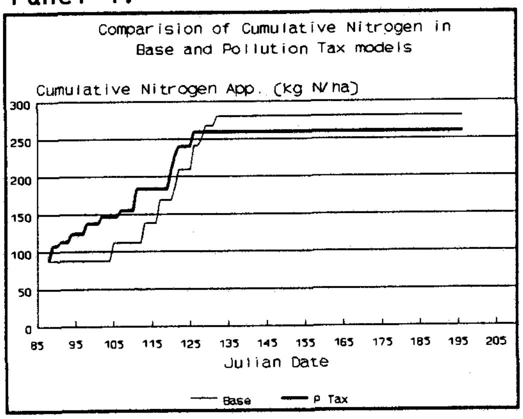


Figure 4.6D. Depiction of Differences in Base and Pigovian Tax Models for Potatoes (after grain).

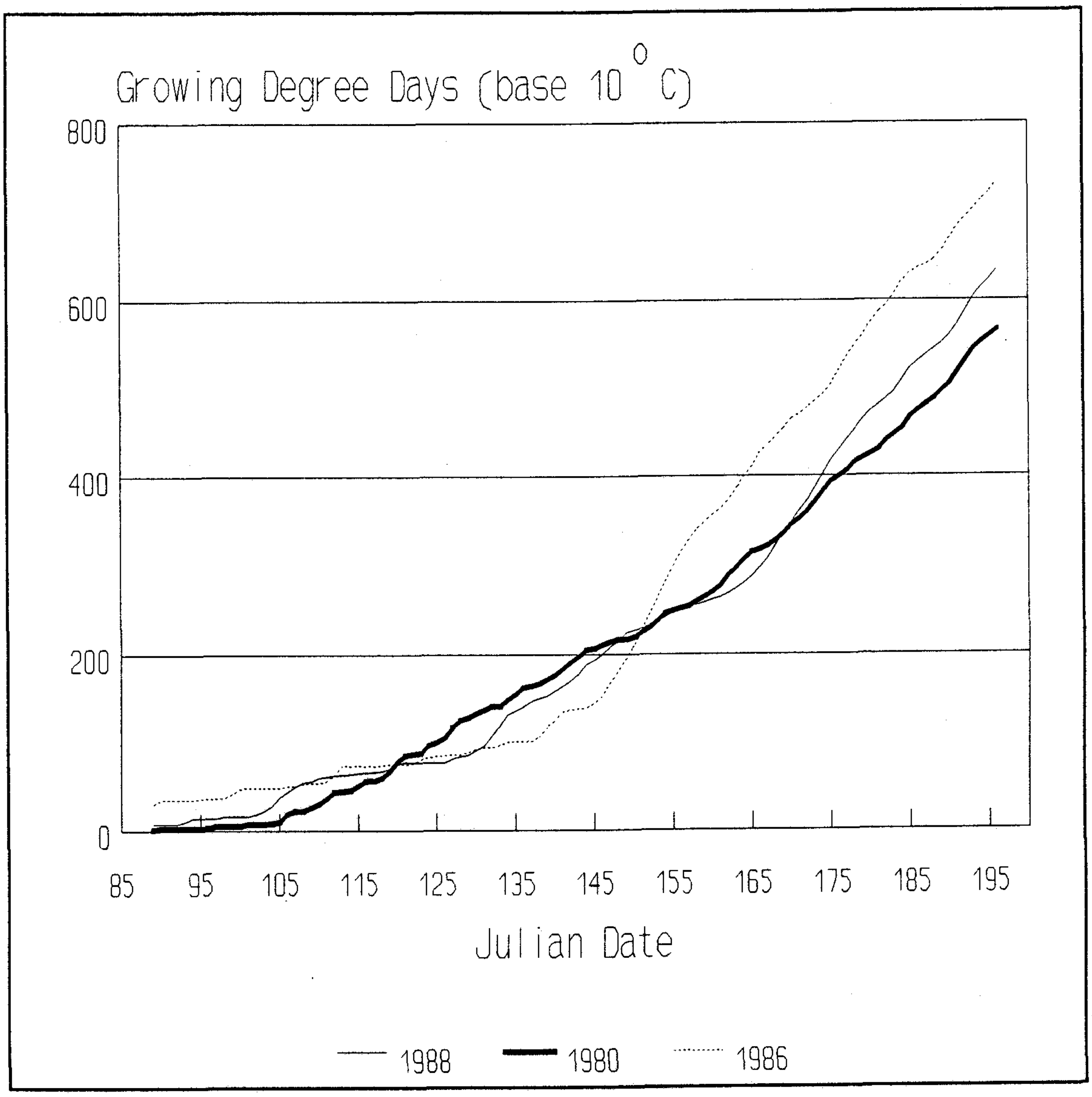


Figure 4.7. Depiction of Cumulative Growing Degree Days for Three Weather Years in the Study Area.

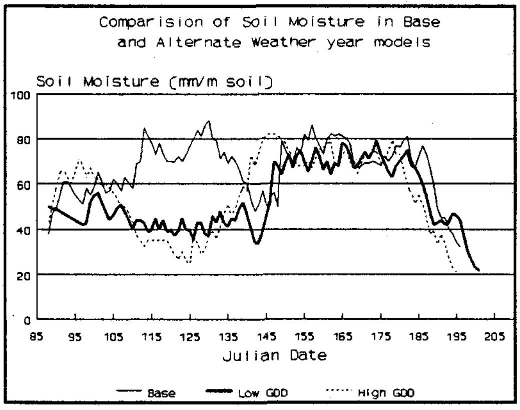
percent increase in leachate as compared to the base scenario keyed to 1988 weather. Panel 3 of Figure 4.8 suggests decreased irrigation levels in the first half of the 1986 season, but increased irrigation levels in the second half of the season when compared to the base model. This pattern was apparently the result of differences in cumulative thermal time. Panel 4 in Figure 4.8 indicated increased demand for nitrogen throughout the growing season.

The second weather analysis looked at a low growing degree day year (1980). The results of this analysis indicated a four percent increase in yield, a six percent increase in profits, a 13 percent decrease in total water use, and a three percent decrease in nitrate leachate. Panel 3 of Figure 4.8 suggests reduction in the demand for irrigation water throughout the growing season presumably because of decreased GDD levels. Panel 4 in Figure 4.8 implies only minor shifts in nitrogen application patterns for this year. The results, as expected, appear to indicate a correlation between GDD and optimal irrigation patterns. This results appears to further validate the optimization models.

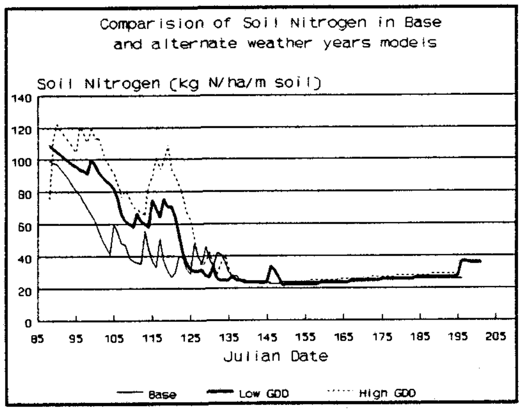
Test scenarios for corn, using slightly different genetics and planting dates[79], were conducted to examine the effect of a high degree day weather year (1986) on the potential for leachate restrictions. In the corn base analysis, it was possible to nearly eliminate nitrate leachate (i.e., 0.23 kg N/ha) without significant loss of yield. However, the

[79]These runs assumed a planting date of Julian date 123 and a potential grain growth rate of 8.5 mg/day.

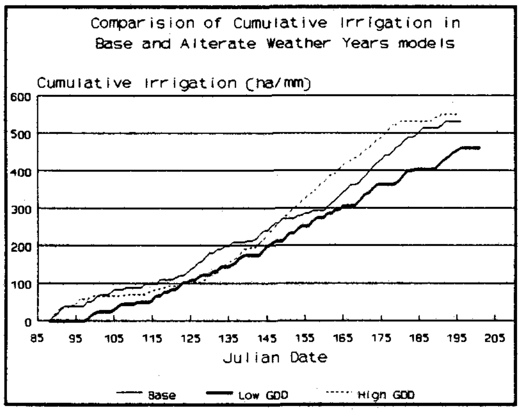
Panel 1.



Panel 2.



Panel 3.



Panel 4.

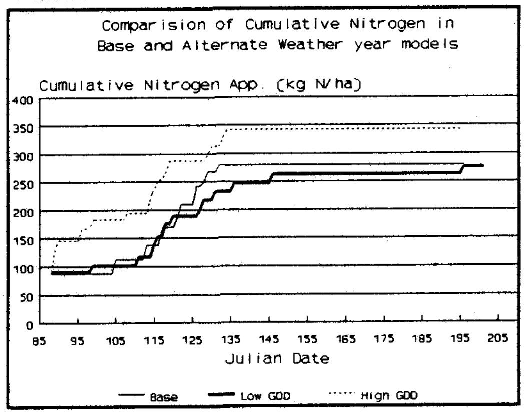


Figure 4.8. Depiction of Differences in Base and Alternative Weather Year Models for Winter Wheat.

results of test scenarios using various constraint levels indicate that, for this particular weather year (1986), yields fall off quickly if a pollution constraint of less than 1.6 kg N/ha was placed in the model. For example, if a constraint of 1.3 kg N was placed on the system, yields fall to approximately a quarter of their unconstrained values, indicating the economic importance of the resulting pollution to a farmer during periods of very high evapotranspiration. Also, the results further highlight the relationship between minimum nitrate levels and occurrence of extended periods of high evapotranspiration.

Figure 4.9 also shows the effect of changes in state space step size on wheat solutions. In the first test of step size, soil moisture step size was reduced from 5 mm/m to 2 mm/m and soil nitrogen was reduced from 20 kg/ha/m to 10 kg/ha/m. In this test, profits decreased by less than one percent, instead of increasing as one might expect when the number of alternatives is increased. In a second test of step size, only the soil moisture step size was reduced from 5 mm/m to 2 mm/m. This test showed that profits also decreased (by almost one percent) from the base when step size goes up in even increments. These apparent anomalies occurred because the new solution space does not include all discrete points in the base analysis (i.e., 2 does not divide into 5 evenly).

Panels 3 and 4 in Figures 4.9 show only modest differences in irrigation and fertigation patterns between the base and alternative step size models. The computational costs of solving these higher resolution state space models were high; therefore, it was necessary to balance

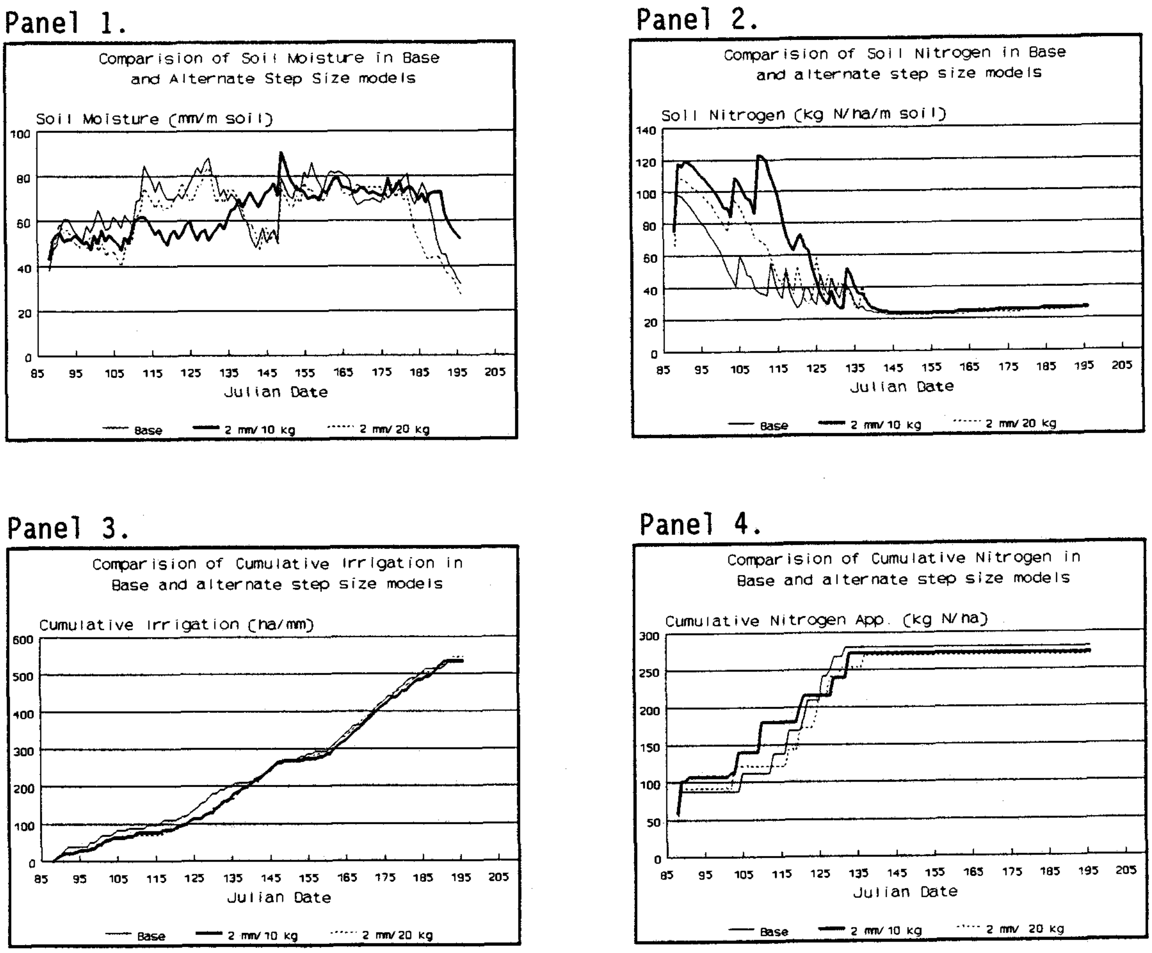


Figure 4.9. Depiction of Differences in Base and Alternative Step Size Models for Winter Wheat.

resolution with the change in results. For example, the first test increased computation time by a factor of 7.2 and the second test by a factor of 2.9 over the base analysis. However, the maximum irrigation and fertigation application rates provide upper limits for steps sizes which allow for movement through the stage and state spaces. To allow for realistic choice sets in irrigation and fertilization patterns, in this study, the step sizes for each state space were set at half of the maximum application rates.

A change in output prices was next considered for the wheat model. A 25 percent decrease in wheat price resulted in a one percent decrease in yield, a five percent decrease in water use, and a 41 percent decrease in leachate. Panels 1 and 3 in Figure 4.10 indicate significant decreases in irrigation and soil moisture levels late in the vernalization stage relative to the base analysis. Panel 4 of Figure 4.10 suggests only minor shifts in nitrogen application patterns. The results suggest that irrigation water applied late in the vernalization stage had the lowest marginal productivity relative to other portions of the growing season. This result suggests that government programs that artificially support crop prices increase nitrate pollution because the resulting increased price levels encourage increased irrigation and fertilization applications.

An important assumption in the base scenario was that each field consisted of three different soils. The impact of this assumption on base results was tested by assuming each field consisted of a homogenous soil.

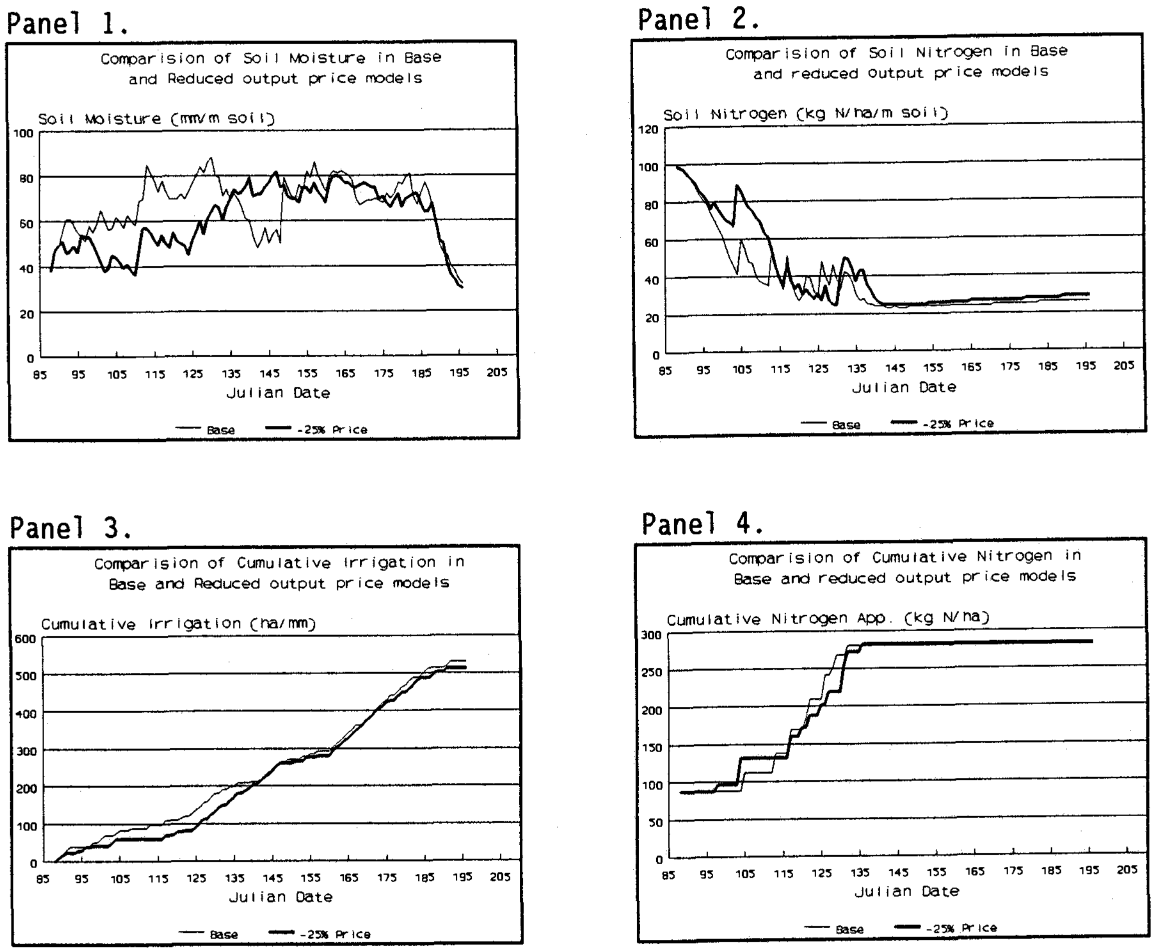
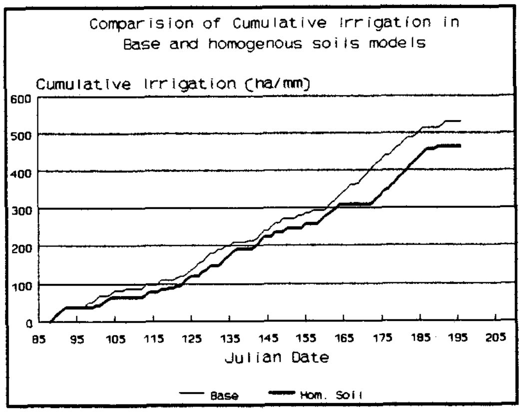


Figure 4.10. Depiction of Differences in Base and Reduced Output Price Models for Winter Wheat.

This analysis used a mid-point soil from the Quincy Sand classification (See Table 3.3). Results suggest a four percent increase in profits, a three percent increase in yield, a 12 percent decrease in water use, and a 46 percent decrease in leachate relative to the base wheat analysis. The leachate levels were reduced 43 percent relative to the same type of soil in the base scenario. Panel 1 in Figure 4.11A indicates decreases in the demand for irrigation water during the vernalization and the flowering stages compared to the base analysis. Panel 2 of Figure 4.11A suggests only minor shifts in nitrogen application patterns. The results imply, as anticipated, that managing a homogeneous field is more profitable and produces less leachate than a heterogeneous field with the same mean water holding capacity. This is because water and nitrogen applications on a homogeneous field can be managed to more precisely match the needs of the crop.

The effect of heterogenous soils in the base potato following alfalfa model was tested through the use of a homogenous soil in another sensitivity analysis. This scenario used the lightest soil from the Quincy Sand classification. Results suggest a four percent increase in profits, a three percent increase in yield, a six percent decrease in water use, and a 108 percent increase in leachate. The nitrate leachate increased 11 percent when compared to the sub-field of the base analysis with the same type of soil. Panel 1 of Figure 4.11B indicates decreases in the use of irrigation water during much of the vegetative stage, especially before and after a major rain storm which occurred in late May (Julian date 149). Panel 2 in Figure 4.11B suggests only minor shifts in

Panel 1.



Panel 2.

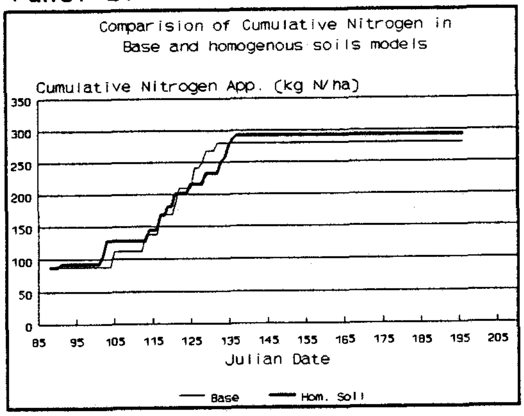
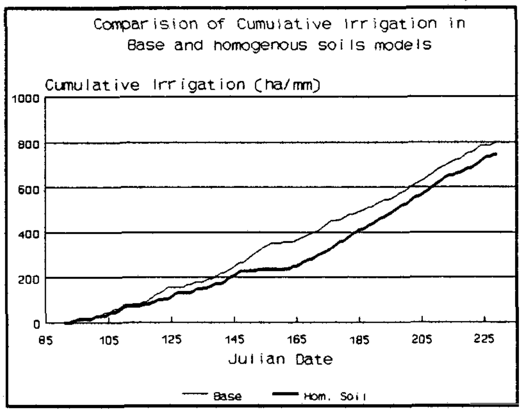


Figure 4.11A. Depiction of Differences in Base and Homogenous Soil Models for Winter Wheat.

Panel 1.



Panel 2.

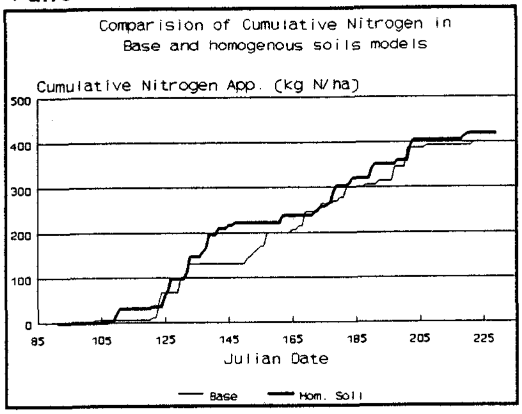


Figure 4.11B. Depiction of Differences in Base and Homogenous Soil Models for Potatoes (following alfalfa).

nitrogen application patterns. As with the test of a uniform soil for wheat, managing a crop with homogenous soil results in higher profits than managing a crop with heterogenous soil. However, it is apparently profitable to leach somewhat more nitrates when the homogenous soil has less water holding capacity than the mean water holding capacity of the heterogenous soils because of the closer water management possible with homogenous soil.

Farm-Level Optimization Results

The farm-level optimization model examined the effects of various levels of whole-farm nitrate leachate constraints on whole farm profits and nitrate leachate levels. The analysis reflects a situation in which the farm participates in the federal farm program during the 1987-88 crop year, requiring 20 and 27.5 percent idlements for corn and wheat. The farm was assumed to have 759 hectares of land with 15 center pivot circles. Because the rotations were of varying lengths (ranging from four to six years), integer programming could not be used to find a long-run equilibrium rotation. Therefore, it was necessary to use linear programming that allows a single circle to be planted in multiple crops. Note that the CERES potatoes model does not account for disease or tilth effects that are dependent on rotation, but does account for differences in organic nitrogen levels between different rotations.

The results of the farm-level LP model (Table 4.5) suggest that potatoes in a grain rotation was the preferred long run equilibrium

Table 4.5. Results of the Farm-Level Linear Programming Model.

Analysis	Returns to Land Man. ($)	Shadow Price on Land ($/ha)	Nitrate Leachate Level (kg N)	Shadow Price N Lch. ($/kg)	Potato Acreage [alf.] (ha)*	Potato Acreage [Grain] (ha)*	Wheat Acreage (ha)*	Corn Acreage (ha)*	Alfalfa Acreage (ha)&	Idlement Acreage (ha)
Base Model	523,000	688	1,526	-	-	190/0	276/0	152/0	-	141
1,250 kg N Leachate Limit	518,000	656	1,250	16	-	190/0	276/0	2/150	-	141
1,000 kg N Leachate Limit	501,000	573	1,000	67	-	190/0	251/26	0/152	-	141
750 kg N Leachate Limit	485,000	573	750	67	-	190/0	50/226	0/152	-	141
500 kg N Leachate Limit	447,000	443	500	220	-	107/83	0/276	0/152	-	141
250 kg N Leachate Limit	372,000	326	250	499	0/43	0/147	0/214	0/118	129	105
100 kg N Leachate Limit	298,000	326	100	499	0/135	0/55	0/80	0/44	405	37
5 Year Average Prices	316,000	416	1,526	-	-	190/0	276/0	152/0	-	141
Current Rotations Only	289,000	381	700	-	152	-	111/0	-	456	37
1988-89 Farm Program:										
Base	617,000	813	1,770	-	-	190/0	171/0	171/0	-	57
Leachate Limit 100 kg N	309,000	324	100	638	0/145	0/45	0/80	0/40	435	13

*The hectares listed in each column are for the production without and with leachate restrictions.
&The hectares listed in this column are evenly distributed between one, two, and three year old alfalfa.

solution when no leachate restrictions was present. The returns to management and land for this base solution were $523,000, with a shadow price on land of $688 per hectare and an annual pollution rate of 1,525 kg N. Table 4.5 shows that as the leachate constraint decreases, the model begins shifting toward production activities that restrict leachate in the grain crops. Further restrictions cause the model to select activities that restrict pollution in potatoes. Finally, the model moves to a potatoes and three year alfalfa rotation. Table 4.5 also suggests that, as the nitrate constraint decreases, land rents fall significantly because of the restrictions on pollution and shift in rotation. These results suggest that the lower cost method of reducing pollution is to restrict nitrate pollution on grain fields. This is because potatoes are substantially more profitable than corn or wheat and management strategies which result in reduction in leachate are more costly.

Table 4.5 also contains the results of several sensitivity analyses. The first uses a five year average of nominal output prices[80]. The results show no change in the optimal rotation relative to the base analysis. A second sensitivity analysis left only the rotations in current use in the study area. This analysis removed the potato-grain rotations and the potato-alfalfa rotations, leaving only potatoes following three or four years of alfalfa following wheat or corn. The LP model selected a potatoes-wheat-three-year-alfalfa rotation as optimal, resulting in returns to land and management of $289,000. The third set of analyses

[80]The five year average prices used, less per unit costs, were: $0.088/kg alfalfa, $0.118/kg wheat, $0.088/kg corn, and $0.069/kg potatoes (National Agricultural Statistics Service, 1985-89).

imposed the 1988-89 federal farm program provisions, which require 10 percent idlements for corn and wheat with and without a 100 kg N leachate constraint. The results of the unconstrained model indicate no change in rotation relative to the base analysis, but pollution was increased by 16 percent. The restricted model suggests similar shifts in rotation to those of 100 kg restrictions in the base LP analyses.

Groundwater Simulator Results

An aquifer geohydrology simulator was used to examine the long term effects of the predicted leachate patterns on aquifer nitrate concentrations. The major simplifying assumptions used in the simulator were discussed in Chapter 2. The two most important of these are that 1) nitrates entering the vadose zone instantaneously reach the water table and 2) once in the aquifer the nitrate will become homogeneously mixed in the aquifer. Given these assumptions and both the 1987-88 and 1989-89 federal farm program provisions (namely a 20 percent idlement for corn and 27.5 for wheat for 1987-88 and a 10 percent idlements for corn and wheat for 1988-89), a 20 year simulation was done for the Butter Creek aquifer (which underlies the study area) assuming the planting of potatoes in an alfalfa-grain rotation, and using the pollution patterns from the base dynamic optimization model.

The results of the simulator indicate an annual loading of the groundwater under the farm of 1525 and 1674 kg N per year under the provisions of the 1987-88 and 1988-89 farm programs. This implies an increase in aquifer nitrate concentrations of 0.098 and 0.114 mg N/l after 20 years of continuous cropping under the 1987-88 and 1988-89 farm programs. These predicted nitrate loading rates were very low given that 18 of 25 wells tested in the study area had nitrate levels in excess of 5 mg N/l. The possible sources from this apparent understatement of leachate rates include problems mentioned earlier with CERES, the assumption that no nitrate pollution occurs while alfalfa is grown on a given field, and that the farmers can manage soil moisture and nitrogen as closely as the optimization model recommends. The results imply that federal farm program can influence pollution rates through the acreage idlement provisions.

Summary

This chapter discussed the various parameters of the dynamic optimization model, results of the dynamic optimization models, the farm-level LP model, and the aquifer simulator. The results of the field-level model provide irrigation and fertigation strategies for corn, wheat, and potatoes under various policy options. The results of the LP model indicate that a four year potato-grain rotation would maximize net profits and a four-year potato-alfalfa would maximize profits under a strong nitrate leachate constraint. The results of the groundwater simulator predict that, over 20 years of continuous cropping, using optimal timing of irrigation and nitrogen fertilizer, will increase the nitrate concentrations in the aquifer by only small amount (0.114 mg N/l). However, based on other studies of measured nitrate loading rates, the concentrations predicted here likely represent significant underestimates of actual concentrations over time. The next chapter provides further interpretations of these results, as well as limitations and identifies specific needs for further research.

CHAPTER 5: CONCLUSIONS AND LIMITATIONS

Conclusions

Introduction

The objective of this dissertation was to examine the on-farm economic effects of adopting alternative strategies to reduce agricultural-related groundwater pollution from nitrates. The empirical focus was an irrigated farming operation in the Columbia Basin of Oregon. The analysis involved development and implementation of a multi-method approach which linked a farm-level LP crop mix model, field-level dynamic optimization models, CERES crop simulators, and a geohydrology model.

The research focused on optimal irrigation and nitrogen fertilizer scheduling for winter wheat, field corn, and potatoes, the principal crops in the study area, under the presence of various groundwater regulatory options. The options included input taxes, restrictions on nitrogen applications, restrictions on nitrate leachate, and Pigovian taxes. The analysis also examined relationships between the physical environment and economic factors affecting nitrate pollution.

The results of the dynamic optimization and LP models provide some important insights into the problem of nitrate pollution, with implications for management of such pollution in irrigated agricultural regions. These insights include an understanding of why profit maximizing producers allow leaching of inputs out of the root zone, and the advantages and disadvantages of various regulatory policy options.

Factors Affecting Nitrate Leaching Rates

It is important to emphasize the role water management plays in any reduction of nitrate pollution. If water does not percolate (i.e., saturated flows) below the root zone, no leaching of nitrates can occur except through unsaturated flow. Therefore, one cannot focus exclusively on fertility management to reduce nitrate pollution rates on irrigated lands; water management is much more important. In fact, the dynamic model suggests that it is not always necessary to reduce aggregate nitrogen quantities to reduce seasonal pollution levels. It is necessary, however, to reduce water quantities and (or) adjust irrigation timing in order to reduce pollution levels. For example, a 50 percent reduction in leachate rates for potatoes (following alfalfa) required a one percent decrease in aggregate nitrogen applications but a ten percent reduction in aggregate water applications. In the case of wheat, a 50 percent reduction in nitrate leachate required a one percent reduction in aggregate nitrogen but a seven percent reduction in total water applications.

Furthermore, the results of the dynamic optimization models (when compared to the simulations of current practices) suggest that farmers in the study area are generally not applying quantities of nitrogen fertilizer above the levels which plants can use. The results do suggest, however, that water applications may well exceed plant requirements for corn and wheat.

The results also make clear that leaching some nitrates is not only profitable but unavoidable in the production of irrigated crops within the study area. Farmers have an economic incentive not to leach water and nitrates, given that both have a positive price. Therefore, it is only profitable to leach when the value of avoiding an expected moisture or nitrogen stress exceeds the costs of the inputs being leached.

There are several factors contributing to the farmer's decision making problem related to leaching. These include soil heterogeneity, uncertain rain events, and periods of high evapotranspiration. For most 65 hectare circles, significant variability exists in soil water holding capacity, making the farmer's irrigation decisions more complex. A strategy that adequately irrigates one part of the field may over-irrigate other parts of the field, while under-irrigating yet another sub-field. Thus, a producer who maximizes profits and is faced with a heterogenous field may over-irrigate some parts of the field in order to avoid stress in other parts of the field, creating opportunities for leaching of nitrates in the over-irrigated portions of the field.

As an example, in the base analysis of potatoes (following alfalfa), the leaching rate for the lightest soil was five times that of the heaviest soil. This result occurred despite the relative homogeneity of the soil profiles. A profit-maximizing farmer with more heterogenous soils (i.e., sand and silty soils in the same field) would likely pollute at much higher rates than those identified here.

Major precipitation events create several problems when attempting to minimize nitrate pollution rates. The first is unique to crops that grow over the winter, namely winter wheat. During the winter season, a farmer generally has no control over soil moisture levels and the resulting percolation rates. This is similar to farming under dryland conditions, where the only method to decrease the over-winter nitrate leachate is to decrease pre-plant nitrogen fertilizer applications. But some nitrate will leach despite the elimination of pre-plant nitrogen applications because of the carryover of mineralized nitrogen in the soil. For example, in the representative wheat field used for this study, there was approximately 34 kg N/ha/m in the root zone at planting time. The minimum amount of over-winter nitrate leachate (when no pre-plant fertilizer was applied) was predicted by CERES to be 0.98 kg N/ha, resulting from winter precipitation in the 1987-88 crop year.

Major rainstorms during the irrigation season also can create pollution problems. A farmer with sandy soils would risk substantial losses from moisture stress if attempting to maintain soil moisture at levels low enough to absorb, without percolation, all the expected rainfall from a major storm event. The farmer's decision problem is further complicated by the fact that rainfall events in the regions are highly uncertain in their frequency and quantity. For example, in late May (1988), there were 20 mm of rain in a single day within the study area[81]. The base analysis for both wheat and corn indicate that the most profitable strategy is to maintain soil moisture at levels that can not fully absorb this rainfall without percolation. In fact, it may be impossible to maintain such a low soil moisture level without killing the crop.

It is also profitable to leach nitrates during extended periods of high evapotranspiration. In particular, leaching occurs early in the growing season when rooting depths are shallow, thus limiting the volume of soil from which to draw water. For example, in the base corn model all the leaching events not resulting from storms were associated with extended periods of high evapotranspiration (of approximately 6 mm/day). The first major leaching event for corn occurred in late May (before the roots had reached maximum depth), with evapotranspiration averaging 5.9 mm/day during the period of leaching. The second significant leaching event occurred in July during a period when evapotranspiration averaged 6.6 mm/day.

Nitrate management problems facing farmers are also influenced by carryover of mineralized or organic nitrogen from a previous crop, such as alfalfa. Because nitrate leaching rates are a function of nitrate concentrations in the soil and the quantity of percolating water, the concentration of nitrates leaching per hectare-millimeter of water is

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[81]Storms of this size are not uncommon for May in the study area. In fact, in six year out of the last nine years (1980 through 1988) there was at least one storm in April, May or June with precipitation in excess of 12 mm in a single day. The magnitude of these storms ranged from 12 to 25 mm.

usually higher for a crop following legumes than one following non-legumes. In this study, estimates of water percolation for potatoes following grain and following alfalfa resulted in predicted nitrate concentrations of 11.7 mg N/l and 16.4 mg N/l with similar water leaching rates. Therefore, careful water management is even more important for fields with either large nitrogen carryovers or large quantities of pre-plant nitrogen.

There are three other factors not accounted for in this research which can further explain the existence of ground water pollution under irrigation. First, farmers make mistakes in estimating average soil moisture as can occur when the soil moisture sample is not representative of the full field, creating the potential for over watering. Second, the application efficiency of center pivot system is not uniform across the length of the pivot (Trimmer and Perkins, 1987), increasing the potential for leaching. Third, a risk averse farmer may use excessive input applications as a form of self-insurance against uncertain weather events or inaccurate measurements.

Alternative Policy Options to Minimize Nitrate Leaching Rates

A number of analyses were conducted to assess the affects of different government policies on nitrogen groundwater pollution. A 25 percent across-the-board reduction in nitrogen from the base optimum level was substantially less profitable than allowing the optimization model to reallocate (across the growing season) a total nitrogen supply that has been reduced 25 percent. This result occurs because the marginal productivity of nitrogen is not constant over the life cycle of the CERES crops examined. Furthermore, allowing the optimization model to determine the timing of the constrained quantity of nitrogen resulted in no higher levels of pollution than the fixed reductions models. Therefore, if restrictions on fertilizer quantities are contemplated by policymakers, the focus should be on limiting total applications rather then arbitrary across-the-board reductions in application rates.

The analysis of input taxes also yielded several conclusions. First, the short run (within a growing season) price elasticities for nitrogen fertilizer and irrigation water are very low. The reasons for these low elasticities relate to factors determining the elasticity of demand for factors of production; namely, the price elasticity of derived demand varies directly with the share of total production cost associated with a given factor[82] and the elasticity of substitution between a given factor and other inputs. In this case, water and nitrogen are the only variable inputs modeled and they are technically independent until one of them becomes limiting to plant growth, at which point they are complements (because of the von Liebig-like production relationships within CERES). Furthermore, the factor shares for water and nitrogen in the base models are small, varying from three to eleven percent. Thus, given that 1) water and nitrogen makeup a relatively small portion of the production costs, 2) the elasticity of substitution between them is greater than or

[82]This results is only true for certain relationship between price elasticity of demand for output and elasticity of substitution among inputs.

equal to zero, and 3) there are no other close substitutes, one would expect their short-run demand elasticities to be low. The low demand elasticities calculated from the modeled nitrogen use imply that in order for input taxes to be effective in reducing pollution, they must be very high.

Even with high input taxes, there is no assurance that pollution rates will fall, especially on high value crops such as potatoes. For example, implementation of a 100 percent nitrogen tax for potatoes (following alfalfa) actually caused the predicted leachate rates to increase. This can occur because of shifts in fertilization and irrigation patterns that cause soil nitrate concentration to increase during periods of significant percolation. Because of the low nitrogen price elasticities, the timing effects can actually counter the price effect of the tax. Input taxes also create equity problems because they affect all farms equally, whether or not any given farm lays over high-risk soils.

The results of the Pigovian (leachate) tax analyses suggest that such taxes will always decrease pollution rates, a finding consistent with qualitative assessments based on economic theory. However, the magnitude of these decreases is somewhat limited in the case of potatoes because of their high value. Pigovian taxes have limited practical value because of the expense that would be incurred to monitor actual pollution rates for every farm that posed a significant risk to the underlaying aquifer. This does not include the added farm management costs related to making input decisions based on complex pollution forecasting models. There are additional problems in defining the social cost associated with a marginal kilogram of nitrate leachate. Despite these problems, analysis of the effects of Pigovian taxes is useful for forming socially optimal pollution goals and general irrigation and fertilization strategies, assuming the tax levels roughly approximate the true marginal social cost of nitrate pollution.

Direct controls on nitrate leachate rates, by definition, assure significant decreases in pollution rates independent of the value of the crop. The results of the dynamic optimization models show there are clear upper bounds on the level of leachate restrictions that can be imposed on any given crop. These upper bounds are determined by the number and size of rainstorms and the number of days with relatively high evapotranspiration within the growing season. For example, in the base wheat model, the minimum amount of nitrate leachate was 0.98 kg N/ha. However, these restrictions, like Pigovian taxes, have limited practical value because it is costly to monitor pollution rates. Nevertheless, they do provide a means for defining (in general terms) the "best management practices" to achieve given target reductions in pollution rates. They also provide a means for defining approximate lower bounds for pollution. These preferred practices, once defined, can be used in the formulation of regulatory guidelines which seek to reducing nitrate leachate from high-risk soils.

The results of the farm-level LP model indicate that, as restrictions on total leachate levels increase, the shadow price of land on the representative farm falls significantly. The shadow price on land reflects the economic profits from a given hectare; thus, any government policy which decreases net farm income will, in time, decrease land values. Therefore, consideration of various policies for decreasing nitrate pollution rates should address the effects on land values and any possible economic dislocations associated with those shifts. The LP results also show that, as the constraint on leachate increases, the model first selects the leachate restricted grain activities then the leachate restricted potato activities as the resulting optimal strategy. Finally, the crop mix shifts from a potatoes-grain rotation to a potatoes-alfalfa rotation. The final shift to a potato-alfalfa rotation is largely because the nitrate leachate levels for fields in alfalfa are assumed to be zero. This assumption should be tested in future research with on-farm trial plots.

The aquifer geohydrology simulator showed the pattern of nitrate concentrations over time for a given annual nitrate loading pattern. The simulator predicts that over 20 years of continuous cropping, with optimal timing of irrigation and nitrogen fertilizer, that the nitrate concentration will increase only slightly (by 0.114 mg N/l). The predictions of a geohydrology model, in the presence of the simple hydrological formations within the study area (i.e., sandy soil down to the aquifer), should be considered relatively reliable. However, its use is largely unnecessary because it adds little insight to the analysis that is not revealed by the yearly nitrate leachate data.

Limitations and Suggestions for Further Research

The models discussed in this thesis have several important limitations which should be addressed. Identification of these limitations is also made to pinpoint areas of future research. First, as discussed in Chapter 2, the dynamic optimization algorithm used in this thesis does not assure global optimality. In fact, given the non-convex and discontinuous nature of CERES's production relationships, no technique short of enumeration can assure global optimality. The algorithm appears to do a reasonably good job of optimizing irrigation and fertigation strategies based on the improvements in predicted net returns over current practices, as simulated with CERES models.

One of the main problems in formulating the dynamic optimization model was selecting the appropriate post-decision period irrigation and fertigation decision rules. An ideal decision rule would provide an accurate ranking of the alternative paths to a given state node at a given point in time. The simple tests of various decision rules suggest that the choice of decision rule can significantly influence the optimal solution of a dynamic optimization model; therefore, it is important that a range of rules be tested to insure the best possible rule is used. One possibility for future work would be to have the algorithm test a number of alternative rules on the first stage of the optimization model. This determines the rule which maximizes net returns, the selected rule is then used for the rest of the growing season instead of a fixed irrigation rule.

The dynamic optimization model was not designed for use as an on-farm real-time irrigation and fertigation scheduler. Like other dynamic programming-type optimization models, the model used here assumes a level of knowledge about future weather events that is unavailable to a farmer. Although daily decisions use expectations for future weather events, the model essentially allows the farmer to maintain multiple irrigation patterns throughout the irrigation season (i.e., one for every state node), then select the best pattern at the end of the season. Obviously, a farmer cannot actually test all paths before making decisions. This restrictive assumption is necessary, however, if one wishes to apply any type of seasonal constraint, such as a limit on total pollution or input applications. It also can provide potential assistance in formulating general rules under various weather conditions and policy environments.

An alternative approach, if one is not interested in applying seasonal constraints, is to use open loop stochastic control model (Rausser, 1978; and Zavaleta, Lacewell, and Taylor, 1980). One variation on this technique would be preform a forward search of discrete decision alternatives for irrigation and fertilization using expected weather for the day of decision and thereafter. Once the optimal input decisions are made for a given day, the model would then be given actual weather for the current day and would reanalyze from the next day onward. Using this technique would permit development of a real-time irrigation and fertigation scheduler which can deal with the minimum irrigation constraints of center pivot systems.

Another limitation of the approach used here is the potential for bias toward early season application of nitrogen when a seasonal fertilizer constraint is used. In the analyses that use this policy option, the algorithm tests each candidate state node to determine if the fertilizer constraint is binding. The algorithm only includes fertilizer applied up to and including the current decision stage, excluding any post decision period applications. The structure of this constraint, as currently formulated, has the potential to limit late season decision alternatives more than early season alternatives. One could reformulate the constraint to include post-decision period nitrogen applications, but that alternative could bias fertilizer decisions in favor of late season applications, depending on the post-period-decision rule for nitrogen. There is the potential for the same type of problem with mildly binding seasonal leachate constraints[83]. But, as with fertilizer constraints, there appears to be no alternatives clearly preferable to the algorithm used here.

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[83]The analyses which have a strong constraint on nitrate leachate (such as the 70 percent constraint on wheat leachate) are <u>not</u> affected because they are typically near the minimum feasible level of leachate for a given crop. Thus, there are minimal alternative irrigation patterns which can meet the constraints. Therefore, no intra-seasonal bias exists for those analyses.

The CERES models are also a potential source of error. First, it should be emphasized that all pollution rates reported in this thesis are values calculated within CERES. They are not based on measured rates of nitrate leachate in the study area. From a limited survey of the agronomy literature, it would appear that CERES significantly understates leachate rates (Robbins and Cater, 1980; and Hergert, 1986). There may be a number of reasons for this apparent underestimation of pollution rates, some of which were discussed in the previous chapter. Despite this possible underestimation, the predicted leachate rates are probably accurate in making relative comparisons between model solutions. The results, therefore, are still useful for understanding relative effects of the various policy options examined on pollution rates, crop yields, and profits.

Additionally, the CERES potato model, unlike the wheat and corn models, is still in development and has not been widely validated. CERES-Potatoes needs significant refining in general and specifically in the routines which generate yield penalties for excessive nitrogen applications (i.e., stage III of the production surface). Also note that the soil nitrogen, soil moisture, and nitrate transport components of the CERES potato model are identical to those used in CERES wheat and corn. Because the optimal level of aggregate nitrogen applications are close to current practices levels, the nitrogen uptake components appear to be approximately correct. Therefore, the problems with excessive yield penalties should not affect the ranking of nitrate leachate in alternative solutions for potatoes to a greater degree than for CERES corn and wheat.

Current formulations of the CERES models provide minimal information about the quality of the crop. CERES can provide estimates of the quantity of nitrogen within the grain or tuber but cannot predict, for example, the percentage of number one tubers (the highest grade) in a potato crop. Furthermore, none of the CERES models account for interactions between disease and input applications. Finally, there are no direct means within CERES, excluding separate genetic growth coefficients, to account for rotational effects (other than from nitrogen carryover) such as soil tilth (e.g., disease, pest, and micro-nutrient effects).

Finally, the data available to estimate the genetic coefficients for each crop were far from ideal. The data were limited to farm records of yield, weekly input application levels, planting rates, incomplete soil nitrogen tests, and planting and harvest dates. No data were available for items such as potential growth rates for grain or tubers and degree days between certain stages. Instead, data developed for other regions of the United States were used. Also, there were no data on carryover residue levels. Therefore, in future work with these or other CERES models, cooperative agreements with several farmers in the area(s) of interest should be made a part of the study design early. Similarly, the estimation of the genetic coefficients should be done in cooperation with appropriately trained agronomists.

Summary

Despite the limitations discussed above, the approach presented in this dissertation represents a methodological contribution to the groundwater quality literature by integrating plant science, economic, and geohydrology models into an unified framework. This approach gives rise to some robust conclusions with respect to why farmers allow nitrate pollution to occur and the effectiveness of various policy government alternatives. First, careful management of soil moisture is critical to the reduction of pollution rates. Second, some nitrate leachate is unavoidable in the production of irrigated crops within the study area. Third, weather events play a significant role in explaining the existence of nitrate leachate under optimal irrigation and fertilization practices (e.g., period of high evapotranspiration and storm events). Fourth, input taxes and restrictions on nitrogen application rate may not always reduce pollution rates. Fifth, Pigovian taxes appear to be the most efficient means of reducing nitrate levels, although they would be difficult to impose. Finally, federal government farm program provisions relating to price supports increase pollution rates and idlement requirements reduce pollution rates.

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APPENDICES

APPENDIX A: SOFTWARE AND DOCUMENTATION

Introduction

This appendix discusses the important changes made in the CERES model, it provides documentation for the dynamic optimization models, it provides source listings of several support programs, and it provides a listing of input files not documented in the body of the dissertation. The model documentation is intended as a supplement to (not a replacement for) information present in the FORTRAN source code and the body of this dissertation. All source code not found in this appendix may be obtained from the author or the Department of Agricultural and Resource Economics at Oregon State University in hard copy or magnetic form. This appendix assumes the reader is an experienced FORTRAN 77 programmer; thus, programming terminology and self-explanatory code fragments will not be explained. As a further supplement to the understanding of the CERES and dynamic optimization models, glossaries are provided for all variables used in the dynamic optimization and the CERES wheat, potato, and corn models. In addition to the descriptive documentation, simple flowcharts are provided for all the dynamic optimization models and CERES models generated by a commercial flowcharting program (Documenter and Diagrammer).

Several items should be mentioned about the glossaries. The glossary entries include a reference to the name of each subroutine that the variable is used. In the case of the CERES glossary, the routine names listed are generally from the wheat model. The exception to this occurs if a variable only appears in the corn model, in which case, the entry lists the routine names for the corn model. The routine names are generally the same between the two CERES models, so the emphasis on the wheat model should not present problems. An equals sign beside a routine name indicates that the variable is altered within that particular routine. An 'R' before the equals sign indicates the variable was read in from a file within the named routine. The letter that appears in the braces '{ }' after a number of entries in the CERES glossary informs the reader what class of variable it is (P for parameter, C for on going value, and R for reset daily).

The source code for optimization/CERES models is divided into three components. These components are 1) the optimization models, 2) input routines for the optimization models, and 3) the CERES models. All the code was designed to be 100 percent portable FORTRAN 77 (i.e., <u>no</u> extensions are used). All arrays used in the program which could possibly need variable dimensions have been dimensioned with parameters or have been dynamically dimensioned (e.g., the number of soil layers).

Documentation for Input Routines

The first component (DREAD.FOR) reads an input file for the dynamic optimization model. This component is identical in all three models. The input file format is similar to NAMELIST format but is written to be portable. An example input file is provided later in this appendix.

Several on these input routines are based in part on public domain FORTRAN 77 routines written by Art Ragosta at the Ames Research Center in 1984. The input subroutines use a free-form tokenized dictionary look-up system; therefore, the order the variables appear is irrelevant. The user is allowed one variable per card. All errors are logged in a file (IRR.ERR).

The subroutine reads a card from the input file (IPARM). Then the routines search for the first token in the current card using commas and spaces as parsers. The token is then checked against a dictionary list (LIST). If the token is not found in the dictionary an error is logged and the routines move on to the next card. The name of each variable may be in either upper or lower case and may be a direct abbreviation of the name (e.g., PRI for PRICE). If the token is found in the dictionary, the routines find the first token which is an '=' and returns an error if no '=' is found. The routines then searches for the first token which appears to be a numeric value (e.g., 3.0, +3.0, .3E+1, and 0.3E+1).

Several attributes of each value are tested. An error message is generated if any of them do not match the defined attribute. The first attribute tested is the numeric type, e.g., real or integer. This is done by looking for decimal points or exponents. If either exists the value is assumed to be real; otherwise the value is assumed to be an integer. Next, the value is compared to its lower (LBD) and upper (UBD) bounds. If an entry is found to be valid, its value and dictionary name is logged in an output file (IRR.LOG). This process continues until all dictionary entries are found or there are no more cards in the input file. All computation is stopped if either 1) any errors have been found in the reading of the input file or 2) all dictionary entries are not found, The only known problem in these routines is that multiple cards with the same dictionary entry will cause unpredictable results.

Comment lines are allowed by making the first token an '!'. In-line comments are allowed after the dictionary token and before an '=' token.

Additions and deletions from the dictionary list may be accomplished with modest changes to DATA and PARAMETER lines. For example, to add an entry to the dictionary, first add '1' to the current value of the parameters LR or LI depending on whether the type of the entry is real or integer. Second, add the dictionary entry's name to the DATA statement associated with the array LIST. Note that the dimensions of LIST are based on the parameters LI and LR, and that all integer entries must precede the real entries. Also, the entries in the DATA statement for LIST must all be upper case. Third, add the lower and upper bounds to the DATA statements associated with the arrays LBD and UBD in the same position as in LIST.

Documentation for Dynamic Optimization Model

The second component of the program includes the 'MAIN', optimization model, report writer, and check-point routines (PIRR.FOR for potatoes, CIRR.FOR for corn, and NIRR.FOR for wheat). These routines only have minor differences between them, primarily related to the dimensions and the names of the CERES routines. The optimization algorithm is based on standard dynamic programming algorithms. The stage space is designed to allow for multiple-day stages but a single-day stage space has been used in all the runs. Thus, the multi-day stage space option cannot be considered reliable without significant testing. All the major arrays include a dimension which is based on the size of the stage space except for the arrays related to leaching which instead include a dimension based on Julian days (at most 366 days/year).

Note that referencing the dimensions for main arrays related to state spaces requires the use of simple hashing functions for encoding and decoding of pointers. This was done to minimize the dimensions on the state and state descriptor arrays. Therefore, the internal units for the dimensions need to be transformed before they can be interpreted. Also note that the code was designed to use the smallest numeric type possible for selected state descriptors (e.g., INTEGER*1 for systems which support short integers). To accomplish this, some real arrays were stored as integers with the decimal point temporally shifted to the right (e.g., ET, RTDEP, PWATER, PNTR, NLHT, WLHT, NLH, and WLH). In the case of variables designed to be typed as INTEGER*1, functions were built to map values in the range from 128 to 255 into the negative number line and back out creating, in essence, an unsigned integer data type; this leads to gain resolution. Thus, here again the internal units require conversion before they can be interpreted. Both, the uniform and standard normal random number generators used are based on algorithms developed by Knuth (1969).

This program starts out opening the main output files rather than calling the input reading routines discussed above. Next, if the check-point file read flag is set, the program reads a check-point file. Otherwise, the program starts its initialization routines. These include setting the vector of pumping cost and capacity equal to the levels specified in the input file (IPARM). Next, the weights of each sub-field (FLDWT) are hard coded. (Note these values should be read from a file but vector input routines were not written for this program.) The minimum management levels (MMI and MMN) and excess irrigation factors (FACI and FACN) are then calculated for soil nitrogen and moisture levels.

The model now hashes the lower bounds on the soil nitrogen and moisture state space. The program then hashes the upper bound on the soil nitrogen state space and checks the hashed value for validity. Next, the routine zeros all the working arrays and various scalers. Subsequently, the program generates a vector of 366 normally distributed values for irrigation efficiencies. CERES is called for the first time to calculate the stage space using real weather and the stage space's dimension is tested for validity. CERES is again called using expected weather after the first day of the stage space by setting the FD flag equal to two. This call returns the average saturation level across the sub-fields, a percentage which is the upper bound for the soil moisture state space (TSA) and the currant values for the soil moisture and nitrogen state spaces. These values are tested for validity against hard coded bounds.

If the values are found to be valid, the state descriptors are saved into the main arrays.

Next, if there are any nitrogen state nodes available above the initial node, CERES is called with various levels of pre-plant fertilizer associated with each available state node. Then, the state descriptors for each are saved into the main arrays.

The algorithm then begins the main while loop for each stage in the dynamic optimization model. Within this loop, expected rainfall and pumping capacity over the next stage are first computed. Next, the main DO loops are started for the soil moisture and nitrogen state spaces. These four loops will sequentially solve each node in the current stage, I. To do this, the routine will check each node in the previous stage for the feasibility of movement into the node currently being solved. This is accomplished through the use of functions which determine if movement from the candidate node is within the upper and lower bounds of the state space neighborhoods given the limits on pumping capacity and on nitrogen applications, and the expectations of irrigation efficiency and of weather conditions. If a candidate node is found to be feasible, the irrigation, fertilization, and leachate vectors are set up for passing to CERES.

CERES is now called, it returns values for yield, state space, input cost, and leachate information. If the policy flag is non-zero, a routine is called to implement one of three policy options: 1) constraint on seasonal leachate levels, 2) constraint on seasonal fertilization levels, and 3) apply a Pigovian tax on nitrate leachate. If a constrained policy option is selected for the current run, the main will not allow any candidate node which exceeds the particular constraint to enter the solution. Next, the model determines if the net returns for movement from the candidate node exceed those of the current optimal solution. If so, the state descriptors for the candidate node are copied into the main arrays. This process continues until all possible nodes from the previous stage are examined for movement into the current node.

At the end of each stage, a small status file is opened written to and closed again in order to provide the user with information on where the model is in the solution process. Also, if the dump flag is set and the requested number of stages has elapsed since the last write, an unformatted check-point file is written. The check-point file routine alternates between two files to minimize the computational costs of a system failure during the writing of a check-point file. Once the writing of the current check-point file is completed, the previous file is deleted. If the system should fail during the writing of a check-point file, the status file will inform the user which file was being written at the time of the failure and thus which file is corrupted by indicating the current setting of NFLAG (0 or 1). The size of the checkpoint file is substantial because it must hold the values of nearly every scaler and array used in all three components of the optimization/CERES model.

Once the main while loop is completed, the solution for irrigation and fertilization is determined. Then, the report writer is called. The report writer extracts the optimal solution from the main pointer arrays for soil moisture (IRPATH) and nitrogen (FRPATH). These arrays preform a link-list type function. After the solutions for irrigation and fertilization patterns are extracted, they are written to files in CERES format. The leachate vectors for each sub-field are written to a file in a format compatible with the geohydrology simulator. The report writer then writes a state descriptor table for the optimal solution which includes information about each stage and some summary statistics.

Documentation for the CERES Models

The third component of the programs are the CERES models (NWC.FOR for wheat, MZ.FOR for corn, and PT.FOR for potatoes). These routines include the growth simulators (which will not be discussed because they are documented elsewhere), initialization routines, and restarting routines. This section of the appendix will discuss the changes made to the growth simulators in general terms and document the intentions on the initialization and restart routines.

A number of changes were made to the CERES crop simulator models. First, the models were reorganized and redesigned to run in batch as subroutines of a larger model. Therefore, <u>all</u> screen input and output was removed. The file input routines were changed to select automatically the first experimental unit in the input file. <u>All</u> common block passing of variables between the CERES subroutines was replaced with parameter passing. All CERES report writing routines were eliminated along numerous supporting variables and computations. Soil-based arrays were change, where possible, to be dynamically dimensioned. Threshold levels of irrigation and fertilization were added to the appropriate routines. Support for multiple independent sub-fields was added. Numerous initialization needed to be added because the original developers of CERES worked on systems which automatically initialized all variables to zero. Extensive death routines, based on leaf area index, were added to deal with extreme moisture and nitrogen stress at all stage of development. The code was restructured to eliminate as many GO TO statements as possible. Additional computations were added to support the needs of the optimization model. Finally, the code was heavily hand optimized in a number of ways including parameterizing invariant expressions and changes in the nesting and loop structures.

The CERES simulators are each controlled by a single routine (WCALL for wheat, CNCALL for corn, and PTCALL for potatoes). If WFIRST is set to -1, this routine will call the CERES initialization routines. The routine then zeros the accumulator variables used for the averages, across sub-fields, of the state descriptors. Next, the main sub-field loop is started. Then, the CERES main restart routine is called which copies the all values required to start or restart CERES from stage I-1 at the candidate node into the working blocks.

There are a number of important items to note about these restart routines. First and foremost, the techniques used are <u>extremely</u> complex; therefore they should <u>not</u> be altered without careful study of the source code and a good FORTRAN 77 manual. These routines use implied equivalencing of a series of scalers in a common block with an array in the same block but different routine and equivalencing of a series of one dimensional arrays in a common block with a two dimensional array. Because of this use of equivalencing it is essential that the order of the subscripts in the restart blocks not be altered or these routines will not work properly.

These routines preform several functions. One routine (SAVSOL) copies nearly every scaler and array used in CERES into temporary common blocks (/YTEMP/, /YATEMP/, /YDAILY/, and /KITEMP/) at the end of the Julian day corresponding to stage I-1 for every sub-field of a candidate node. If a node is found to be an improvement over the current best solution by the optimization model, another routine (SAVOP) copies the values from these temporary blocks to the solution blocks (/WTEMP/, /WATEMP/, /WDAILY/, and /JITEMP/). This process continues until every candidate node has been examined by the optimization model. These solution blocks contain, in a sense, three dimensional arrays made up of nearly every scaler and array used in CERES. There are dimensions for both the soil moisture [G] and nitrogen [N] state spaces and a dimension for each sub-field [NF] within a node of the state spaces. Thus, the solution blocks act like internal check-point files; containing all the necessary information to restart the CERES models from any given sub-field at stage I-1. When a new stage of the optimization model has begun (stage I+1), a routine [TRADAT] is used to copy the values in the solution blocks in to the active solution blocks (/QTEMP/, /QATEMP/, /QDAILY/, and

/LITEMP/). The CERES restart values for any given candidate node are extracted from these active solution blocks and copied into CERES's working blocks (/TEMP/, /ATEMP/, /DAILY/, and /ITEMP/) for each sub-field. The reason for this complex memory management is to eliminate the need to repeat the main CERES while loop for days up to and including stage I-1 for any given candidate node.

At this juncture CERES's working blocks are set up, the model starts the expected-real weather DO loop. On the first call of CERES and in the last stage of the optimization model, the loop is only executed once. In which case, CERES is called with real weather. Otherwise, the loop is executed twice. The first iteration of the loop CERES is called using expected weather from stage I to harvest. Then, the working blocks are reset and the iteration of the loop then calls CERES using real weather from the starting date in the reset blocks to stage I. This second call stops CERES after stage I because this call is only used to calculate the actual state descriptors at stage I. Next, the values of the state descriptors are added to the accumulators for the averages. One final note, that the CERES model uses the post-decision period threshold irrigation and fertilization patterns generated by the first sub-field for all subsequent sub-field of a given candidate node.

Glossary for Variables Used in the Dynamic Optimization Model

A - PARAMETER which defines the number of soil moisture states and used in dynamic dimensioning of arrays.
AM - Used in random normal number generator. [MAIN, =RANDN]
ANTR - Average soil nitrogen level. [=OUT2]
ASA - Average soil moisture level. [=OUT2]

B - PARAMETER which defines the number of days in the growing season and used in dynamic dimensioning of arrays.
BEST - Optimal soil moisture state. [MAIN, =FINDMAX, OUT2, GETREP]
BN - Initial soil nitrogen state. [MAIN, =SAVBSA]
BSA - Initial soil moisture state. [=MAIN, SAVBSA, SVBSA, SVBSA]

C - PARAMETER which defines the maximum number Julian days per year of and used in dynamic dimensioning of arrays. [=MAIN, INTMAT, SAVBSA, SVBSA, SETLCH, TRALCH, SAVMAX, NPOLCY, OUT2]

D - PARAMETER which defines the maximum number of soil layers and used in dynamic dimensioning of arrays. [=MAIN]
DAY - Current Julian date. [=MAIN, GETIRR, =CONVPT, GETFRT, =FCONVPT, STATUS, NPOLCY, =OUT2]
DCOUNT- Checkpoint frequency counter. [=MAIN]
DDAY - Current julian date. [=MAIN, CONVPT, FCONVPT, OUT2, =CJDATE]
DNLH - Used in the report writer as a temporary value for decoded nitrogen leachate quantity (kg). [=OUT2]
DONE - Flag used to indicate last day of decision period. [=MAIN]
DTN - Used in the fertilizer encoding routines for case when NDAYS greater than one. [=GETFRT, =FCONVPT]
DWLH - Used in the report writer as a temporary value for decoded water leachate quantity (mm). [=OUT2]

EFFIRR- Mean irrigation system efficiency (%). [R=PREAD, MAIN, LBOUND, GETIRR]
ELASP - Elapsed time for each call of CERES. [=MAIN, STATUS]
ET - Evapotranspiration array (mm). [=INTMAT, =SAVBSA, =SVBSA, =SVBSA, UBOUND, LBOUND, GETIRR, =SAVMAX, FINDMIN, OUT1, OUT2]

FACI - Multiplication factor for calculating required irrigation in the auto-irrigator routine. Used to decrease the frequency of auto-irrigator (1.0 > X > 1.5) [=MAIN]
FACN - Multiplication factor for calculating required fertigation in the auto-fertigator routine. Used to decrease the frequency of auto-fertigator (1.0 > X > 1.5). [=MAIN]
FCOUNT- Used in the report writer as denominator in calculating average fertilizer applications. [=OUT2]
FD - Flag used to indicate whether or not ceres SHOULD use real (1) or expected (2) weather. [=MAIN]
FDUMP - Counter used to indicate the frequency of check point calls. [R=PREAD, MAIN]
FEAS - Flag used to indicate the candidate state is or is not feasible with respect to the nitrogen state space. [=MAIN]

FLDWT - Weighing array for each sub-fields (percent). [=MAIN, NPOLCY, OUT2]

FNTR - Temporary value use to determine feasibility in the nitrogen state space (kg). [=UNBOUND]

FOUND - Flag used to indicate if any solutions have been found for a given state and stage. [=MAIN]

FROM - Pointer array used to point to previous optimal soil moisture state. [=INTMAT, =SAVBSA, =SVBSA, =SAVMAX, OUT1, OUT2, GETREP]

FRPATH- Optimal fertilizer quantity path (encoded: kg). [=INTMAT, FCONVPT, =SAVMAX, OUT1, OUT2]

FSA - Temporary value use to determine feasibility in the soil moisture state space (mm). [=UBOUND]

HINCR - Used in the state space compression routine. [=RCLOSE, UCLOSE, =ICLOSE]

I - WHILE loop variable used to indicate the stage.

ICERES- Number of calls of CERES. [=MAIN]

IDUMP - Flag used to indicate whether or not to use check point feature. [R=PREAD, MAIN]

IERR - Error flag used in timing routine call. [MAIN]

II - Loop variable used when NDAYS is greater than one to convert multi-day treatment quantity to a daily basis. [=CONVPT, =FCONVPT]

IJ - Loop variable used when NDAYS is greater than one to convert multi-day treatment quantity to a daily basis. [=CONVPT]

ILDAY - Last Julian day in the growing season. [MAIN]

ILOAD - Flag used to indicate whether or not to restart from a LOAD file. [R=PREAD, MAIN]

INC - Used in the random number generator. [=RANG]

INCR - Increment between soil moisture state space (mm). [R=PREAD, MAIN, SAVBSA, UBOUND, LBOUND, GETIRR, SAVMAX, FINDMIN, RCLOSE, UCLOSE, ICLOSE, OUT1, FMAT, I1MAT, I2MAT, I2MAT, OUT2]

IRPATH- Optimal irrigation quantity path (encoded: mm). [MAIN, =INTMAT, CONVPT, FCONVPT, =SAVMAX, OUT1, OUT2]

ISA - Soil moisture level for current state and stage (mm). [=MAIN]

ISCR - Flag used to indicate screen output. [R=PREAD, MAIN]

ISHORT- Dummy variable. [=MAIN]

ISOW - Sowing date (Julian date). [MAIN, FCONVPT, NPOLCY, OUT2]

ITEMP - Temporary value evapotranspiration (mm). [=SAVMAX]

IX - Temporary value used in the encoding and decoding of short integers. [=INCODE1, DECODE1]

J - Loop variable generally used to indicate the current soil moisture state.

JDATE - Julian date array used to tell if the current year is a leap year. [CONVPT, FCONVPT, OUT2]

JF - Loop variable generally used to indicate sub-field number. [=MAIN, =INTMAT, =SAVBSA, =SVBSA, =SETLCH, =TRALCH, =SAVMAX, =NPOLCY, =OUT2]

JUNK - Dummy variable. [=MAIN]

JUNK1 - Dummy variable. [=MAIN]
JUNK2 - Dummy variable. [=MAIN]
JWR3 - Used in the uniform normal routine. [RANG]

K - Loop variable generally used to indicate the current soil nitrogen state.
KLDAY - Number of days before maturity to end the optimization model (days). [R=DREAD, MAIN, WCALL]

L - General purpose loop variable. [=MAIN, GETIRR, GETFRT, =FINDMIN, =OUT2]
LABEL - Label used for formatted array dumps routines. [=OUT1, FMAT, FVEC, I1VEC, I1MAT, I2MAT, OUT2]
LDAY - Last decision date (Julian date). [=MAIN, STATUS, FINDMAX]
LFEAS - Flag indicating feasibility of the currant candidate state. [=MAIN]
LOW - Minimum soil moisture state (mm/m). [=PREAD, MAIN, SAVBSA, UBOUND, LBOUND, GETIRR, SAVMAX, FINDMIN, FINDMAX, RCLOSE, UCLOSE, OUT1, FMAT, I1MAT, I2MAT, OUT2]

MATRIX- Dummy value used in the array dump routines. [FMAT, I1MAT, I2MAT]
MAX - Maximum objective function value for current stage and state in MAIN, maximum state space value in the state compression routines, and maximum normal random value in the normal random routine. [=MAIN, =SAVMAX, =FINDMAX, RCLOSE, ICLOSE, RANDN]
MAXIRR- Irrigation system capacity (mm). [R=PREAD, MAIN]
MDX - Used in the uniform random number generator. [=RANG]
MDX128- Used in the uniform random number generator. [=RANG]
MIN - Minimum soil moisture state level. [MAIN, =SAVBSA, =FINDMIN, RANDN]
MINFRT- Minimum nitrogen application quantity (kg). [R=PREAD, MAIN, GETFRT]
MINIR - Array holding the minimum soil moisture level for each stage. [=MAIN, SAVBSA]
MINIRR- Minimum irrigation application quantity (mm). [R=PREAD, MAIN, GETIRR]
MIN1 - Minimum soil moisture state in the previous stage. [MAIN, =SAVBSA, =FINDMIN]
MMI - Minimum management level for soil moisture used in the auto-irrigator (percent). [=MAIN]
MMN - Minimum management level for soil nitrogen used in the auto-irrigator (kg). [=MAIN]
MNPRAN- Percentage of rainfall which is allowed to be used in determining feasibility of soil moisture state. [R=PREAD, MAIN]
MNRAN - Threshold level for rainfall to be used in determining feasibility of soil moisture state (mm). [R=PREAD, MAIN]
MTSA - Maximum number soil moisture states. [MAIN, INTMAT, =SAVBSA, SVBSA, FINDMAX]
MULT - Used in the uniform random number generator. [=RANG]

N - PARAMETER which defines the number of soil nitrogen states and used in dynamic dimensioning of arrays.

NAR - Used in the uniform random number generator. [=RANG]

NBEST - Optimal soil nitrogen state. [MAIN, =FINDMAX, OUT2, GETREP]

NCOST - Total fertilizer costs for the current candidate state includes auto-fertigator nitrogen. [=MAIN, NET, SAVBSA, SVBSA, SAVMAX]

NDAS - Number of days in the growing season. [MAIN]

NDAYS - Length between stages (days). [R=PREAD, GETIRR, CONVPT, GETFRT, FCONVPT, OUT2]

NDIFF - Temporary value used in computing the bound on the nitrogen state space. [=MAIN]

NF - PARAMETER which defines the number of sub-fields and used in dynamic dimensioning of arrays. [=MAIN, INTMAT, SAVBSA, SVBSA, SETLCH, TRALCH, SAVMAX, NPOLCY, OUT2]

NFLAG - Flag indicating which DUMP file to write next. [=MAIN, RCLOSE]

NFLD - Number of sub-fields requested. [R=PREAD, MAIN, INTMAT, INTMAT, SAVBSA, SVBSA, SETLCH, TRALCH, SAVMAX, NPOLCY, OUT2]

NFROM - Pointer array used to point to previous optimal soil nitrogen state. [MAIN, =INTMAT, =SAVBSA, =SVBSA, =SAVMAX, OUT1, OUT2, GETREP]

NINCR - Increment between soil nitrogen state space (kg). [R=PREAD, MAIN, UNBOUND, UNBOUND, LNBOUND, GETFRT, OUT1, FMAT, I1MAT, I2MAT, OUT2]

NJ - Loop variable used to indicate soil moisture pointer state level for current candidate state. [=MAIN, SVBSA, UNBOUND, LNBOUND, GETFRT, =TRALCH, SAVMAX]

NK - Loop variable used to indicate soil nitrogen pointer state level for current candidate state. [=MAIN, =INTMAT, CONVPT, GETFRT, FCONVPT, SETLCH, SAVMAX, NPOLCY, =FINDMAX, =FMAT, =I1MAT, =I2MAT, =OUT2]

NL - Temporary value. [=FINDMIN]

NLAYR - Number of soil layers. [MAIN, SAVBSA, SVBSA, SAVMAX]

NLEACH- Daily nitrogen leachate levels (kg). [MAIN, =INTMAT, SAVBSA, SVBSA, SETLCH, SAVMAX]

NLH - Main array for daily nitrogen leachate levels for optimal states (kg). [MAIN, =INTMAT, SAVBSA, SVBSA, SETLCH, =TRALCH, SAVMAX, NPOLCY, OUT2]

NLHT - Main temporary array for daily nitrogen leachate levels for optimal states (kg). [MAIN, =INTMAT, TRALCH]

NLOW - Minimum nitrogen level for the state space (R=kg/m & pointer). [R=PREAD, =MAIN, UNBOUND, LNBOUND, GETFRT, OUT1, FMAT, I1MAT, I2MAT, OUT2]

NMAX - Maximum nitrogen level for the state space (R=kg/m). [R=PREAD, =MAIN, INTMAT, UNBOUND, TRALCH, FINDMIN, FINDMAX, OUT1, FMAT, I1MAT, I2MAT, OUT2]

NMCON - Maximum concentration of nitrogen in irrigation water (kg/mm). [R=PREAD, MAIN, LNBOUND, GETFRT, FCONVPT]

NMIN - Minimum nitrogen state level for the current stage. [=MAIN, FINDMIN]

NMIN1 - Minimum nitrogen state level for the previous stage. [=MAIN]

NNTR - Temporary value used to store soil nitrogen levels (kg). [=MAIN, =OUT2]
NOR - Used in normal random number generator. [=RANDN]
NREPORT- Optimal nitrogen path up to the current stage and state. [MAIN, CONVPT, FCONVPT, =OUT2, =GETREP]
NREV - Net revenue for the candidate stage and state ($). [MAIN, =NET, SAVBSA, SVBSA, SAVMAX, =NPOLCY]
NRUN - Not Used. [=MAIN]
NSA - Temporary value used in the report writer related to soil moisture (mm). [=OUT2]
NTR - Main soil nitrogen array (kg). [MAIN, =INTMAT, =SAVBSA, =SVBSA, UNBOUND, LNBOUND, GETFRT, =SAVMAX, OUT1, OUT2]
NTR1 - Dummy argument for previous NTR (kg). [SAVMAX]
NU - Main nitrogen use array (kg). [MAIN, =INTMAT, UNBOUND, LNBOUND, GETFRT, =SAVMAX, OUT1, OUT2]

OLDS - Temporary value used in determining the optimal soil moisture path. [CONVPT, =OUT2, =GETREP]

P - Price of yield ($). [MAIN, NET]
PERIODS- Temporary dummy value used either for number stages or Julian days. [=MAIN, CONVPT, FCONVPT, FMAT, FVEC, I1VEC, I1MAT, I2MAT, OUT2, GETREP]
PL - Price of irrigation labor ($). [R=PREAD, MAIN, OUT2]
PLN - Price of fertigation labor ($). [R=PREAD, MAIN]
PN - Price of nitrogen ($). [R=PREAD, MAIN]
PNTR - Expenditure for nitrogen and nitrogen labor for each node ($). [MAIN, =INTMAT, =SAVBSA, =SVBSA, =SAVMAX, OUT2]
POLICY- Policy value, for TPOLICY=1: it is the maximum seasonal nitrogen leachate (kg N), for TPOLICY=2: it is the maximum seasonal fertilizer (kg N). [R=PREAD, MAIN, NPOLCY]
PPW - Cost of irrigation water ($). [R=PREAD, MAIN]
PTN - Price of pre-plant fertilizer ($). [R=DREAD, MAIN]
PTNL - Application cost of pre-plant nitrogen fertilizer ($). [R=DREAD, MAIN]
PUMPCP- Array of daily pumping capacities (mm/day). [=MAIN, LBOUND, GETIRR, CONVPT, OUT2]
PW - Array of daily irrigation costs ($). [=MAIN]
PWATER- Main array storing irrigation costs including those costs associated with the auto-irrigator ($). [MAIN, =INTMAT, =SAVBSA, =SVBSA, =SAVMAX, OUT1, OUT2]
PY - Price of yield ($). [R=DREAD, MAIN]

QNMAX - Maximum bound on soil nitrogen state space (kg/m). [R=DREAD, MAIN]

R - Used in normal random number generator. [RANDN]
RAIN - Array of daily rainfall amounts (mm). [MAIN, GETIRR, OUT2, FINDMIN, =RCLOSE]
REPORT- Optimal soil moisture path up to the current stage and state. [MAIN, CONVPT, FCONVPT, OUT2, GETREP]

RNIRR - Array of random irrigation efficiencies (percent). [=MAIN, =INTMAT, =INTMAT]
RNMAX - Upper bound of random irrigation efficiency (percent). [=MAIN]
RNMIN - Lower bound of random irrigation efficiency (percent). [=MAIN]
RRTDEP- Temporary value holding decoded RTDEP (m). [=OUT2]
RTDEP - Root depth stored as a encoded integer (used: m, store: mm). [MAIN, =INTMAT, =SAVBSA, =SVBSA, UBOUND, LBOUND, UNBOUND, LNBOUND, GETIRR, GETFRT, =SAVMAX, FINDMIN, OUT1, OUT2]
RWATER- Temporary value used in the calculation of required irrigation water to move to the current stage and state (mm). [=GETIRR, =CONVPT]

S - Temporary value used in determining the optimal soil moisture path. [CONVPT, FCONVPT, =OUT2, =RANDN, =GETREP]
SA - Soil moisture state array (mm). [MAIN, =INTMAT, =SAVBSA, =SVBSA, UBOUND, LBOUND, GETIRR, =SAVMAX, FINDMIN, FINDMAX, OUT1, OUT2]
SAMAX - Percentage of soil saturation to use as upper bound for soil moisture state space. [R=DREAD, MAIN, SAVBSA]
SA1 - Dummy argument representing soil moisture in the previous stage of the candidate state (mm). [SAVMAX]
SCROUT- Flag indicating whether or not normal screen output will occur. [=MAIN, NPOLCY, OUT1, FMAT, FVEC, I1VEC, I1MAT, I2MAT, OUT2]
SEED - Seed for random number generator. [=MAIN, RANDN]
SKK - Used in the uniform random number generator. [=RANG]
SPFILL- Not used. [R=DREAD, MAIN]
SS - Temporary value used in determining the optimal soil nitrogen path. [CONVPT, =OUT2, =GETREP]
STD - Standard deviation used in the normal random number generator. [RANDN]
STDIRR- Standard deviation of irrigation efficiency. [R=DREAD, MAIN]
STRAIN- Temporary value used in the report writer related the rainfall which occurs during a given stage (mm). [=OUT2]
SUM - Main array used to store objective function values ($). [MAIN, =INTMAT, =SAVBSA, =SVBSA, =SAVMAX, FINDMAX, OUT1, OUT2]

TELASP- Total elapse CPU time. [=MAIN, OUT2]
TEMPMIN- Dummy argument used in determining minimum soil moisture level. [=FINDMIN]
TESW - Total extricable soil moisture (mm). [MAIN, SAVBSA]
TET - Temporary value related to evapotranspiration (mm). [=OUT2]
TFERT - Total amount of fertilizer applied in the current stage (kg). [=MAIN, =GETFRT, SAVMAX, =OUT2]
TFRT - Total amount of fertilizer applied in the growing season (kg). [MAIN, =NPOLCY]
TIRR - Total amount of irrigation applied in the current stage (mm). [MAIN, LNBOUND, =GETIRR, GETFRT, SAVMAX, OUT2]
TNLEACH- Total amount of nitrogen leachate in the current stage (kg). [=OUT2]

TNLH - Total amount of nitrogen leachate in the growing season (kg). [MAIN, =NPOLCY, =OUT2]

TNU - Total amount of nitrogen used in the current stage (kg). [=OUT2]

TPOLICY- Policy flag indicating type of policy options, =1 leachate quantity restriction, =2 fertilizer quantity restriction, =3 leachate tax. [R=DREAD, MAIN, NPOLCY]

TPUMP - Total pumping capacity in the current stage (mm). [=MAIN]

TRAIN - Total rainfall in the current stage (mm). [=MAIN, UBOUND, LBOUND, =OUT2]

TSA - Upper bound on the soil moisture state space (mm/m). [MAIN, =SAVBSA, UBOUND, UNBOUND, TRALCH, SAVMAX, FINDMIN, OUT1, FMAT, I1MAT, I2MAT]

TSTET - Evapotranspiration returned from CERES (mm). [MAIN, SAVBSA, SVBSA, SAVMAX]

TSTMMI- Minimum management level for soil moisture used in the auto-irrigator used in the first call of CERES (percent). [=MAIN]

TSTMMN- Minimum management level for soil nitrogen used in the auto-irrigator used in the first call of CERES (kg). [=MAIN]

TSTRTD- Root depth returned from CERES (m). [MAIN, SAVBSA, SVBSA, SAVMAX]

TSTRTN- Soil nitrogen in the root zone returned from CERES (kg). [MAIN, SAVBSA, SVBSA, SAVMAX]

TSTSA - Soil moisture in the root zone returned from CERES (mm). [MAIN, SAVBSA, SVBSA, SAVMAX]

TSTYLD- Crop yield returned from CERES (kg). [MAIN, SAVBSA, SVBSA, SAVMAX]

TWLEACH- Total water percolation in the current stage (mm). [=OUT2]

TWLH - Total seasonal water percolation (mm). [=OUT2]

UFEAS - Flag used to indicate a feasibility of the current candidate state. [=MAIN]

V - Used in the normal random number generator. [RANDN]

VALUE - Dummy argument used in the state compression routines. [RCLOSE, UCLOSE, ICLOSE]

VECTOR- Dummy argument used in the vector dump routines. [FVEC, I1VEC]

VIOLATE- Flag used to indicate whether the policy constraint is violated. [MAIN, =NPOLCY]

WC - Number of irrigations if count is greater than or equal to one and equal to one otherwise. [=OUT2]

WCOST - Total seasonal irrigation costs for the current stage and state ($). [MAIN, NET, SAVBSA, SVBSA, SVBSA, SAVMAX]

WCOUNT- Number of irrigations. [=OUT2]

WFIRST- Flag used to indicate the type of call in terms of where to start growth. -1 - first call, start simulation from ISIM, and read data from file; 0 - start simulation from day ISIM; 1 - start simulation from DAY using the data associated with current stage; 2 - new decision day so transfer temporary solution block to starting point blocks, and start simulation

	from DAY using the data associated with current state. [=MAIN]
WLEACH-	Water leachate by Julian date and sub-field (mm). [MAIN, =INTMAT, SAVBSA, SVBSA, SETLCH, SAVMAX]
WLH -	Main array used to store water leachate for each state (mm). [MAIN, =INTMAT, SAVBSA, SVBSA, =SETLCH, =TRALCH, SAVMAX, OUT2]
WLHT -	Main temporary array used to store water leachate for each state (mm). [MAIN, =INTMAT, TRALCH]
X -	Temporary value. [INCODE1, RANDN]
Y -	Temporary value. [RANDN]
YLD -	Main array used to store yield values (kg). [MAIN, NET, =INTMAT, =SAVBSA, =SVBSA, =SAVMAX, OUT1, OUT2]
ZIRR -	Temporary value related to irrigation efficiency (percent). [MAIN]
ZJUNK -	Dummy variable. [MAIN]
ZJUNK1-	Dummy variable. [MAIN]
ZNTR -	Temporary value used in the check for feasibility in the soil nitrogen state space (kg). [=UNBOUND]
ZSA -	Temporary value used in the check for feasibility in the soil moisture state space (kg). [=UBOUND]

Glossary for Variables Used in the CERES Wheat and Corn Models

A - Zero to unity factor for relative nitrification rate (unitless). [=NTRANS]

ABD - Average soil bulk density (g/cm**3). [WHEAT, =SOILNI]

ADD - Temporary variable used in the calculation of crop residue distribution (kg/ha). [=SOILNI]

AFERT(J)- Amount of nitrogen added as fertilizer on Julian date J (kg N/ha). [WCALL, IWHEAT, WHEAT, R=IPNIT2, NTRANS] {P}

AFERTZ(J)- Amount of nitrogen added as fertilizer on Julian date J for auto-fertilizer. Used on sub-fields for JF > 1 to insure each sub-field recieves the same quantity of fertilizer from the auto-fertigation routines (kg N/ha). [WCALL, IWHEAT, WHEAT, =NTRANS] {P}

AIRR(J)- Amount of irrigation added on Julian date J (ha/mm). [WCALL, IWHEAT, WHEAT, R=IPTRT, WATBAL] {P}

AIRRZ(J)- Amount of irrigation added on Julian date J for auto-irrigator. Used on sub-fields for JF > 1 to insure each sub-field recieves the same quantity of irrigation from the auto-irrigation routines (mm). [WCALL, IWHEAT, WHEAT, =WATBAL] {P}

ALBEDO- Integrated crop and soil albedo - unitless (reflective power). [WHEAT, =SOILNI, SOLT, NTRANS, WATBAL, =CALEO] {C}

ALX - Current Julian date as a radian fraction of 1 year for soil temperature calculations. [=SOLT] {R}

AMOUNT- Used to estimate irrigation water in auto-irrigator (mm) [=WATBAL]

AMT - Temporary value used to hold irrigation water quantity (mm) [R=IPTRT]

AMP - Annual amplitude in annual average temperature. (degrees C) [WCALL, IWHEAT, WHEAT, R=IPSOIL, SOILNI, SOLT, NTRANS] {P}

ANDEM - Crop N demand (kg N/ha). [=NUPTAK] {R}

APTNUP- Vegetative n uptake (kg N/ha)* [=WHEAT, =OPHARV, =PHENOL] {C}

AT - Parameter defining the number of variables in the array restart blocks.

ATOT - Accumulator used to calculate moving average soil surface temperatures. [WHEAT,IWHEAT,=SOILNI, =SOLT, NTRANS] {R}

AW - Available water used in soil temperature calculations (cm). [=SOLT]

AWR - Assimilate area to weight ratio (square cm/g). [=GRO1]

B - Interim variable used in the Gamma function to predict soil temperature. [=SOILNI, =SOLT, =NTRANS] {R}

BD - Bulk density of soil. (g/cm**3) [WCALL, IWHEAT, WHEAT, R=IPSOIL, SOILNI, NTRANS] {P}

BIOMAS- The accumulated dry weight biomass of above ground plant material following seedling emergence. (g/sq.meter) [WHEAT, OPHARV, =PHASE9, PH9, PHENOL, =GROSUB] {R}

C1 - Cosine of the latitude. (radians) [WHEAT, IWHEAT =PROGRI, PH1, PHENOL,WCALL] {P}

CARBO - The daily biomass production. (g/plant) [=GROSUB, GRO1, GRO2, GRO3, GRO4, =GRO5]

CF - Temporary variable used in leaf area reduction calculations. [=GROSUB]
CGPE - Predicted number of grains per ear. [=OPHARV] {R}
CK - Variable which determines the fraction of green leaf area which is reduced by cold temperature. [=COLD] {R}
CLAI - Predicted crop leaf area index at anthesis. [WHEAT, OPHARV, PHENOL] {R}
CN1 - Intermediate quantity used to calculate daily runoff. [=SOILRI]
CN2 - Curve number input used to calculate daily runoff. [WCALL, IWHEAT, WHEAT, IPSOIL, SOILRI] {P}
CNI(L)- Capacity for nitrification index in layer L. This is a zero to unity number indicating the relative capability for nitrification to proceed. (0-1) [WHEAT, =SOILNI, NTRANS, IWHEAT] {C}
CNR - C:N ratio calculated as (kg C in FOM)/(kg N in FOM + kg mineral N). [=NTRANS]
CNRF - Zero to unity C:N ratio factor for decomposition rate. [=NTRANS]
CUMDEP- Cumulative depth of the soil profile. (cm) [IWHEAT, =WHEAT, =IPSOIL, =SOILRI, =SOILNI, SOLT, NTRANS, =PHASE9, =WATBAL, =PH7, PH9, PHENOL]
CUMPH - Accumulated phyllochron intervals and equivalent leaf number on primary tiller. (unitless) [WHEAT, =PHASE9, WATBAL, PH9, PHENOL, =GROSUB, GRO1, GRO2] {C}
CUMVD - Cumulative vernalization days. [WHEAT, =PHASE8, PH1, PH8, PH9, PHENOL, =COLD] {C}
CW - Water soluble carbon content of soil (ppm). [=NTRANS]

D - Variable used for dynamic dimensioning of soil related arrays.
DAY - Current Julian date. [=WHEAT, =IWHEAT, =CJDATE]
DBAR - Average soil water diffusivity used to calculate upward water flow in top layers. [=WATBAL]
DD - Soil temperature damping depth (mm). [=SOLT]
DDAY - Decision Julian date in the DP model. [WCALL, WHEAT]
DEC - Declination of the sun. (radians) [=PH1]
DEF - Interim variable used to ensure soil nitrogen pools remain positive. [=NTRANS]
DEPMAX- Maximum soil depth where soil water content changes (mm) [WCALL, IWHEAT, WHEAT, =IPSOIL, SOILRI, SOILNI, WATBAL] {P}
DEPTH - Depth to the bottom of a layer from the surface (cm). [=SOILNI, =NTRANS]
DF - Day length factor-effect of day length on thermal development units - unitless. [WHEAT, =PHASE9, =PH1, PH9, PHENOL] {C}
DFERT(J)- Depth of incorporation of fertilizer application on Julian date. (cm) [WCALL, IWHEAT, WHEAT, IPNIT2, NTRANS] {P}
DIFF - Temporary value used to compute root zone moisture. (cm) [=WATBAL] RTDEP-CUMDEP
DIFFSW- Available soil water. (Volume fraction) [WHEAT, IWHEAT, SOILRI, SOILNI, NTRANS, WATBAL, PH8, PHENOL, GROSUB, NUPTAK] SW - LL {C}

DLAYR(L)- Depth increment of soil layer L. (cm) [WCALL, IWHEAT, WHEAT, R=IPSWIN, R=IPSOIL, SOILRI, SOILNI, NFLUX, NTRANS, PHASE9, WATBAL, PH7, PH9, PHENOL, GROSUB, NUPTAK] {P}

DLFWT - Change in leaf weight (g/m**2). [=GROSUB]

DLV - Temporary variable used in the determination of day length. [=PH1]

DMINR - Humic fraction decay rate (1/days). [WHEAT, =PROGRI, =SOILNI, NTRANS, WCALL, IWHEAT] {P}

DMOD - Zero to unity dimensionless factor used to decrease to rate of mineralization in soils with chemically protected organic matter. [WCALL, IWHEAT, WHEAT, R=IPSOIL, =SOILNI, NTRANS] {P}

DNG - N demand of potential new growth of tops (g N/plant). [=NUPTAK]

DNRATE- Denitrification rate (kg N/ha/day). [=NTRANS]

DP - Maximum damping depth for the soil layer (mm). [WCALL, IWHEAT,WHEAT, =SOILNI, SOLT, NTRANS] {P}

DRAIN - Drainage rate. (cm/day and mm/day) [=WATBAL]

DROOTN- Daily change in plant root nitrogen content (g N/plant). [=NUPTAK]

DSOIL - Not Used. [IPEXP]

DT - Difference between moving average soil surface temperature and long-term daily average ambient temperature. [=SOLT]

DTN - Change in tiller number. [=GRO1, =GRO2]

DTOPSN- Daily change in plant tops nitrogen content (g N/plant). [NUPTAK]

DTT - Daily thermal time. (degree C days) [IWHEAT, WHEAT, =PROGRI, =PHASE6, =PHASE9, =THTIME, WATBAL, PH1, PH9, PHENOL, GROSUB, GRO2, GRO3, GRO4, GRO5). {C}

DUL(L)- Drained upper limit soil water for soil layer L. (volume fraction) [WCALL, IWHEAT, WHEAT, R=IPSOIL, SOILRI, SOILNI, NTRANS, WATBAL, GROSUB, NUPTAK] {P}

DY - Parameter defining the number of variables in the daily (initialized in the middle of the growing season) real scaler restart blocks.

E - Parameter for the dimension of soil layer related arrays, used for common blocks and local arrays.

EARS - Ear number (ears/sq. m) {MZ}. [CORN, =PHENOL, YIELDS] {R}

EARWT - Ear weight (g/ear) {MZ}. [CORN, =PHASEI, =GROSUB] {C}

EEQ - Equilibrium evaporation used to calculate potential evapotranspiration. (mm/day) [=CALEO]

EFFIRR- Irrigation system efficiency (percent) [IPEXP]

EGFT - Zero to unity index describing the effect of temperature on leaf extension growth. [WHEAT, =GROSUB, GRO1] {C}

ELASP - Elapse time for any given call of CERES (seconds). [WCALL, WHEAT]

ELNC - Environmental limit on nitrification capacity (zero to unity unitless factor). [=NTRANS]

EMAT - Flag used to determining excessively slow grain maturity rates {MZ}. [CORN, =PHASEI, =GROSUB] {C}

EO - Potential evapotranspiration. (mm/day) [WATBAL, =CALEO]

EOS - Potential soil evaporation. (mm/day) [WATBAL, =CALEO] {C}

EP - Actual plant evaporation (transpiration). (mm/day) [=WATBAL]
EP1 - Actual transpiration. (cm/day) [=WATBAL]
ES - Actual soil evaporation. (mm/day) [WHEAT, =WATBAL]
ES1 - Actual soil evaporation. (cm/day) [=WATBAL]
ESW(L)- Extractable soil water content for soil Layer L (the difference between DUL and LL - volume fraction). [WHEAT, =SOILRI, WATBAL, GROSUB, NUPTAK] {P}
ESX - Temporary soil evaporation variable. (mm/day) [=WATBAL]
ET - Actual soil and plant evaporation. (mm/day) [WCALL, WHEAT, =WATBAL] {R}
EXLFW - Temporary holding variable for LFWT. [=GROSUB]

F - Interim variable used to calculate soil temperature. [=SOILNI, =SOLT], {R}
FAC(L)- Conversion factor for PPM N to kg N/ha for Layer L. [WCALL, IWHEAT, WHEAT, =SOILNI, NFLUX, NTRANS, WATBAL, GROSUB, NUPTAK] {P}
FACI - Multiplication factor for calculating required irrigation in the auto-irrigator routine. Used to decrease the frequency of auto-irrigator (1.0 > X > 1.5) [WCALL, WHEAT, WATBAL]
FACN - Multiplication factor for calculating required fertigation in the auto-fertigator routine. Used to decrease the frequency of auto-fertigator (1.0 > X > 1.5) [WCALL, WHEAT, NTRANS]
FACTOR - Relative weighting to distribute crop root residues at the beginning of a simulation. [=SOILNI]
FD - Flag used to indicate if real weather (1) or expected weather (2) should be used in the post decision day plant growth. [WCALL, WHEAT]
FLOW(L)- Volume of water moving from Layer L due to unsaturated flow (cm) positive indicates upward movement and negative value indicates downward movement. [IWHEAT, WHEAT, SOILRI, NFLUX, WATBAL] {C}
FLUX(L)- Water moving downward from Layer L with drainage (cm). [IWHEAT, WHEAT, SOILRI, NFLUX, =WATBAL]
FNH4 - Unitless soil ammonium supply index. [=NUPTAK]
FNO3 - Unitless soil nitrate supply index. [=NUPTAK]
FOM(L)- Fresh organic matter (residue) in Layer L (kg/ha). [IWHEAT, WHEAT, =SOILNI, =NTRANS] {C}
FON(L)- N in fresh organic matter in Layer L (kg N/ha). [IWHEAT, WHEAT, =SOILNI, NTRANS, GROSUB, NUPTAK] {C}
FPOOL (L,J) - Fresh organic matter in Layer L (kg/O.M./ha). If J=1 pool is comprised of carbohydrates, if J=2 pool is comprised of cellulose, and if J=3 pool is comprised of lignin. [WCALL, IWHEAT, WHEAT, =SOILNI, NTRANS] {P}
FR - Unitless value used to distribute crop residue. [=SOILNI]
FT - Temperature factor affecting denitrification rate. [=NTRANS]
FW - Unitless soil moisture factor affecting denitrification rate. [=NTRANS]

G - Parameter defining the dimension for soil moisture states used in the restart blocks.

G1 - Genetic specific constant related to rate of vegetative expansion growth during Stage 1. [=NTRANS] {R}

G2 - Genetic specific constant related to the number of grains produced (kernels/ g STMWT) G2=5+0.35*G2<R>. [WCALL, IWHEAT, WHEAT, IPVAR, =ECHO, PH4, PHENOL] {P}

- {MZ} Maximum kernel number (kernels/pt). [CRCALL, ICORN, CORN, PHENOL, R=IPVAL]

G3 - Genetic coefficient for determining grain fill rate (mg/day) G3=0.65+0.35*G3<R> [WCALL, IWHEAT, WHEAT, R=IPVAR, ECHO, GROSUB, GRO5] {P}

- Potential kernel growth rate (mg/kernel). [CRCALL, ICORN, CORN, GROSUB, R=IPVAL]

G4 - Genetic specific constant for determination of tiller number. it is the weight of a single typical tiller stem (excluding leaves) and ear, at the time the stem and ear stop elongating. (g) G4=0.005+0.35*G4<R> [WCALL, IWHEAT, WHEAT, IPVAR, =ECHO, GROSUB, GRO2, GRO3] {P}

G5 - Genetic specific constant related to winter hardiness - unitless. [WCALL, IWHEAT, WHEAT, =ECHO, PH1, PH9, PHENOL] {P}

G6 - [WCALL, IWHEAT, WHEAT, =ECHO] {P}

GNUP - Grain N content. (kg N/ha) [=OPHARV] {C}

GPLA - Green plant leaf area (sq.cm/plant). [WHEAT, =PHASE2, =PHASE3, =PHASE4, PH2, PH3, PH4, PHENOL, GROSUB, GRO3, GRO4, GRO5] {C}

GPP - Number of grains per plant. [WHEAT, PHASE4, PH1, =PH4, =PH8, PH9 PHENOL, GROSUB, GRO5, =COLD, OPHARV] {C}

GPSM - Grains per square meter. [WHEAT, =OPHARV, =PH4, PHENOL] {R}

GRAINN- Grain n content (g N/plant). [WHEAT, PHASE9, PH9, PHENOL, GROSUB, GRO5, OPHARV] {R}

GRCOM - Gross release of carbon from organic matter decomposition (kg C/ha). [=NTRANS]

GRF - Growth factor for above-ground biomass {MZ} [=GROSUB] {R}

GRNOM - Gross release of N from organic matter decomposition (kg N/ha/day). [=NTRANS]

GRNWT - Weight of grains. (g/pt) [WHEAT, =PHASE4, =PHASE9, PH1, PH4, =PH5, =PH8, PH9, PHENOL, GROSUB, =GRO5, =COLD ,OPHARV] {C}

GROEAR- Ear growth rate (g/ear d) {MZ} [=GROSUB] {R}

GROGRN- Daily growth of the grain. (g) [GROSUB, =GRO5]

GROLF - Daily leaf growth. (g) [WHEAT, =PHASE2, PH2, PHENOL, GROSUB, =GRO1, =GRO2] {R}

GRORT - Daily root growth. (g) [WHEAT, =PHASE9, WATBAL, PH9, PHENOL, GROSUB, =GRO1, =GRO2, =GRO3, =GRO4, =GRO5, NUPTAK] {C}

GROSTM- Daily stem growth. (g) [WHEAT, PHENOL, GROSUB, =PHASE9, PH9, =GRO2, =GRO3, =GRO4, =GRO5] {C}

GRPCTN- Observed grain N% at maturity. [OPHARV]

HDAY - Day of the year of the hottest day (200 <- northern hemisphere, 20 <- southern hemisphere). [WCALL, IWHEAT, WHEAT, =SOILNI, SOLT, NTRANS] {P}

HI - Hardiness index to calculate cold hardening - unitless varies from 0 (no hardening) to 2 (maximum hardening). [IWHEAT, WHEAT, =PROGRI, PH1, PH9, PHENOL, GROSUB, =COLD] {C}

HOLDW - The amount of water a soil layer will hold above its present level, used to calculate downward flow. (cm) [=WATBAL]
HRLT - Day length including civil twilight. (hrs) [=PH1]
HTI - Temporary variable used to compare HI with G5. [=COLD]
HUM(L)- Stable humic fraction material in Layer L (kg/ha). [IWHEAT, WHEAT, SOILNI, NTRANS] {C}

I - Loop variable. [=IPWTH, =IPSWIN, =SOILNI, =GROSUB, =COLD, =WRESET, =SAVSOL, =TRADAT, =FLTRANS, =FBTRANS, ILTRANS]
IANTJD- Observed Julian date of anthesis. [OPHARV]
IC - Loop variable which indicates whether this call of CERES uses real weather (IC=1) or expected weather (IC=2). [WCALL, WHEAT]
ICSDUR- Accumulates days of each growth stage for calculating mean soil water deficit factors and other related items (Days) {MZ}. [CORN, ICORN, =PROGRI, =PHASEI, GROSUB, =WATBAL] {C}
IDONE - Flag use to indicate last decision day and used to turn off all post decision period treatments of water and fertilizer such as auto-irrigation. [WATBAL, NTRANS, WCALL, WHEAT]
IDRSW - An integer containing information about downward flowing soil water, = 0 no downward flow, = 1 downward flow. [IWHEAT, WHEAT, =SOILRI, =WATBAL] {C}
IDURP - Duration of stage 4 of development (days) {MZ}. [ICORN, CORN, =PHASEI, PHENOL, =GROSUB] {R}
IFLAG - Switch variable used to direct control to either the leaching component of the upward flux component of subroutine NFLUX. [NFLUX, =WATBAL, =RESTNS, =SAVOPS, FLTRANS, FBTRANS, ILTRANS]
IFTYPE(J)- Code number for fertilizer type. 0,1,3 ammonium based fertilizers; 2,4 ammonium nitrate fertilizers; 5 nitrate based fertilizers [WCALL, IWHEAT, WHEAT, IPNIT2, NTRANS] {P}
IIRR - Switch variable to indicate type of irrigation (maybe none). 2 => manual irrigation; 3 => stress based auto-irrigator; 5 => threshold based auto-irrigator. [IWHEAT, =WHEAT, IPTRT, IPEXP, WATBAL] {P}
IJUNK - Temporary variable used as a dummy value in integer passing.
INLAYR- Another name use for NLAYR. [WCALL]
IOFF - Switch variable to disable runoff during irrigation. [=WATBAL]
IOUT - Switch variable used in the distribution of organic matter. [=SOILNI]
IPHASE- Flag used to indicate a change in ISTAGE has just occurred {MZ}. [CORN, =PROGRI, =PHENOL] {C}
IRET - Variable to specify an alternate return from subroutine PHENOL when growth stage 6 is reached. [=WHEAT, =PH5, =PHENOL] {R}
ISDATE- Silking date (Julian date) {MZ}. [CORN, =PHENOL, YIELDS] {R}
ISIM - Date which the simulation begins (Julian date). [WCALL, IWHEAT, R=IPEXP] {P}
ISOW - Julian date of sowing. [WCALL, IWHEAT, WHEAT, IPEXP] {P}
IST - Variable to determine number of layers considered in unsaturated flow. [=WATBAL]
ISTAGE- Phenological stage. [IWHEAT, WHEAT, =PROGRI, =PHASE1, =PHASE2, =PHASE3, =PHASE4, =PHASE5, =PHASE6, =PHASE7, =PHASE8, =PHASE9,

WATBAL, CALEO, PH1, PH2, PH3, PH4, PH5, PH7, PH8, PH9, PHENOL, GROSUB, =COLD, NFACTO] {C}
= 1 Emergence to terminal spikelet
= 2 Terminal spikelet to end of vegetative growth
= 3 End of vegetative growth to end of pre-anthesis ear growth
= 4 Pre-anthesis ear growth to beginning of grain fill (anthesis occurs during this phase)
= 5 Beginning of grain fill to physiological maturity
= 6 Physiological maturity to fallow (harvest)
= 7 Fallow to sowing
= 8 Sowing to germination
= 9 Germination to emergence

ISTATE- Candidate soil moisture state passed from the DP model. This value is used to as a pointer to the appropriate array index in the restart routines.

ISWDF - Flag related whether or not there is any moisture deficits in the root system [IWHEAT, WHEAT, =PROGRI, =WATBAL] {C}

ISWNIT- A switch parameter specified as input that determines whether nitrogen calculators are performed. Not used [R=IPEXP]

IT - Parameter defining the number of variables in the integer restart blocks.

ITRTNO- Treatment number [R=OPHARV]

J - Loop variable. [=IPNIT2, =IPSOIL, =NFLUX, =NTRANS]

JANTH - Predicted Julian date of anthesis. [WHEAT, OPHARV, =PH4, PHENOL] {R}

JDATE - Julian date. [WCALL, IWHEAT, WHEAT, R=IPWTH, SOILNI, SOLT, NTRANS, CJDATE, PH1, PH4, PHENOL, OPHARV] {P}

JITEMP- Array used in the restart routines to store integer static values.

JNDAS - Another name for NDAS.

JF - Sub-field number. [=WCALL, WHEAT, =IWHEAT, IPSOIL, GETMAN, (All common block dump routines)]

JP - Loop variable. [=NTRANS]

JPHMA - Predicted Julian date of maturity. [=OPHARV] {P}

K - In NFLUX used for reverse loop variable for upflux calculations and day indicator in moving average soil surface temperature calculations. [=IPWTH, =IPNIT2, =IPTRT, =NFLUX, =SOLT]

KDATE - Julian date used in [IPWTH, IPNIT2, IPTRT]

KEEPIR- [IWHEAT, WHEAT, =PROGRI, =WATBAL] {C}

KOLD(J)- Temporary value holding previous Julian date. Used in error checking for valid Julian date. [=IPWTH]

L - Layer in the soil identified with the sowing depth. [=WRESET, =RESTNS, =SAVSOL, =SAVOPS, =TRADAT, =FTRANS, =ITRANS, =FLTRANS, =FBTRANS, =ILTRANS, =WHEAT, =SOILRI, =NFLUX, =SOLT, =NTRANS, =PHASE9, =WATBAL, =PH7, =NUPTAK]

L0 - Layer in the soil identified with sowing depth {MZ} [CORN, ICORN, =PROGRI, =PHENOL, WATBAL]

L1 - The number of soil layers to the bottom of the root zone. [WHEAT, =PHASE9, =WATBAL, GROSUB, =NUPTAK] {C}

LAI - Leaf area index. [IWHEAT, WHEAT, =PROGRI, =PHASE5, =PHASE9, WATBAL, CALEO, PH2, PH5, PH9, PHENOL, =GROSUB] {C}

LAT - Latitude - degrees (use negative for southern hemisphere). [WCALL, IWHEAT, WHEAT, IPWTH, PROGRI, SOILNI] {P}

LDAY - Last Julian day of the growing season. [WCALL, WHEAT]

LFWT - Leaf weight of all leaves on a plant. (g) [WHEAT, PHASE9, PH1, PH9, PHENOL, =GROSUB, =COLD] {C}

LINE - Character variable used in reading data files to trap errors in data. [=IPWTH, =IPNIT2]

LITEMP- Array used in the restart routines to store integer static values.

LJ - Loop variable use to indicate variable number in the restart routines.

LK - Loop variable use to indicate soil moisture state in the restart routines.LL(L) -Lower limit soil water content for soil Layer L. (volume fraction) [WCALL, IWHEAT, WHEAT, IPSOIL, SOILRI, NTRANS, WATBAL, PH8, PHENOL, GROSUB] {P}

LN - Leaf number of the primary tiller. [WHEAT, PH1, PH9, PHENOL, =GROSUB, GRO1, GRO2, COLD] {C}

M - Temporary value used to hold fertilizer type. [=NTRANS]

MATJD - Observed Julian date of maturity. [R=OPHARV]

MAXIRR- Maximum pumping capacity (mm/day) [WCALL, WHEAT, WATBAL]

MAXLAI- Predicted LAI at silking {MZ}. [CORN, =PHENOL, YIELD]

MDATE - Predicted maturity date (Julian date) {MZ}. [CORN, =PHENOL, YIELDS]

MF - Zero to unity moisture factor for residue decomposition rate. [=NTRANS]

MMI - Minimum moisture level. Used in auto-irrigator. (mm/mm) [WCALL, WHEAT, WATBAL]

MMN - Minimum nitrogen level. Used in auto-fertigator. (kg N/ha) [WCALL, WHEAT, NTRANS]

MU - Loop variable to indicate layer below the current layer. [WHEAT, NFLUX, =WATBAL] {C}

N - Parameter defining the dimension for soil nitrogen states used in the restart blocks.

NCOST - Cost per kilogram of nitrogen fertilizer. ($/kg) [WCALL, WHEAT, NTRANS]

NDAS - Number of days after sowing. [WCALL, WHEAT, =PH1, =PH2, =PH3, =PH4, =PH5, =PH7, =PH8, =PH9, PHENOL] {C}

NDAYS - Number of days period in the DP. [WCALL, CJDATE]

NDEF1 - Zero to unity N deficiency factor for photosynthetic rate. [GROSUB, =NFACTO] {R}

NDEF2 - Zero to unity N deficiency factor for expansion growth. [GROSUB, GRO1, GRO2, GRO3, GRO4, GRO5, =NFACTO] {R}

NDEF3 - Zero to unity N deficiency factor for tiller number. [GROSUB, GRO1, =NFACTO] {R}

NDEF4 - Zero to unity N deficiency factor for grain N determination. [GROSUB, =NFACTO] {R}

NDEM - Plant nitrogen demand (g/plant). [=NUPTAK] {R}

NF - Parameter defining the dimension for the number of sub-fields used in the restart blocks.

NFAC - Zero to unity factor based on actual and critical N concentrations. [=NFACTO]

NFERT - Number of fertilizer applications made. [WCALL, IWHEAT, WHEAT, NTRANS] {P}

NH4(L)- Soil ammonium in Layer L. (PPM) [IWHEAT, WHEAT, IPSWIN, SOILNI, NTRANS, WATBAL, GROSUB, NUPTAK] {C}

NHUM(L)- N associated with the stable humic fraction in Layer I (kg N/ha). [IWHEAT, WHEAT, =SOILNI, =NTRANS] {C}

NIND - Variable to indicate second from bottom layer. [=WATBAL]

NIRR - Number of irrigations. [IWHEAT, =IPTRT]

NLAYR - Number of layers in soil. [WCALL, WRESET, RESTNS, SAVSOL, SAVOPS, TRADAT, FBTRANS, IWHEAT, WHEAT, =IPSOIL, SOILRI, SOILNI, NFLUX, SOLT, NTRANS, PHASE9, WATBAL, PH7, PH9, PHENOL, GROSUB, NUPTAK] {P}

NLEACH-(J,JF) Nitrogen leachate by Julian date and sub-field. [WCALL, =WHEAT]

NNRR - Switch variable to indicate type of fertilization (maybe none). 2 => manual fertigation; 5 => threshold based auto-fertigator. [IWHEAT, =WHEAT, NTRANS] {P}

NNOM - Net N released from all organic sources in a layer (kg N/ha). [=NTRANS]

NO3(L)- Soil nitrate in Layer L. (PPM) [WCALL, WRESET, IWHEAT, WHEAT, IPSWIN, SOILNI, NFLUX, NTRANS, WATBAL, GROSUB, NUPTAK] {C}

NOUT(L)- Nitrate leaching from layer (kg N/ha). [WCALL, WHEAT, NFLUX, WATBAL] {R}

NPOOL - Total plant N available for translocation to grain (g/plant). [=GRO5]

NPOOL1- Tops N available for translocation to grain (g/plant). [=GRO5]

NPOOL2- Root N available for translocation to grain (g/plant). [=GRO5]

NSDR - Plant N supply/demand ratio used to modify grain N content. [=GRO5]

NSINK - Demand for N associated with grain filling (g/plant/day). [=GRO5]

NSTATE- Candidate soil nitrogen state passed from the DP model. This value is used to as a pointer to the appropriate array index in the restart routines.

NUF - Plant N supply/demand ratio used to modify uptake. [=NUPTAK]

NUP(L)- Nitrate N moving from Layer L with unsaturated flow (kg N/ha). [WHEAT, WCALL, =NFLUX, WATBAL] {R}

OBSOL - Long-term annual average solar radiation (Langleys). [=SOILNI]

OBTMN - Long-term annual average minimum temperature. (degrees C) [=SOILNI]

OBTMX - Long-term annual average maximum temperature. (degrees C) [=SOILNI]

OC(L) - Organic carbon in Layer L (%). [IWHEAT, R=IPSOIL, SOILNI] {P}

OLDB - Parameter used in soil temperature calculation. [WCALL, IWHEAT, WHEAT, =SOILNI, SOLT, NTRANS] {P}

OUTN - Nitrate N leaching from a layer (kg N/ha). [=NFLUX]

P1 - Growing degree days (base 8 C) from seedling emergence to end of the juvenile phase {MZ}. [CRCALL, CORN, ICORN, R=IPVAR, PHENOL]

P1D - Genetic specific coefficient that determines sensitivity to day length P1D=0.002*P1D<R>. [WCALL, IWHEAT, WHEAT, IPVAR, =ECHO, PH1, PHENOL] {P}

P1V - Genetic specific coefficient that determines sensitivity to vernalization. [WCALL, IWHEAT, WHEAT, R=IPVAR, =ECHO, PH1, PH9, PHENOL, GROSUB, COLD, NFACTO] {P}

P2 - Thermal time between terminal spikelet and end of vegetative growth, equal to 3 phyllochron intervals. (degree C days) [WCALL, IWHEAT, WHEAT, =PROGRI, PHASE2, PH1, PH2, PHENOL] {P}.

- {MZ} Photoperiod sensitivity coefficient (1/hr). [CRCALL, CORN, ICORN, R=IPVAR, PHENOL]

P3 - Thermal time between terminal spikelet and end of pre-anthesis ear elongation growth, equal to 2 phyllochron intervals. (degree C days) [WCALL, IWHEAT, WHEAT, =PROGRI, PHASE3, PH2, PHENOL] {P}

- {MZ} Cumulative growing degree days (base 8 C) required to complete stage 3. [CRCALL, CORN, ICORN, =PHASEI, PHENOL]

P4 - Thermal time between end of pre-anthesis ear growth and beginning of grain fill. (degree C days) [WCALL, IWHEAT, WHEAT, =PROGRI, PHASE4, PH4, PHENOL] {P}

P5 - Thermal time between beginning of grain fill and maturity. (degree C days) P5=430+20*P5<R>. [WCALL, IWHEAT, WHEAT, IPVAR, =ECHO, PH5, PHENOL, GROSUB, GRO5] {P}

- {MZ} Cumulative growing degree days (base 8 C) from silking to physiological maturity. [CRCALL, CORN, ICORN, R=IPVAR, PHENOL]

P9 - Thermal time from germination to seedling emergence. (degree C days) [WCALL, IWHEAT, WHEAT, =PROGRI, PHASE9, PH9, PHENOL] {P}

- {MZ} Cumulative growing degree days (base 8 C) germination to seedling emergence. [CRCALL, CORN, ICORN, =PHASEI, PHENOL]

PA - Parameter defining the number of variables in the soil array restart blocks.

PAR - Daily photosynthetically active radiation, calculated as half the solar radiation. (MJ/square meter) [=GROSUB]

PB - Intermediate quantity for calculating daily runoff. (cm) [=WATBAL]

PBIOMS- Predicted crop biomass at maturity (kg/ha). [=OPHARV]

PCARB - Daily amount of carbon fixed. (g) [=GROSUB]

PDWI - Potential increment of new shoot growth (g/plant). [=GROSUB, =NUPTAK]

PESW - Potentially extractable soil water in the profile equal to total soil water in the profile equal to total soil water (TSW) minus total water at the lower limit (TLL). (cm) [IWHEAT, WHEAT, =SOILRI, SOILNI, SOLT, NTRANS, =WATBAL] {C}

PGNP - Predicted gain N% at maturity. [=OPHARV] {R}

PGRNWT- Predicted weight of individual grains (mg). [=OPHARV] {R}

PGRORT- Potential increment of new root growth (g/plant). [=GROSUB, NUPTAK] {R}

PH(L) - Soil pH in Layer L. [WCALL, IWHEAT, WHEAT, R=IPSWIN, SOILNI] {P}

PHFAC3- Not used. [IPSOIL]

PHINT - The phyllochron interval-the interval in thermal time between successive leaf and tiller appearances. (degree days) [WCALL, IWHEAT, WHEAT, IPEXP, PROGRI, PHASE2, PH1, PHENOL, GROSUB, WATBAL, GRO2, GRO3] {P}

PHN(L)- Zero to unity factor describing the effect of soil pH or nitrification rate on Layer L. [WCALL, IWHEAT, WHEAT, SOILNI, NTRANS] {P}

PINF - The precipitation that infiltrates into the soil. (cm/day) [=WATBAL]

PLA - Plant leaf area. (sq. cm.) [WHEAT, PHASE2, PHASE3, PHASE4, PHASE9, PH1, PH2, PH3, PH4, PH9, PHENOL, GROSUB, =GRO1, =GRO2, COLD] {C}

PLAG - The rate of expansion of leaf area on one plant. (sq.cm/day) [=GRO1]

PLAGMS- Plant leaf area growth rate on the main stem. (sq.cm/day) [=GRO1]

PLALR - Plant leaf area loss rate. (sq.cm/plant/day) [=GROSUB, =GRO1, =GRO2, =GRO3, =GRO4, =GRO5]

PLANTS- Number of plants per square meter. [IWHEAT, WHEAT, IPEXP, PROGRI, PHASE1, PHASE9, WATBAL, PH1, =PH4, =PH5, =PH8, PH9, PHENOL, GROSUB, GRO1, GRO2, =COLD, NUPTAK, OPHARV] {C}

PLN - Price of fertigation labor ($/day). [WCALL, WHEAT, NTRANS]

PLSC(LN)- Cumulative leaf area at the time when each main stem leaf reaches full size. LN is the leaf number on the main stem. [WHEAT, WRESET, RESTNS, SAVSOL, =PHASE9, PH1, PH9, PHENOL, GROSUB, GRO1, GRO2, COLD] {C}

PN - Price of nitrogen fertilizer ($/kg). [WCALL, WHEAT, NTRANS]

PNUP - Plant N uptake from layer (kg N/ha). [=NUPTAK]

PRECIP- Temporary variable used for rain. (mm) [=WATBAL]

PRFT - Photosynthetic reduction factor for low and high temperatures. [=GROSUB]

PS - Parameter defining the number of variables in the real scaler restart blocks.

PSKER - Average rate of photosynthesis during stage 4 {MZ}. [=PHENOL]

PSW - 1) Stage 1 specific leaf weight. (mg/sq.cm) 2) Stages 2-5 average tiller stem plus ear weight divided by the potential stem plus ear weight, in both cases for printing purposes. [=GROSUB]

PTEMP1- Equal to 35.4*0.5 (17.7) [=WATBAL]

PTEMP2- Equal to 0.2/0.04 (5.0) in NTRANS, 0.22*95.0 (20.9) in WATBAL/ [=NTRANS, =WATBAL]

PTEMP3- Equal to -0.693/25.0 (0.02772). [=NTRANS]

PTEMP5- Equal to 0.58*0.0031 (0.001798). [=NTRANS]

PTF - Fraction of photosynthesis partitioned to above ground plant parts. [WHEAT, =GROSUB, =GRO1, =GRO2, =GRO3, =GRO4, =GRO5, NUPTAK] {R}

PW - Price of water per millimeter. ($ mm/ha) [WCALL, WHEAT, WATBAL]

QATEMP- Real array used in the restart routines.
QDAILY- Real array used in the restart routines.
QTEMP - Real array used in the restart routines.
QTMA - Real array used in the restart routines.

R2 - Intermediate quantity used to calculate daily runoff. [=WATBAL]
RAIN(J)- Precipitation. (mm/day) [WCALL, IWHEAT, WHEAT, IPWTH, WATBAL, CALEO, =CALSNW] {P}
RANC - Root actual nitrogen concentration (g N/g root dry weight). [IWHEAT, WHEAT, =PROGRI, =PHASE9, PH9, PHENOL, GROSUB, =GRO5, NUPTAK] {C}
RATEIN- Rate of floral induction (sums to 1.0) {MZ}. [=PHENOL]
RCN - C:N ratio of root residue of previous crop. [=SOILNI]
RCNP - Root critical nitrogen concentration (g N/g root dry weight). [WHEAT, GROSUB, GRO5, NUPTAK, =NFACTO] {R}
RDECR(J)- The maximum rate constant for decay of residue components (1/days). [=NTRANS] [3]
RFAC - Interim variable describing the effects of root length density on potential N uptake from a layer. [=NUPTAK]
RGFILL- Rate of grain fill. ([0,1] index) [=GRO5]
RGNFIL- Rate of daily grain N accumulation. (micrograms/grain/day) [=GRO5]
RHMIN - N mineralized from humus in a layer (kg N/ha). [=NTRANS]
RKK - Used in uniform random number generator. [RANG]
RLDF(L)- A root length density factor for soil layer L used to calculate new root growth distribution. (unitless) [=WATBAL]
RLNEW - New root length to be added to the total root system length - cm root per sq.cm.ground. [=WATBAL]
RLV(L)- Root length per unit soil volume for soil Layer L. (cm/cm**3) [WHEAT, WRESET, =PHASE9, WATBAL, =PH9, PHENOL, GROSUB, NUPTAK] {C}
RLVF - Factor constrain root growth at depth (unitless). [=WATBAL]
RMNC - Root minimum nitrogen concentration (g N/g root dry weight). [=GRO5]
RNAC - Immobilization rate of N associated with the decay of residues (kg N/ha/day). [=NTRANS]
RNAR - Used in uniform random number generator. [RANG]
RNDEM - Plant root demand for nitrogen (g/plant). [=NUPTAK]
RNFAC(L)- Zero to unity factor describing mineral N availability effect on root growth in Layer L. [=WATBAL]
RNH4U(L)- Potential ammonium uptake from Layer L (kg N/ha). [NUPTAK]
RNKG - Amount of N added to soil profile as root residue kg N/ha. [=SOILNI]
RNLOSS- Loss of N from the plant via root exudation in one layer (g N/plant). [=NUPTAK]
RNLF - Intermediate factor used to calculate distribution of new root growth in the soil - unitless value between 0 and 1. [=WATBAL]
RNO3U(L)- Potential nitrate uptake from Layer L (kg N/ha). [=NUPTAK]
RNTRF - Amount of ammonium nitrified in a layer (kg N/ha/day). [=NTRANS]

ROOT - Mass of root residue of previous crop (kg/ha). [WCALL, IWHEAT, WHEAT, IPNIT1, SOILNI] {P}

ROOTN - Plant root N content (g N/plant). [IWHEAT, WHEAT, =PROGRI, =PHASE9, PH9, PHENOL, GROSUB, =GRO5, =NUPTAK] {C}

ROWSPC- Row spacing [R=IPEXP]

RP2 - Temporary variable used in nitrification calculations. [=NTRANS]

RTDEP - Depth of rooting. (cm) [WCALL, IWHEAT, WHEAT, =SOILRI, =PHASE7, PHASE9, =WATBAL, PH7, =PH9, PHENOL] {C}

RTSW - Weight of an average stem plus ear relative to a potential stem plus ear. [=GRO2, =GRO3]

RTWT - Root weight. (g/sq. meter) [WHEAT, =PHASE9, PH1, PH9, PHENOL, =GROSUB, GRO5, =COLD, =COLD, NUPTAK] {C}

RUNOFF- Daily runoff. (cm) [=WATBAL]

RWATER- Required water, used by the auto-irrigation routine [=WATBAL]

RWU(L)- Root water uptake from soil Layer L. (cm) [IWHEAT, WHEAT, SOILRI, PHASE9, WATBAL, PH9, PHENOL]{C}

RWUMX - Maximum daily root water uptake per unit root length. (cm**3/cm root) [WCALL, IWHEAT, WHEAT, IPSOIL, =SOILRI, WATBAL] {P}

S1 - Sine of latitude. [WCALL, IWHEAT, WHEAT, =PROGRI, PH1, PHENOL] {P}

SA - Total available soil moisture in root zone (mm). [WCALL]

SALB - Bare soil albedo - unitless (reflective power). [WCALL, IWHEAT, WHEAT, IPSOIL, SOILNI, WATBAL, CALEO] {P}

SANC - Supply of ammonium effect on nitrification capacity. (0-1) [=NTRANS]

SARNC - Supply of ammonium effect on the reduction of nitrification capacity (zero to unity, unitless). [=NTRANS]

SAT(L)- Field saturated soil water content in Layer L. (cm volume fraction) [WCALL, IWHEAT, WHEAT, R=IPSOIL, SOILNI, NTRANS, WATBAL, GROSUB, NUPTAK] {P}

SCN - C:N ratio of surface residue of previous crop. (kg C/kg N) [IWHEAT, WCALL, WHEAT, R=IPNIT1, SOILNI] {P}

SDEP - Depth of incorporation of residue (CM). [WCALL, IWHEAT, WHEAT, IPNIT1, SOILNI] {P}

SDEPTH- Depth of seeding in soil. (cm) [WCALL, IWHEAT, WHEAT, R=IPEXP, PROGRI, PHASE7, PH7, PHENOL] {P}

SEEDRV- Reserve carbohydrates in seed for use by plant in seedling stage. (g) [WHEAT, =PHASE9, PH1, PH9, PHENOL, =GROSUB, =GRO1, =COLD] {C}

SENLA - Area of leaf that senesces from a tiller on a given day. (sq cm) [WHEAT, PHASE2, PHASE3, PHASE4, =PHASE9, PH1, PH2, PH3, PH4, PH9, PHENOL, =GROSUB, GRO1, GRO2, =COLD] {C}

SENTIL- Number of senescenced tillers (tillers/m2). [IWHEAT, WHEAT, =PROGRI, GROSUB, =GRO1, =GRO2] {C}

SFAC - Drought stress factor for grain nitrogen concentration (unitless) {MZ}. [=GROSUB]

SIND - Summed photoperiod induction rate ([0,1] index) {MZ}. [CORN, =PHENOL, =PHASEI]

SKERWT- Weight of a single kernel. (g) [=OPHARV]

SKK - Used in uniform random number generator. [RANG]

SLAN - Total normal leaf senescence since emergence (sq. cm/pt) {MZ}. [=GROSUB]

SLFC - Leaf senescence factor due to competition for light ([0,1] index) {MZ}. [=GROSUB]

SLFT - Leaf senescence due to low temperature ([0,1] index) {MZ}. [=GROSUB]

SLFW - Leaf senescence due to water stress ([0,1] index) {MZ}. [=GROSUB]

SMDFR - Soil moisture deficit factor affecting N uptake. [=NUPTAK]

SMIN - Conversion factor for kg N/ha to PPM N for Layer L. Used as interim variable to prevent soil N pools from becoming less than 1 ppm. [=NFLUX, =NTRANS, =NUPTAK]

SMX - Intermediate quantity used to calculate daily runoff. [WCALL, IWHEAT, WHEAT, =SOILRI, WATBAL] {P}

SN1 - Temporary variable to describe N stress effect on tiller reduction. [=GROSUB, =GRO1]

SNH4(L)- Soil ammonium in Layer L (kg N/ha). [IWHEAT, WHEAT, SOILNI, NTRANS, GROSUB, NUPTAK] {C}

SNO3(L)- Soil nitrate in Layer L (kg N/ha). [IWHEAT, WHEAT, SOILNI, NFLUX,NTRANS, WATBAL, GROSUB, NUPTAK] {C}

SNOW(J)- Precipitation in the form of snowpack total on Julian day J. (mm) [WCALL, IWHEAT, WHEAT, IPWTH, CALTHM, WATBAL, CALEO, PH1, PH9, PHENOL, COLD, =CALSNW] {P}

SNOMLT- Daily rate of snow melting (mm). [=CALSNW]

SOILC - Soil carbon content (kg C/ha). [=NTRANS]

SOLRAD- Solar radiation. (Read in MJ/sq. m/day then converted to LY/day) [WCALL, IWHEAT, WHEAT, IPWTH, SOILNI, SOLT, NTRANS, WATBAL, CALEO, GROSUB] {P}

ST(L) - Soil temperature in Layer L (degrees C). [IWHEAT, WHEAT, SOILNI, SOLT, NTRANS] {C}

STMWT - Stem weight of an average tiller after terminal spikelet. (g) [WHEAT, PHASE3, =PHASE9, PH3, PH4, PH9, PHENOL, =GROSUB, GRO2, GRO3, GRO5] {C}

STOVN - Stover nitrogen content (g N/pt) {MZ}. [ICORN, CORN, =PROGRI, =PHASEI, =GROSUB, =NUPTAK]

STOVWT- Stover weight (g/pt) {MZ}. [ICORN, CORN, =PROGRI, =PHASEI, =GROSUB, =NUPTAK]

STOVER- Predicted straw biomass at maturity (kg/ha).[=OPHARV] {R}

STRAW - Mass of surface residue of previous crop (kg/ha). [WCALL, IWHEAT, WHEAT, IPNIT1, SOILNI] {P}

SUM - Intermediate quantity used to calculate runoff. [=WATBAL]

SUMDTT- The sum of daily thermal time (DTT) for various phenological stages - degree days. [IWHEAT, WHEAT, =PROGRI, =PHASE1, =PHASE2, =PHASE3, =PHASE4, =PHASE8, PHASE9, =THTIME, PH1, PH2, PH3, PH4, PH5, PH8, PH9, PHENOL, PHENOL, GROSUB, GRO2, GRO5] {C}

SUMES1- Accumulative soil evaporation in stage 1. (mm) [IWHEAT, WHEAT, =SOILRI, =WATBAL] {C}

SUMES2- Accumulative soil evaporation in stage 2. (mm) [IWHEAT, WHEAT, =SOILRI, =WATBAL] {C}

SUMP - Accumulator for carbohydrate production in stage 4 (g/pt) {MZ}. [CORN, =PHASEI, PHENOL, =GROSUB] {C}

SW(L) - Actual soil water content in Layer L. (volume fraction) [IWHEAT, WHEAT, IPSWIN, SOILRI, SOILNI, NFLUX, NTRANS, WATBAL, PH8, PHENOL, GROSUB, NUPTAK] {C}

SWCON - Constant for calculating drainage rate. [WCALL, IWHEAT, WHEAT, IPSOIL, WATBAL] {P}

SWCON1- Not used. [R=IPSOIL]

SWCON2- Not used. [R=IPSOIL]

SWCON3- Not used. [R=IPSOIL]

SWDF - Soil water deficit factor for Layer L used to calculate root growth and water uptake - unitless value between 0 and 1. [=WATBAL]

SWDF1 - Soil water deficit factor used to calculate the reduction in the less sensitive process of photosynthesis and transpiration - unitless value between 0 and 1. [IWHEAT, WHEAT, =PROGRI, =WATBAL, GROSUB, GRO2, GRO3, GRO4] {C}

SWDF2 - Soil water deficit factor used to calculate the reduction in more sensitive process of leaf growth and tiller formation - unitless value between 0 and 1. [IWHEAT, WHEAT, =PROGRI, =WATBAL, GROSUB, GRO1] {C}

SWEF - Soil water evaporation fraction. The fraction of the lower limit water content that determines the lowest possible value the top soil layer water content can become by soil evaporation. The value depends on the depth of the first layer. [WCALL, IWHEAT, WHEAT, =SOILRI, WATBAL] {P}

SWINIT(L)- Default initial water content for each soil layer. (cm/cm) [IWHEAT, R=IPSWIN, IPSOIL] {P}

SWMIN - Minimum stem weight of a plant after anthesis, used to calculate amount of reserves that can be used to fill grain. (g) [WHEAT, =PHASE3, PH3, PHENOL, GROSUB, GRO5] {C}

SWR - Unitless value used to calculate initial value of SUMES2. [=SOILRI]

SWSD - An approximation of the soil water content above the lower limit at the seeding depth used to determine whether the seed can germinate (volume fraction). [=PH8]

SWX(L)- Temporary array for soil water in layers (volume fraction). [WATBAL] {R}

T - Time after 2nd stage soil evaporation is reached. (days) [IWHEAT, WHEAT, =SOILRI, =WATBAL] {C}

TA - [=SOLT]

TAFERT- Temporary value holding fertilization treatment for manual fertilization. [=GETMAN, WHEAT]

TAIRR - Temporary value holding irrigation treatment for manual irrigation. [=GETMAN, WHEAT]

TANC - Tops actual nitrogen concentration (g N/g dry wt). [IWHEAT, WHEAT, =PROGRI, PHASE4, =PHASE9, PH4, PH9, PHENOL, GROSUB, =NUPTAK, =NFACTO] {C}

TAV - Annual average ambient temperature (degrees C). [WCALL, IWHEAT, WHEAT, IPSOIL, =SOILNI, SOLT, NTRANS] {P}

TBASE - Base temperature where development rate is zero calculate winter dormancy - degrees. [IWHEAT, WHEAT, =PROGRI, =PHASE4, =PHASE8, =PHASE9, THTIME, PH1, PH4, PH8, PH9, PHENOL, COLD] {C}

TBD - Accumulator used to calculate average bulk density. [=SOILNI]

TC1 - Tiller competition factor 1. [=GRO1]

TC2 - Tiller competition factor 2. [=GRO1]

TCNP - Tops critical N concentration (g N/g dry weight). [WHEAT, GROSUB, NUPTAK, =NFACTO] {R}

TCOR - A correction used to calculate thermal time when the minimum temperature falls below the base temperature degree C day. [=THTIME]

TD - Weighted temperature used to calculate potential evaporation. (degrees) [WATBAL, =CALEO]

TDR - Total seasonal deep percolation of water (mm). [WCALL]

TDU - Thermal development units. (degree C days) [WHEAT, =PHASE9, =PH1, PH9, PHENOL, GROSUB, GRO1] {C}

TEMKIL- Loss of tillers due to cold temperature. [=COLD]

TEMP1 - Temporary variable. [=SOILNI, =SOLT, =NTRANS, =GROSUB, =COLD, =NUPTAK]

TEMP2 - 0.4/SCN [=SOILNI]

TEMP3 - PTT*PTEMP2 [=WATBAL]

TEMP4 - TF*MF [=NTRANS]

TEMP6 - G1*X [=NTRANS]

TEMPCN(J)- Minimum daily temperature estimate for plant crown. (degrees C) [WCALL, IWHEAT, WHEAT, IPWTH, THTIME, =CALTHM, PHENOL] {P}

TEMPCR(J)- Mean daily temperature estimate for plant crown. (degrees C) [WCALL, IWHEAT, WHEAT, IPWTH, THTIME, PH1, PH9, PHENOL, COLD, =CALTHM] {P}

TEMPCX(J)- Maximum daily temperature estimate for plant crown. (degrees C) [WCALL, IWHEAT, WHEAT, IPWTH, THTIME, =CALTHM, PHENOL] {P}

TEMPM - Mean temperature. (degrees C) [=GROSUB, GRO5]

TEMPMN(J)- Minimum temperature. (degrees C) [WCALL, IWHEAT, WHEAT, R=IPWTH, CALTHM, NTRANS, WATBAL, CALEO, PH1, PH9, PHENOL, GROSUB, GRO5, COLD] {P}

TEMPMX(J)- Maximum temperature. (degrees C) [WCALL, IWHEAT, WHEAT, R=IPWTH, CALTHM, SOILNI, SOLT, NTRANS, WATBAL, CALEO, PH1, PH9, PHENOL, GROSUB, GRO5, COLD, CALSNW] {P}

TESW - Total extractable soil water in the soil profile (mm). [=WCALL, IWHEAT, =SOILRI]

TF - Temperature factor for nitrification on mineralization. [=NTRANS]

TFY(L)- Yesterday's temperature factor for nitrification in Layer L. [IWHEAT, WHEAT, SOILNI, NTRANS] {C}

THET1 - The soil water content above the lower limit (LL) for the upper layer of soil for water flow from a lower layer-volume fraction. [=WATBAL]

THET2 - The soil water content above the lower limit (LL) for the lower layer of soil for water flow into an upper layer-volume fraction. [=WATBAL]

THETAC- Not Used. [R=IPEXP]

TI - Fraction of a phyllochron interval which occurred as a fraction of today's daily thermal time. [WHEAT, =GROSUB, GRO1, GRO2] {C}
TILN - Number of tillers per plant. [IWHEAT, WHEAT, =PROGRI, =PHASE1, =PHASE9, PH1, PH9, PHENOL, GROSUB, =GRO1, =GRO2, =GRO3, =COLD] {C}
TILNO - Total number of leaves the plant produces {MZ}. [CORN, =PHASEI, GROSUB]
TILSW - Potential weight of a single tiller stem plus ear, used to calculate final tiller numbers. (g/tiller) [WHEAT, =PHASE9, PH9, PHENOL, GROSUB, =GRO2, =GRO3] {C}
TLL - Total soil water in the soil profile at the lower limit. (cm) [WCALL, IWHEAT, WHEAT, =SOILRI, WATBAL] {P}
TMA(K)- 5 day moving average soil surface temperature for day K. [WHEAT, IWHEAT, SOILNI, SOLT, NTRANS, RESTNS, SAVSOL, WRESET] {C}
TMFAC(I)- Eight 3-hourly correction factors for air temperature {MZ}. [CRCALL, ICORN, CORN, =PROGRI, PHENOL, GROSUB]
TMN - Mean temperature (degrees C). [=SOILNI, SOLT, =NTRANS] {R}
TMNC - Plant tops minimum nitrogen concentration (g N/g dry weight). [GROSUB, WHEAT, PHASE4, PH4, PHENOL, =NFACTO] {C}
TNDEM - Plant tops demand for nitrogen (g N/plant). [=NUPTAK]
TNOLD - Previous day's tiller number. [=GRO1, =GRO2]
TNN - Total seasonal nitrogen leachate (kg). [WHEAT]
TNOX - Daily total denitrification (kg). [=NTRANS]
TNUP - Total N uptake from the profile on 1 day (kg N/ha). [=NUPTAK]
TOPSN - N contained in plant tops excluding grain (g N/plant). [IWHEAT, WHEAT, =PROGRI, =PHASE9, PH9, PHENOL, GROSUB, =GRO5, =NUPTAK]
TOPWT - Weight of plant tops excluding grain. (g) [WHEAT, =PHASE9, PH9, PHENOL, =GROSUB, GRO5, NUPTAK] {R}
TOTN - Total mineral N in a soil layer. (kg N/ha) [=NTRANS, =WATBAL]
TOTNUP- Predicted total shoot N uptake at maturity (kg N/ha)*[WHEAT, =OPHARV, PHENOL]
TP - Parameter defining the number of variables in the real scaler initial restart blocks.
TPSM - Tillers per square meter. [WHEAT, =PHASE9, PH9, PHENOL, =GROSUB, GRO1, OPHARV] {C}
TRLDF - An intermediate calculation used to calculate distribution of new root growth in soil. Sum of RLDF for all soil layers. (unitless) [=WATBAL]
TRLV - Total root length density variable. [=NUPTAK]
TRNLOS- Total plant N lost by root system. (g N/plant) [=NUPTAK]
TRNS - [=NUPTAK]
TRNU - Total potential root nitrogen uptake from the soil (kg N/ha). [=NUPTAK]
TRLL - Total root soil wilting point (-15 bars). (cm) [IWHEAT, WHEAT, =PROGRI, =WATBAL] {C}
TRSAT - Total root soil saturation point (-0.5 bars). (cm) [IWHEAT, WHEAT, =PROGRI, =WATBAL] {C}
TRSW - Total root soil moisture. (cm) [IWHEAT, WHEAT, =PROGRI, =WATBAL] {C}

TRWU - Total potential daily root water uptake from the soil-plant system. (cm) [WHEAT, =WATBAL] {C}

TSAT - Total soil water in profile at filed saturation. (cm) [IWHEAT, =IPSOIL]

TSW - Total soil water in the profile. (cm) [IWHEAT, WHEAT, =SOILRI, =WATBAL] {R}

TTMP - 3-hour mean air temperature (degrees C) {MZ}. [=PHENOL, GROSUB]

U - Upper limit of stage 1 soil evaporation. (mm) [WCALL, IWHEAT, WHEAT, IPSOIL, =SOILRI, WATBAL]

UNH4 - Plant uptake of ammonium from a layer (kg N/ha). [=NUPTAK]

UNO3 - Plant uptake of nitrate from a layer (kg N/ha). [=NUPTAK]

UP1 - Interim variable used to prevent soil N pools from becoming less than 1 ppm. [=NUPTAK]

VANC - Plant vegetative actual N concentration (g N/plant). [WHEAT, =PHASE4, PH4, PHENOL, GROSUB, =GRO5, NFACTO] {C}

VD - Vernalization for a day - unitless value between 0 and 1. [=COLD]

VD1 - Intermediate calculation used to calculate VD. [=COLD]

VD2 - Intermediate calculation used to calculate VD. [=COLD]

VF - Vernalization factor - effect of vernalization on thermal development units (TDU). (unitless) [WHEAT, =PHASE8, PH1, PH8, PH9, PHENOL, =COLD] {C}

VMNC - Plant vegetative minimum N concentration (g N/g dry weight). [WHEAT, =PHASE4, PH4, PHENOL, GROSUB, GRO5, =NFACTO] {C}

W1 - Temporary variable to describe moisture stress effect on tiller reduction. [=GROSUB, =GRO1]

WAT1 - Temporary variable used in upward flow calculations. [=WATBAL]

WATEMP- Real array used in the restart routines.

WC - Moisture content affect on soil temperature. [=SOLT]

WCOST - Total expenditures on irrigation water and irrigation labor ($). [WCALL, IWHEAT, WHEAT, =PROGRI, =WATBAL] {C}

WCOUNT- Number of irrigation days [WCALL, IWHEAT, =PROGRI, WHEAT, =WATBAL] {C}

WDAILY- Real array used in the restart routines.

WF(L) - Weighting factor for soil depth L to determining runoff amounts. (unitless) [WCALL, IWHEAT, WHEAT, SOILRI, WATBAL] {P}

WFD - Today's water factor for nitrification. (0-1)[=NTRANS]

WFIRST- Flag used to indicate the type of call in terms of where to start growth. -1 - first call, start simulation from ISIM, and read data from file; 0 - start simulation from day ISIM; 1 - start simulation from DAY using the data associated with ISTATE and NSTATE; 2 - new decision day so transfer temporary solution block to starting point blocks, and start simulation from DAY using the data associated with ISTATE and NSTATE [=WCALL]

WFY(L)- Yesterday's water factor for nitrification in Layer L. (0-1) [IWHEAT, WHEAT, SOILNI, NTRANS] {C}

WINF -	Amount of water infiltrating into the soil as used in the soil evaporation routine. (mm) [=WATBAL]
WLEACH-(J,JF)	Water leachate by Julian date and sub-field. (mm) [WCALL, =WHEAT]
WR(L) -	Weighting factor for soil depth L to determine new root growth distribution. (0-1) [WCALL, IWHEAT, WHEAT, IPSOIL, WATBAL] {P}
WRN(L)-	Temporary variable used to calculate distribution of residues in the soil. [SOILNI]
WSUM -	Variable used to calculate distribution of organic residues. [=SOILNI]
WTEMP -	Real array used in the restart routines.
WTMA -	Real array used in the restart routines.
WUF -	An intermediate factor used to calculate root water uptake. (0-1) [=WATBAL] {R}
WW -	Soil porosity. [WCALL, IWHEAT, WHEAT, =SOILNI, SOLT, NTRANS] {P}
WX -	Intermediate value used to calculate runoff. [=SOILRI]
X -	FPOOL(L,JP)/FOM(L) [=NTRANS]
XAPTNP-	Observed total straw N uptake at maturity (kg N/ha). [R=OPHARV]
XBIOM -	Observed biomass at maturity (kg/ha). [R=OPHARV]
XGNUP -	Observed grain N uptake (kg grain N/ha). [R=OPHARV]
XGPE -	Observed number of grains per ear. [R=OPHARV]
XGPSM -	Observed number of grains per square meter.[R=OPHARV]
XGRWT -	Observed grain weight [R=OPHARV]
XI -	Non-integer Julian date. [=SOLT]
XL -	Temporary variables used to determine soil. [=NTRANS]
XL2 -	Moisture effect on mineralization rate. [=NTRANS]
XLAI -	Observe maximum leaf area index. [R=OPHARV]
XN -	number of the oldest expanding leaf {MZ}. [CORN, =PHASEI, =GROSUB]
XNIT -	Number of leaves at tassel initiation {MZ}. [CORN, =PHASEI, =GROSUB]
XPLANT-	Temporary variable to transfer the value of the numbers of plants/sq.meter. [WCALL, IWHEAT, WHEAT, =PROGRI, PH5, PHENOL] {P}
XS -	Represents snow ($\leq$ 15mm) in equation to modify DTT. [=CALTHM]
XSTAGE-	Non-integer growth stage indicator ranging from zero to six. [WHEAT =PH1, =PH2, =PH3, =PH4, =PH5, =PH9, PHENOL, GROSUB, NUPTAK, NFACTO] {R}
XSTRAW-	Observe biomass of straw at harvest (kg/ha). [R=OPHARV]
XT -	Temperature effect on nitrification capacity. [=NTRANS]
XTOTNP-	Observe total shoot N uptake at maturity (kg N/ha). [OPHARV]
XW -	Moisture effect on nitrification capacity. [=NTRANS]
XX -	Intermediate value used to calculate runoff. [=SOILRI]
XYIELD-	Observed grain yield (kg/ha). [R=OPHARV]
YIELD -	Yield. (kg/ha) [WCALL, WHEAT, OPHARV, =PH5, PHENOL] {R}
YSTAGE-	[=NFACTO]

Z(L) -	Depth to midpoint of soil layer L (mm). [WCALL, IWHEAT, WHEAT, SOILNI, SOLT, NTRANS] {P}
ZD -	Variable used in the calculation of soil temperature. [=SOLT]
ZEFFIRR-	Irrigation system efficiency. (percent) [WHEAT, WCALL]
ZET -	Non common block version of ET on DDAY. (mm) [=WHEAT]
ZNCOST-	Non common block version of nitrogen cost. ($/kg) [WCALL]
ZRTDEP-	Non common block version of root depth on DDAY (m). [=WHEAT]
ZRTN -	Root total nitrogen NH4 + NO3. (kg N/ha) [WCALL, WHEAT, =SAVSTT]
ZS2 -	Square of Zadoks' growth stage used in critical concentration calculations. [=NFACTO]
ZSA -	Root zone available soil moisture on Julian date DDAY. (mm) [=WHEAT]
ZSTAGE-	Zadoks' growth stage. [=NFACTO]
ZTRSW -	Total root soil moisture. Used as a temporary value used in the auto-irrigator. (cm) [=WATBAL]
ZWCOST-	Non common block version of irrigation water cost. ($ ha/mm) [WCALL]
ZWFIRST-	Another name use for WFIRST.

Glossary for Variables Used in the CERES Potato Model

A1 - Genetic coefficient used in calculating tempfac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

A2 - Genetic coefficient used in calculating tempfac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

A3 - Genetic coefficient used in calculating areafac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

A4 - Genetic coefficient used in calculating solfac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

A5 - Genetic coefficient used in calculating ampfac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

A6 - Genetic coefficient used in calculating ampfac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

A7 - Genetic coefficient used in calculating dlfac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

A8 - Genetic coefficient used in calculating dlfac. [PTCALL, IPOT, POTATO, PHENOL, R=IPVAL, MENU, DUMP, LOAD]

AMPFAC- Factor expressing effect of daily temperature range on tuber induction. [=PHENOL]

AREAFAC- Factor expressing effect of plant leaf area on tuber induction. [=PHENOL]

AVAILN- Nitrogen available for new growth, from root uptake and from the seed piece. [=GROSUB, =PRTTNVG, =PARTTN]

BUFROOT- Nitrogen in the roots above the minimum level potentially available for redistribution (gm N/plant). [=PRTTNVG]

BUFTOP- Nitrogen in the haulm above the minimum level potentially available for redistribution (gm N/plant). [=PRTTNVG]

CLAI - Calculated maximum LAI (unitless). [IPOT, POTATO, OPHARV, =GROSUB, =PROGRI, MENU]

CTPP - Calculated tubers/plant (not calculated yet). [=OPHARV]

CUMSTT- Cumulative thermal time calculated from soil temperature. [IPOT, POTATO, =PHENOL, =PHASEI, =PROGRI, MENU]

DAYHRS- Time from sunrise to sunset (hours). [PTCALL, IPOT, POTATO, PHENOL, MENU, DUMP, LOAD]

DAYLG - Hours from sunrise to sunset. [=DAYLTH]

DEADLF- Dry weight of dead leaves (gm/plant). [IPOT, POTATO, =PHASEI, =GROSUB, =PROGRI, MENU]

DL - Hours from sunrise to sunset. [=DAYLTH]

DLFAC - Factor expressing effect of day length on tuber induction. [=PHENOL]

ETGT - Temperature based factor used to limit potential tuber growth (unitless). [=GROSUB]

G1 - Genetic coefficient for determinacy in tuber growth (unitless). [PTCALL, IPOT, POTATO, GROSUB, R=IPVAR, =NTRANS, MENU, DUMP, LOAD]

G2 - Genetic coefficient for potential daily leaf growth (cm2/m2). [PTCALL, IPOT, POTATO, GROSUB, R=IPVAR, MENU, DUMP, LOAD]

G3 - Genetic coefficient for potential daily tuber growth. (gm/plant/day). [PTCALL, IPOT, POTATO, GROSUB, R=IPVAR, MENU, DUMP, LOAD]

G4 - Not used. [R=IPVAR]
GRF - Ratio of available carbohydrate to potential growth of plant parts.
GROSPR- Daily change in sprout length from germination to emergence (cm/day). [=PHENOL]
GROTUB- Daily change in tuber dry weight (gm/plant/day). [=GROSUB, =PARTTN]
HAULM - Stems and leaves dry weight (Kg/Ha). [=OPHARV]
HWLAR - Haulm dry weight to plant leaf area ratio (gm/cm2). [=GROSUB]
IEMERG- Crop emergence date (day of year). [PTCALL, IPOT, POTATO, PHENOL, R=IPEXP, MENU, DUMP, LOAD]
INITJD- Observed date of tuber initiation. [OPHARV, IPTRTB]
JINIT - Tuber initiation date, calculated by model (day of year). [POTATO, =PHENOL, OPHARV]
JPHMA - Calculated date of maturity. [=OPHARV]
MATJD - Observed date of maturity. [PTCALL, IPOT, POTATO, PHENOL, OPHARV, IPTRTB, MENU, DUMP, LOAD]
PARTUB- Fraction of daily net growth potentially going into tuber growth (unitless). [IPOT, POTATO, =PHENOL, GROSUB, =PROGRI, MENU]
PBIOMS- Plant dry weight (Kg/Ha). [=OPHARV]
PGRTUB- Potential daily tuber growth--PARTUB*CARBO (gm/plant). [=GROSUB, PARTTN]
PI - Constant=3.1415927 (unitless). [=DAYLTH, =PROGRI]
PRFT - Daily ratio of tuber growth to total growth. [=GROSUB]
PTUBNP- Tuber nitrogen content (Kg/Ha). [=OPHARV]
R0 - Constant conversion factor. [IPOT, DAYLTH, =PROGRI]
R1 - Constant conversion factor. [IPOT, DAYLTH, =PROGRI]
R2 - Constant conversion factor. [IPOT, DAYLTH, =DRAINS, =PROGRI]
R3 - Day length on a 0 to 1 scale. [=DAYLTH]
RATIO - ratio of nitrogen uptake to nitrogen demand (unitless). [=PRTTNVG, =PARTTN]
RFAC - Root uptake factor based on soil water and root density (unitless). [=PNUPTK]
RRATIO- ratio of nitrogen demand for roots to total demand. [=PRTTNVG]
SEEDAV- Carbohydrate from seed piece available for daily growth (gm/plant). [=GROSUB]
SLAN - Daily leaf senescence in absence of stress (cm2/plant). [=GROSUB]
SLFC - Factor expressing effect of LAI on rate of leaf senescence (unitless). [=GROSUB]
SLFN - Factor expressing effect of nitrogen stress on rate of leaf senescence (unitless). [=GROSUB]
SLFT - Factor expressing effect of temperature stress on rate of leaf senescence (unitless). [=GROSUB]
SLFW - Factor expressing effect of water stress on rate of leaf senescence (unitless). [=GROSUB]
SOLDEC- Solar declination. [=DAYLTH]
SOLFAC- Factor expressing effect of daily light intensity on tuber. [=PHENOL] induction
SPGROF- Sprout length growth factor (unitless). [=PHENOL]

SPLTHP- Sprout length on seed piece at planting (cm). [PTCALL, IPOT, POTATO, PHENOL, PHASEI, IPEXP, MENU, DUMP, LOAD]

SPRLTH- Daily value of sprout length from germination to emergence (cm/day). [IPOT, POTATO, =PHENOL, =PROGRI, MENU]

SPRWT - Daily change in sprout weight from germination to emergence. [=PHENOL] (gm/plant)

SRVBEG- Carbohydrate in seed piece available at start of day (gm/plant). [=GROSUB]

SRVNU - Nitrogen in seed piece available at start of day (gm N/plant). [=GROSUB]

SRVUSD- Carbohydrate used from seed piece (gm/plant). [=GROSUB]

STOPSN- surplus nitrogen in haulm (n above minimum n% for haulm) (gm N/plant). [=PARTTN]

STT - Daily thermal time calculated from soil temperature (unitless). [POTATO, =PHENOL, ROOTGR, MENU]

T1 - Temperture variable for calculation effects of advection on ET. [PTCALL, IPOT, POTATO, PET, =PROGRI, MENU, DUMP, LOAD]

T2 - Temperture variable for calculation effects of advection on ET. [PTCALL, IPOT, POTATO, PET, =PROGRI, MENU, DUMP, LOAD]

TCARBO- Total accumulated net photosynthesis, not used (gm/plant). [IPOT, POTATO, =GROSUB, =PROGRI, MENU]

TDAY - Daily amount of tuber induction (unitless). [=PHENOL]

TEMPFAC- Factor expressing effect of daily mean temperature on tuber induction. [=PHENOL]

TIND - Degree of tuber induction (unitless). [IPOT, POTATO, =PHENOL, =PROGRI, MENU]

TOPCNT- Daily thermal time of plant stems and leaves (unitless). [=PHENOL]

TRATIO- Ratio of nitrogen demand for tops to total demand. [=PRTTNVG]

TSPRWT - Sprout dry weight (gm/plant). [POTATO, =PHENOL, =PHASEI, MENU]

TUBANC- Nitrogen to carbohydrate ratio in the tubers (unitless). [=PARTTN]

TUBCNP- Nitrogen content of tubers to support maximum growth (unitless). [=GROSUB, PARTTN]

TUBCNT- Daily thermal time of tubers and roots (unitless). [=PHENOL]

TUBDEM- Nitrogen demand by the tubers to maintain N content at TUBCNP (unitless). [=PARTTN]

TUBN - Nitrogen content of the tubers (gm N/plant). [POTATO, OPHARV, =PHASEI, GROSUB, =PARTTN, MENU]

TUBNUP- Tuber nitrogen content (Kg/Ha). [=OPHARV]

TUBSM - Tubers per square meter (not calculated yet). [=OPHARV]

TUBPCN- Observed tuber N content. [R=OPHARV, IPTRTB]

TUBWT - Tuber dry weight (gm/plant). [POTATO, OPHARV, =PHASEI, =GROSUB, PARTTN, =MENU]

X - Portion of available carbo initially assigned to top growth that tuber can use with available n (unitless). [=PARTTN, =NTRANS, RRANDN]

XANC - N content: TANC * 100.0 (percent). [=PHENOL]

XC - Carbo available for tuber growth not matched by available nitrogen including STOPSN (gm/plant). [=PARTTN]

XLAI - Measured maximum LAI. [=PARTTN, =NTRANS]

XT	-	Carbo released from haulm for tuber growth because of nitrogen deficiency in haulm caused by n extraction by tuber (gm/plant). [=PARTTN]
XTPP	-	Measured number of tubers/plant. [=OPHARV]
XTUBSM	-	Measured number of tubers/m2. [=OPHARV]
XTUBWT	-	Measured tuber fresh weight (T/Ha). [=OPHARV]
XYIELD	-	Measured tuber dry weight (Kg/Ha). [=OPHARV]
YLDFR	-	Tuber fresh weight (T/Ha). [=OPHARV]

Sample Input File for the Dynamic Optimization Model

```
        SPFILL    (%)                            = 0.65
        NDAYS                                    = 1
        DDAY                                     = 88
        KLDAY                                    = 0
        SCROUT   (YES)                           = 0
        MAXIRR   (mm)                            = 11.18
        MINIRR   (mm)                            = 4.0
        IPLABOR ($)                              = 0.13
        NPLABOR ($)                              = 0.065
! ->$2.50 ACRE INCLUDING MACH.
        NTPLABOR ($)     TRACTOR APPLIED         = 6.17
!      WPYIELD ($)     $0.052/lb. CORN          = 0.114
        WPYIELD ($)              WHEAT           = 0.16
!        WPYIELD ($)              WHEAT           = 0.12
        PNITROGEN  ($)/kg                        = 0.37
        PTNITROGEN ($)/kg TRACTOR APPLIED        = 0.37
!      PNITROGEN  ($)/kg                        = 0.74
!      PTNITROGEN ($)/kg TRACTOR APPLIED        = 0.74
        INCR       (mm/m)                        = 5
        NINCR      (kg/ha/m)                     = 20
! MAXIMUM N CONCENTRATION
        NMCON ->5 kg/ha/mm                       = 4.0
        LOW        (mm/m)                        = 50
        NLOW       (kg/ha)                       = 20
        EFFIRR     (%)                           = 0.90
        QNMAX      (kg/ha/m)                     = 120.0
        MINFRT     (kg/ha)                       = 5.0
        PWATER   ->$20.00 AC/FT                  = 0.16
        SAMAX      (%) % OF SOIL SATUATION       = 1.0
        MINRAIN    (mm)                          = 3.0
        MINPRAIN (%)                             = 0.75
        STDIRREFF (%)                            = 0.025
        NUMFIELDS                                = 3
        npolicy                                  = 0.85
        tpolicy                                  = 0
        DUMPFILE                                 = 1
        USELOAD                                  = 1
        FREQDUMP                                 = 2
```

Flowchart for the Wheat Model

DIAGRAM'er v2.1 Run: 09/07/1989 23:38:05

```
          Program    WHEAT

 \-P.WHEAT
    | C/IPARM/
    | C/RPARM/
    |-S.PREAD
    |  | C/IPARM/
    |  | C/RPARM/
    |  |-S.ISORT
    |  \-S.PARSE
    |     |-S.CAPS
    |     |-S.GETOKE
    |     |-S.LEFT
    |     |-S.SEARCH
    |     |  |-F.LENGTH
    |     |  \-S.COMPAR
    |     |-S.FEQUAL
    |     |-S.RIGHT
    |     \-S.BLANK
    |-S.LOAD
    |  | C/APARA/
    |  | C/ZAPARA/
    |  | C/ZTEMP/
    |  | C/ZATEMP/
    |  | C/ZITEMP/
    |  | C/ITEMP/
    |  | C/TEMP/
    |  | C/ATEMP/
    |  | C/DAILY/
    |  | C/QDAILY/
    |  | C/LITEMP/
    |  | C/QTEMP/
    |  | C/QATEMP/
    |  | C/YDAILY/
    |  | C/KITEMP/
    |  | C/YTEMP/
    |  | C/YATEMP/
    |  | C/WDAILY/
    |  | C/JITEMP/
    |  | C/WTEMP/
    |  | C/WATEMP/
    |  \ C/PARA/
    |-F.ICLOSE
    |-F.RCLOSE
    |-S.INTMAT
    |-S.RANDN
    |  \-F.RANG
    |     \ C/JWR3/
    |-S.WCALL
    |  | C/PARA/
    |  | C/APARA/
    |  |-S.IWHEAT
    |  |  | C/ITEMP/
    |  |  | C/TEMP/
    |  |  | C/ATEMP/
    |  |  | C/APARA/
    |  |  |-S.IPEXP
    |  |  |-S.IPTRT
    |  |  |-S.IPVAR
    |  |  |-S.ECHO
    |  |  |-S.IPNIT1
    |  |  |-S.IPNIT2
    |  |  |-S.IPWTH
    |  |  |  |-S.CALSNW
```

```
|  |  |  \-S.CALTHM
|  |  |-S.PROGRI
|  |  |-S.IPSOIL
|  |  |  \-S.ERSOIL
|  |  |-S.SOILRI
|  |  |-S.SOILNI
|  |  |  \-S.SOLT
|  |  \-S.DPSOIL
|  |     |  C/APARA/
|  |     |  C/ZAPARA/
|  |     |  C/ZTEMP/
|  |     |  C/ZATEMP/
|  |     |  C/ZITEMP/
|  |     |  C/ITEMP/
|  |     |  C/TEMP/
|  |     |  C/ATEMP/
|  |     |-S.FCTRN
|  |     \-S.ICTRN
|  |-S.GETRST
|  |  |-S.WRESET
|  |  |  |  C/ZTEMP/
|  |  |  |  C/ZATEMP/
|  |  |  |  C/ZITEMP/
|  |  |  |  C/ITEMP/
|  |  |  |  C/TEMP/
|  |  |  |  C/ATEMP/
|  |  |  |  C/DAILY/
|  |  |  |-S.FBTRN
|  |  |  \-S.IBTRN
|  |  |-S.TRSOIL
|  |  |  |  C/APARA/
|  |  |  \  C/ZAPARA/
|  |  |-S.TRADAT
|  |  |  |  C/QDAILY/
|  |  |  |  C/LITEMP/
|  |  |  |  C/QTEMP/
|  |  |  |  C/QATEMP/
|  |  |  |  C/WDAILY/
|  |  |  |  C/JITEMP/
|  |  |  |  C/WTEMP/
|  |  |  |  C/WATEMP/
|  |  |  |-S.FTRANS
|  |  |  \-S.ITRANS
|  |  \-S.RESTNS
|  |     |  C/DAILY/
|  |     |  C/ITEMP/
|  |     |  C/TEMP/
|  |     |  C/ATEMP/
|  |     |  C/QDAILY/
|  |     |  C/LITEMP/
|  |     |  C/QTEMP/
|  |     |  C/QATEMP/
|  |     |-S.FBATRAN
|  |     |-S.FBTRANS
|  |     \-S.IBTRANS
|  \-S.WHEAT
|     |  C/ITEMP/
|     |  C/TEMP/
|     |  C/ATEMP/
|     |  C/DAILY/
|     |-S.SAVSTT
|     |-S.SAVSOL
|     |  |  C/YDAILY/
|     |  |  C/KITEMP/
|     |  |  C/YTEMP/
|     |  |  C/YATEMP/
|     |  |  C/DAILY/
|     |  |  C/ITEMP/
|     |  |  C/TEMP/
```

```
|     |  |  C/ATEMP/
|     |  |-S.FCTRN
|     |  \-S.ICTRN
|     |-S.GETMAN
|     |-S.NTRANS
|     |  \-S.SOLT
|     |-S.WATBAL
|     |  |-S.CALEO
|     |  \-S.NFLUX
|     |-S.PHENOL
|     |  |-S.THTIME
|     |  |-S.PH7
|     |  |  \-S.PHASE7
|     |  |-S.PH8
|     |  |  \-S.PHASE8
|     |  |-S.PH9
|     |  |  |-S.COLD
|     |  |  \-S.PHASE9
|     |  |-S.PH1
|     |  |  |-S.COLD
|     |  |  \-S.PHASE1
|     |  |-S.PH2
|     |  |  \-S.PHASE2
|     |  |-S.PH3
|     |  |  \-S.PHASE3
|     |  |-S.PH4
|     |  |  \-S.PHASE4
|     |  |-S.PH5
|     |  |  \-S.PHASE5
|     |  \-S.PHASE6
|     |-S.GROSUB
|     |  |-S.NFACTO
|     |  |-S.GRO1
|     |  |-S.GRO2
|     |  |-S.GRO3
|     |  |-S.GRO4
|     |  |-S.GRO5
|     |  \-S.NUPTAK
|     \-S.CJDATE
|-S.NET
|-S.SAVBSA
|  |-F.RCLOSE
|  |-F.INCODE1
|  \-S.SAVOPS
|     |  C/YDAILY/
|     |  C/KITEMP/
|     |  C/YTEMP/
|     |  C/YATEMP/
|     |  C/WDAILY/
|     |  C/JITEMP/
|     |  C/WTEMP/
|     |  C/WATEMP/
|     |-S.FCATRAN
|     |-S.FCTRANS
|     \-S.ICTRANS
|-S.GETFRT
|  \-F.UCLOSE
|-S.SETLCH
|  \-F.DECODE1
|-S.SVBSA
|  |-F.INCODE1
|  \-S.SAVOPS
|     |  C/YDAILY/
|     |  C/KITEMP/
|     |  C/YTEMP/
|     |  C/YATEMP/
|     |  C/WDAILY/
|     |  C/JITEMP/
|     |  C/WTEMP/
```

```
|       | C/WATEMP/
|       |-S.FCATRAN
|       |-S.FCTRANS
|       \-S.ICTRANS
|-F.DECODE1
|-F.UBOUND
|  \-F.UCLOSE
|-F.LBOUND
|  \-F.UCLOSE
|-S.GETIRR
|  \-F.UCLOSE
|-F.UNBOUND
|  \-F.UCLOSE
|-F.LNBOUND
|  \-F.UCLOSE
|-S.GETREP
|-S.CONVPT
|  \-S.CJDATE
|-S.FCONVPT
|  \-S.CJDATE
|-F.UCLOSE
|-S.NPOLCY
|  \-F.DECODE1
|-S.SAVMAX
|   |-F.INCODE1
|   |-F.RCLOSE
|   |-F.UCLOSE
|   \-S.SAVOPS
|       | C/YDAILY/
|       | C/KITEMP/
|       | C/YTEMP/
|       | C/YATEMP/
|       | C/WDAILY/
|       | C/JITEMP/
|       | C/WTEMP/
|       | C/WATEMP/
|       |-S.FCATRAN
|       |-S.FCTRANS
|       \-S.ICTRANS
|-S.STATUS
|-S.CJDATE
|-S.FINDMIN
|   |-F.RCLOSE
|   \-F.DECODE1
|-S.TRALCH
|-S.DUMP
|   | C/APARA/
|   | C/ZAPARA/
|   | C/ZTEMP/
|   | C/ZATEMP/
|   | C/ZITEMP/
|   | C/ITEMP/
|   | C/TEMP/
|   | C/ATEMP/
|   | C/DAILY/
|   | C/QDAILY/
|   | C/LITEMP/
|   | C/QTEMP/
|   | C/QATEMP/
|   | C/YDAILY/
|   | C/KITEMP/
|   | C/YTEMP/
|   | C/YATEMP/
|   | C/WDAILY/
|   | C/JITEMP/
|   | C/WTEMP/
|   | C/WATEMP/
|   \ C/PARA/
|-S.FINDMAX
```

```
\-S.OUT2
   |-F.UCLOSE
   |-S.CONVPT
   |  \-S.CJDATE
   |-S.FCONVPT
   |  \-S.CJDATE
   |-F.DECODE1
   \-S.CJDATE
```

Flowchart for the Corn Model

DIAGRAM'er v2.1 Run: 09/07/1989 23:52:31

```
         Program    CORN

\-P.CORN
   | C/IPARM/
   | C/RPARM/
   |-S.PREAD
   |  | C/IPARM/
   |  | C/RPARM/
   |  |-S.ISORT
   |  \-S.PARSE
   |     |-S.CAPS
   |     |-S.GETOKE
   |     |-S.LEFT
   |     |-S.SEARCH
   |     |  |-F.LENGTH
   |     |  \-S.COMPAR
   |     |-S.FEQUAL
   |     |-S.RIGHT
   |     \-S.BLANK
   |-S.LOAD
   |  | C/APARA/
   |  | C/ZAPARA/
   |  | C/ZTEMP/
   |  | C/ZATEMP/
   |  | C/ZITEMP/
   |  | C/ITEMP/
   |  | C/TEMP/
   |  | C/ATEMP/
   |  | C/DAILY/
   |  | C/QDAILY/
   |  | C/LITEMP/
   |  | C/QTEMP/
   |  | C/QATEMP/
   |  | C/YDAILY/
   |  | C/KITEMP/
   |  | C/YTEMP/
   |  | C/YATEMP/
   |  | C/WDAILY/
   |  | C/JITEMP/
   |  | C/WTEMP/
   |  | C/WATEMP/
   |  \ C/PARA/
   |-F.ICLOSE
   |-F.RCLOSE
   |-S.INTMAT
   |-S.RANDN
   |  \-F.RANG
   |     \ C/JWR3/
   |-S.CRCALL
   |  | C/PARA/
   |  | C/APARA/
   |  |-S.ICORN
   |  |  | C/ITEMP/
   |  |  | C/TEMP/
   |  |  | C/ATEMP/
   |  |  | C/APARA/
   |  |  |-S.IPEXP
   |  |  |-S.IPTRT
   |  |  |-S.IPVAR
   |  |  |-S.IPNIT1
   |  |  |-S.IPNIT2
   |  |  |-S.IPWTH
   |  |  |  \-S.CALSNW
   |  |  |-S.PROGRI
   |  |  |-S.IPSOIL
   |  |  |
```

```
|   |   |   \-S.ERSOIL
|   |   |-S.SOILRI
|   |   |-S.SOILNI
|   |   |   \-S.SOLT
|   |   \-S.DPSOIL
|   |       | C/APARA/
|   |       | C/ZAPARA/
|   |       | C/ZTEMP/
|   |       | C/ZATEMP/
|   |       | C/ZITEMP/
|   |       | C/ITEMP/
|   |       | C/TEMP/
|   |       | C/ATEMP/
|   |       |-S.FCTRN
|   |       \-S.ICTRN
|   |-S.GETRST
|   |   |-S.WRESET
|   |   |   | C/ZTEMP/
|   |   |   | C/ZATEMP/
|   |   |   | C/ZITEMP/
|   |   |   | C/ITEMP/
|   |   |   | C/TEMP/
|   |   |   | C/ATEMP/
|   |   |   | C/DAILY/
|   |   |   |-S.FBTRN
|   |   |   \-S.IBTRN
|   |   |-S.TRSOIL
|   |   |   | C/APARA/
|   |   |   \ C/ZAPARA/
|   |   |-S.TRADAT
|   |   |   | C/QDAILY/
|   |   |   | C/LITEMP/
|   |   |   | C/QTEMP/
|   |   |   | C/QATEMP/
|   |   |   | C/WDAILY/
|   |   |   | C/JITEMP/
|   |   |   | C/WTEMP/
|   |   |   | C/WATEMP/
|   |   |   |-S.FTRANS
|   |   |   \-S.ITRANS
|   |   \-S.RESTNS
|   |       | C/DAILY/
|   |       | C/ITEMP/
|   |       | C/TEMP/
|   |       | C/ATEMP/
|   |       | C/QDAILY/
|   |       | C/LITEMP/
|   |       | C/QTEMP/
|   |       | C/QATEMP/
|   |       |-S.FBATRAN
|   |       |-S.FBTRANS
|   |       \-S.IBTRANS
|   \-S.CORN
|       | C/ITEMP/
|       | C/TEMP/
|       | C/ATEMP/
|       | C/DAILY/
|       |-S.SAVSTT
|       |-S.SAVSOL
|       |   | C/YDAILY/
|       |   | C/KITEMP/
|       |   | C/YTEMP/
|       |   | C/YATEMP/
|       |   | C/DAILY/
|       |   | C/ITEMP/
|       |   | C/TEMP/
|       |   | C/ATEMP/
|       |   |-S.FCTRN
|       |   \-S.ICTRN
|       |
```

```
|      |-S.GETMAN
|      |-S.NTRANS
|      |  \-S.SOLT
|      |-S.WATBAL
|      |  |-S.CALEO
|      |  \-S.NFLUX
|      |-S.PHENOL
|      |  \-S.DEAD
|      |-S.PHASEI
|      |-S.NFACTO
|      |-S.GROSUB
|      |-S.NUPTAK
|      \-S.CJDATE
|-S.NET
|-S.SAVBSA
|  |-F.RCLOSE
|  |-F.INCODE1
|  \-S.SAVOPS
|      | C/YDAILY/
|      | C/KITEMP/
|      | C/YTEMP/
|      | C/YATEMP/
|      | C/WDAILY/
|      | C/JITEMP/
|      | C/WTEMP/
|      | C/WATEMP/
|      |-S.FCATRAN
|      |-S.FCTRANS
|      \-S.ICTRANS
|-S.GETFRT
|  \-F.UCLOSE
|-S.SETLCH
|  \-F.DECODE1
|-S.SVBSA
|  |-F.INCODE1
|  \-S.SAVOPS
|      | C/YDAILY/
|      | C/KITEMP/
|      | C/YTEMP/
|      | C/YATEMP/
|      | C/WDAILY/
|      | C/JITEMP/
|      | C/WTEMP/
|      | C/WATEMP/
|      |-S.FCATRAN
|      |-S.FCTRANS
|      \-S.ICTRANS
|-F.DECODE1
|-F.UBOUND
|  \-F.UCLOSE
|-F.LBOUND
|  \-F.UCLOSE
|-S.GETIRR
|  \-F.UCLOSE
|-F.UNBOUND
|  \-F.UCLOSE
|-F.LNBOUND
|  \-F.UCLOSE
|-S.GETREP
|-S.CONVPT
|  \-S.CJDATE
|-S.FCONVPT
|  \-S.CJDATE
|-F.UCLOSE
|-S.NPOLCY
|  \-F.DECODE1
|-S.SAVMAX
|  |-F.INCODE1
|  |-F.RCLOSE
```

```
|  |-F.UCLOSE
|  \-S.SAVOPS
|       | C/YDAILY/
|       | C/KITEMP/
|       | C/YTEMP/
|       | C/YATEMP/
|       | C/WDAILY/
|       | C/JITEMP/
|       | C/WTEMP/
|       | C/WATEMP/
|       |-S.FCATRAN
|       |-S.FCTRANS
|       \-S.ICTRANS
|-S.STATUS
|-S.CJDATE
|-S.FINDMIN
|  |-F.RCLOSE
|  \-F.DECODE1
|-S.TRALCH
|-S.DUMP
|   | C/APARA/
|   | C/ZAPARA/
|   | C/ZTEMP/
|   | C/ZATEMP/
|   | C/ZITEMP/
|   | C/ITEMP/
|   | C/TEMP/
|   | C/ATEMP/
|   | C/DAILY/
|   | C/QDAILY/
|   | C/LITEMP/
|   | C/QTEMP/
|   | C/QATEMP/
|   | C/YDAILY/
|   | C/KITEMP/
|   | C/YTEMP/
|   | C/YATEMP/
|   | C/WDAILY/
|   | C/JITEMP/
|   | C/WTEMP/
|   | C/WATEMP/
|   \ C/PARA/
|-S.FINDMAX
\-S.OUT2
    |-F.UCLOSE
    |-S.CONVPT
    |   \-S.CJDATE
    |-S.FCONVPT
    |   \-S.CJDATE
    |-F.DECODE1
    \-S.CJDATE
```

Flowchart for the Potato Model

DIAGRAM'er v2.1 Run: 09/08/1989 00:05:51

```
        Program    POTATO

\-P.POTATO
    | C/IPARM/
    | C/RPARM/
    |-S.PREAD
    |  | C/IPARM/
    |  | C/RPARM/
    |  |-S.ISORT
    |  \-S.PARSE
    |     |-S.CAPS
    |     |-S.GETOKE
    |     |-S.LEFT
    |     |-S.SEARCH
    |     |  |-F.LENGTH
    |     |  \-S.COMPAR
    |     |-S.FEQUAL
    |     |-S.RIGHT
    |     \-S.BLANK
    |-S.LOAD
    |  | C/APARA/
    |  | C/ZAPARA/
    |  | C/ZTEMP/
    |  | C/ZATEMP/
    |  | C/ZITEMP/
    |  | C/ITEMP/
    |  | C/TEMP/
    |  | C/ATEMP/
    |  | C/DAILY/
    |  | C/QDAILY/
    |  | C/LITEMP/
    |  | C/QTEMP/
    |  | C/QATEMP/
    |  | C/YDAILY/
    |  | C/KITEMP/
    |  | C/YTEMP/
    |  | C/YATEMP/
    |  | C/WDAILY/
    |  | C/JITEMP/
    |  | C/WTEMP/
    |  | C/WATEMP/
    |  \ C/PARA/
    |-F.ICLOSE
    |-F.RCLOSE
    |-S.INTMAT
    |-S.RANDN
    |  \-F.RANG
    |     \ C/JWR3/
    |-S.PTCALL
    |  | C/PARA/
    |  | C/APARA/
    |  |-S.IPOT
    |  |  | C/ITEMP/
    |  |  | C/TEMP/
    |  |  | C/ATEMP/
    |  |  | C/APARA/
    |  |  |-S.IPEXP
    |  |  |-S.IPWTH
    |  |  |  \-S.CALSNW
    |  |  |-S.IPTRTA
    |  |  |-S.IPTRTB
    |  |  |-S.IPVAR
    |  |  |-S.IPVAL
    |  |  |-S.IPNIT1
```

```
|    |    |-S.IPNIT2
|    |    |-S.PROGRI
|    |    |-S.DAYLTH
|    |    |-S.IPSOIL
|    |    |  \-S.ERSOIL
|    |    |-S.SOILRI
|    |    |-S.SOILNI
|    |    |  \-S.SOLT
|    |    \-S.DPSOIL
|    |         | C/APARA/
|    |         | C/ZAPARA/
|    |         | C/ZTEMP/
|    |         | C/ZATEMP/
|    |         | C/ZITEMP/
|    |         | C/ITEMP/
|    |         | C/TEMP/
|    |         | C/ATEMP/
|    |         |-S.FCTRN
|    |         \-S.ICTRN
|    |-S.GETRST
|    |    |-S.WRESET
|    |    |    | C/ZTEMP/
|    |    |    | C/ZATEMP/
|    |    |    | C/ZITEMP/
|    |    |    | C/ITEMP/
|    |    |    | C/TEMP/
|    |    |    | C/ATEMP/
|    |    |    | C/DAILY/
|    |    |    |-S.FBTRN
|    |    |    \-S.IBTRN
|    |    |-S.TRSOIL
|    |    |    | C/APARA/
|    |    |    \ C/ZAPARA/
|    |    |-S.TRADAT
|    |    |    | C/QDAILY/
|    |    |    | C/LITEMP/
|    |    |    | C/QTEMP/
|    |    |    | C/QATEMP/
|    |    |    | C/WDAILY/
|    |    |    | C/JITEMP/
|    |    |    | C/WTEMP/
|    |    |    | C/WATEMP/
|    |    |    |-S.FTRANS
|    |    |    \-S.ITRANS
|    |    \-S.RESTNS
|    |         | C/DAILY/
|    |         | C/ITEMP/
|    |         | C/TEMP/
|    |         | C/ATEMP/
|    |         | C/QDAILY/
|    |         | C/LITEMP/
|    |         | C/QTEMP/
|    |         | C/QATEMP/
|    |         |-S.FBATRAN
|    |         |-S.FBTRANS
|    |         \-S.IBTRANS
|    \-S.POTATO
|         | C/ITEMP/
|         | C/TEMP/
|         | C/ATEMP/
|         | C/DAILY/
|         |-S.SAVSTT
|         |-S.SAVSOL
|         |    | C/YDAILY/
|         |    | C/KITEMP/
|         |    | C/YTEMP/
|         |    | C/YATEMP/
|         |    | C/DAILY/
|         |    | C/ITEMP/
```

```
|     |  | C/TEMP/
|     |  | C/ATEMP/
|     |  |-S.FCTRN
|     |  \-S.ICTRN
|     |-S.GETMAN
|     |-S.NTRANS
|     |  \-S.SOLT
|     |-S.PET
|     |-S.CLIMAT
|     |-S.DRAINS
|     |-S.NMOVE
|     |  \-S.NFLUX
|     |-S.EVAP
|     |  \-S.NFLUX
|     |-S.ROOTGR
|     |-S.WSTRSS
|     |-S.PHENOL
|     |-S.PHASEI
|     |-S.GROSUB
|     |   |-S.NFACTO
|     |   |-S.PNUPTK
|     |   |-S.PRTTNVG
|     |   |-S.PARTTN
|     |   \-S.POTNUP
|     \-S.CJDATE
|-S.NET
|-S.SAVBSA
|  |-F.RCLOSE
|  |-F.INCODE1
|  \-S.SAVOPS
|      | C/YDAILY/
|      | C/KITEMP/
|      | C/YTEMP/
|      | C/YATEMP/
|      | C/WDAILY/
|      | C/JITEMP/
|      | C/WTEMP/
|      | C/WATEMP/
|      |-S.FCATRAN
|      |-S.FCTRANS
|      \-S.ICTRANS
|-S.GETFRT
|  \-F.UCLOSE
|-S.SETLCH
|  \-F.DECODE1
|-S.SVBSA
|  |-F.INCODE1
|  \-S.SAVOPS
|      | C/YDAILY/
|      | C/KITEMP/
|      | C/YTEMP/
|      | C/YATEMP/
|      | C/WDAILY/
|      | C/JITEMP/
|      | C/WTEMP/
|      | C/WATEMP/
|      |-S.FCATRAN
|      |-S.FCTRANS
|      \-S.ICTRANS
|-F.DECODE1
|-F.UBOUND
|  \-F.UCLOSE
|-F.LBOUND
|  \-F.UCLOSE
|-S.GETIRR
|  \-F.UCLOSE
|-F.UNBOUND
|  \-F.UCLOSE
|-F.LNBOUND
```

```
|  \-F.UCLOSE
|-S.GETREP
|-S.CONVPT
|  \-S.CJDATE
|-S.FCONVPT
|  \-S.CJDATE
|-F.UCLOSE
|-S.NPOLCY
|  \-F.DECODE1
|-S.SAVMAX
|   |-F.INCODE1
|   |-F.RCLOSE
|   |-F.UCLOSE
|   \-S.SAVOPS
|        |  C/YDAILY/
|        |  C/KITEMP/
|        |  C/YTEMP/
|        |  C/YATEMP/
|        |  C/WDAILY/
|        |  C/JITEMP/
|        |  C/WTEMP/
|        |  C/WATEMP/
|        |-S.FCATRAN
|        |-S.FCTRANS
|        \-S.ICTRANS
|-S.STATUS
|-S.CJDATE
|-S.FINDMIN
|   |-F.RCLOSE
|   \-F.DECODE1
|-S.TRALCH
|-S.DUMP
|    |  C/APARA/
|    |  C/ZAPARA/
|    |  C/ZTEMP/
|    |  C/ZATEMP/
|    |  C/ZITEMP/
|    |  C/ITEMP/
|    |  C/TEMP/
|    |  C/ATEMP/
|    |  C/DAILY/
|    |  C/QDAILY/
|    |  C/LITEMP/
|    |  C/QTEMP/
|    |  C/QATEMP/
|    |  C/YDAILY/
|    |  C/KITEMP/
|    |  C/YTEMP/
|    |  C/YATEMP/
|    |  C/WDAILY/
|    |  C/JITEMP/
|    |  C/WTEMP/
|    |  C/WATEMP/
|    \  C/PARA/
|-S.FINDMAX
\-S.OUT2
     |-F.UCLOSE
     |-S.CONVPT
     |  \-S.CJDATE
     |-S.FCONVPT
     |  \-S.CJDATE
     |-F.DECODE1
     \-S.CJDATE
```

Source Code for DTT.FOR

```
      REAL TMFAC(8)
      DO 30 I=1,8
         TMFAC(I)=0.931+0.114*I-0.0703*I**2+0.0053*I**3
   30 CONTINUE
      DTT=0.0
      IYEAR=1910
C       OPEN (11,FILE = 'W.DAT',STATUS = 'OLD')
      OPEN (11,FILE = 'SIMWTHR',STATUS = 'OLD')
      READ (11,50)
40    READ (11,50,END=20) JDATE,SOLRAD,TEMPMX,TEMPMN,RAIN
      IF ((JDATE.GE.152).AND.(JDATE.LE.242)) THEN
         TMN=((TEMPMN+TEMPMX)/2.)-10.
         IF (TMN.LT.0.0) TMN=0.
         DTT=DTT+TMN
      ELSE IF (JDATE.EQ.243) THEN
         WRITE (*,55) IYEAR,DTT
         IYEAR=IYEAR+1
         DTT=0.0
      END IF
      GO TO 40
 20   CONTINUE
      STOP
50    FORMAT (8X,I3,1X,F5.2,2(1X,F5.1),1X,F5.1,1X,F6.2)
 55   FORMAT (' YEAR=',I4,' SUMMER DTT=',F7.2)
      END
```

Source Code for LAMB.FOR

```
      PROGRAM LAMB
      REAL AIRR,HOURS,RATE,ZNSET,SET,TMPSET
      INTEGER JDATE,JDATEO,SETDAY
      CHARACTER*15 FNAME,ONAME
      OPEN (10,FILE='FILELIST.W',STATUS='OLD',ERR=991)
      READ (10,15,ERR=981) FNAME
      READ (10,15,ERR=981) ONAME
      READ (10,16,ERR=981) SET
      SETDAY=INT(.99+SET/24.0)
      SUMR=0.0
      SUMC=0.0
 15   FORMAT (A15)
 16   FORMAT (F5.1)
      CLOSE (10)
      OPEN (12,FILE=FNAME,STATUS='OLD',ERR=992)
      OPEN (13,FILE=ONAME,STATUS='UNKNOWN',ERR=993)
      CLOSE (13,STATUS='DELETE')
      OPEN (13,FILE=ONAME,STATUS='NEW',ERR=993)
      READ (12,25,ERR=982) JDATE,AIRR,HOURS
      JDATEO=JDATE
      AIRR=AIRR*25.4
      SUMR=SUMR+AIRR
 25   FORMAT (1X,I3,1X,F5.2,1X,F5.2)
 35   FORMAT (1X,I3,1X,F4.0)
      WRITE (13,15) FNAME
      IF (HOURS.LE.24.0) THEN
         WRITE (13,35,ERR=983) JDATE,AIRR
         SUMC=SUMC+AIRR
         RATE=AIRR/HOURS
C         WRITE (*,*) 'RATE=',RATE
      ELSE
         RATE=AIRR/HOURS
 100     CONTINUE
            IF (HOURS.LE.24.) THEN
               WRITE (13,35,ERR=983) JDATE,HOURS*RATE
               SUMC=SUMC+HOURS*RATE
               GO TO 110
            ELSE
               WRITE (13,35,ERR=983) JDATE,24.0*RATE
               SUMC=SUMC+24.0*RATE
               HOURS=HOURS-24.0
               JDATE=JDATE-1
               GO TO 100
            END IF
 110     CONTINUE
      END IF
 1000 CONTINUE
         READ (12,25,END=2000,ERR=982) JDATE,AIRR,HOURS
         AIRR=AIRR*25.4
```

```
      SUMR=SUMR+AIRR
C
C  ONLY IRRIGATE FOR ONE DAY THIS WEEK
C
      IF (HOURS.LE.24.0) THEN
         WRITE (13,35,ERR=983) JDATE,AIRR
         SUMC=SUMC+AIRR
         JDATEO=JDATE
C         IF (AIRR.le.10.) THEN
C            WRITE (*,*) AIRR,HOURS,JDATE
C         END IF
      ELSE
         RATE=AIRR/HOURS
         JDIFF=JDATE-JDATEO
         JDATEO=JDATE
C
C  NUMBER OF SETS PER PERIOD
C
         ZNSET=HOURS/SET
C
C  NUMBER OF OFF DAYS PER PERIOD
C
         JFREE=JDIFF-INT(.99+ZNSET*REAL(SETDAY))
C
C  ONLY ONE BIG MULTI-DAY SET
C
         IF ((JDIFF.LE.SETDAY).OR.(JFREE.LE.0)) THEN
 200        CONTINUE
               IF (HOURS.LE.24.) THEN
                  WRITE (13,35,ERR=983) JDATE,HOURS*RATE
                  SUMC=SUMC+HOURS*RATE
                  GO TO 210
               ELSE
                  WRITE (13,35,ERR=983) JDATE,24.0*RATE
                  SUMC=SUMC+24.0*RATE
                  HOURS=HOURS-24.0
                  JDATE=JDATE-1
                  GO TO 200
               END IF
 210        CONTINUE
         ELSE
C
C  THE NUMBER OF OFF DAYS BETWEEN SETS WITH THE MODULUS GOING TO THE
C     BEGINNING OF THE PERIOD
C
            INCR=INT(.99+ZNSET)*SETDAYS/JDIFF
            TMPSET=SET
 300        CONTINUE
               IF (TMPSET.LE.24.) THEN
                  WRITE (13,35,ERR=983) JDATE,TMPSET*RATE
                  SUMC=SUMC+TMPSET*RATE
                  ZNSET=ZNSET-1.0
```

```
                    IF (ZNSET.LE.0) THEN
                       GO TO 310
C
C  ADD THE FRACTIONAL AMOUNT TO LAST SET
C
                    ELSE IF ((ZNSET.LT.2.0)) THEN
C                    .AND.(REAL(ZNSET-
C    +                  INT(ZNSET)).GE.1.0)) THEN
                       TMPSET=SET*ZNSET
                       ZNSET=0.0
                       JDATE=JDATE-1-INCR
                       GO TO 300
C
C  INCREMENT BACK TO THE NEXT SET
C
                    ELSE
                       TMPSET=SET
                       JDATE=JDATE-1-INCR
                       GO TO 300
                    END IF
                 ELSE
                    WRITE (13,35,ERR=983) JDATE,24.0*RATE
                    SUMC=SUMC+24.0*RATE
                    TMPSET=TMPSET-24.0
                    JDATE=JDATE-1
                    GO TO 300
                 END IF
 310          CONTINUE
           END IF
        END IF
     GO TO 1000
 2000 CONTINUE
     WRITE(13,35,ERR=983) -1,-1.
     WRITE (*,75) SUMC,SUMR
 75  FORMAT (' Calculated irrigation: ',F8.2,' Read Irrigation: ',F8.2)
     STOP
 991 WRITE (*,*) 'Problems opening filelist'
     STOP
 992 WRITE (*,*) 'Problems opening irrigation file: ',FNAME
     STOP
 993 WRITE (*,*) 'Problems opening output file: ',ONAME
     STOP
 981 WRITE (*,*) 'Problems reading filelist'
     STOP
 982 WRITE (*,*) 'Problems reading irrigation file: ',FNAME
     STOP
 983 WRITE (*,*) 'Problems writting irrigation file: ',ONAME
     STOP
     END
```

APPENDIX B: INPUT AND OUTPUT FILES

Example SHAZAM Source Code for Forecasting Model

```
*
*  herministon solar radiation data
*
* par 100
* size 50
file 4 c:\qu\junk.prn
set nowide
read (4) j y tmx tmn prc
genr tm=(tmx+tmn)/2
genr td=tmx-tmn
genr lntm=log(tm+15)
genr lntd=log(td+1)
genr lny=log(y)
genr lntm=log(tm+15)
genr lntd=log(td+1)
genr dp=0.
if(prc.gt.0.0) dp=1.0
genr lnprc=0.
if(prc.gt.0) lnprc=log(prc)
skipif ((y.le.0))
stat   lntd lntm lnprc / pcor
ols y  td tm dp /gf rstat lm
* delete skip$
set noskip
fc /beg=22 end=35 list
print y td /beg=22 end=35
set skip
skipif ((y.le.0))
ols lny lntd  lntm dp /gf rstat loglog lm
set noskip
* delete skip$
fc /beg=22 end=35  list
print lny lntd  lntm lnprc/beg=22 end=35
stop
```

Example SHAZAM Output File from the Forcasting Model

```
SHAZAM - IBM-PC VERSION   SITE NO.  XX

FOR USE ONLY BY:
AT: Oregon State University

If this does not describe you then you have stolen this copy
and if you type anything except STOP or HELP SHAZAM you agree
to send payment to SHAZAM within 7 days for a software license

(c) SHAZAM 5.1  *** if you need assistance type HELP or DEMO

Hello/Bonjour -
Welcome to SHAZAM - Version 5.1  -  AUG 1986 SYSTEM=IBM-PC   PAR=  250

|_*
|_*  HERMINISTON SOLAR RADIATION DATA
|_*
|_* PAR 100
|_* SIZE 50
|_FILE 4 c:\qu\junk.prn
UNIT  4 IS NOW ASSIGNED TO: c:\qu\junk.prn
|_SET NOWIDE
|_READ (4) J Y TMX TMN PRC

...SMPL RANGE IS NOW SET TO:        1        56
|_GENR TM=(TMX+TMN)/2
|_GENR TD=TMX-TMN
|_GENR LNTM=LOG(TM+15)
|_GENR LNTD=LOG(TD+1)
|_GENR LNY=LOG(Y)
...WARNING...ILLEGAL LOG  IN OBS.   22, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   23, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   24, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   25, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   26, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   27, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   28, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   29, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   30, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   31, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   32, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   33, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   34, VALUE REPLACED BY ZERO    0.00000E+00
...WARNING...ILLEGAL LOG  IN OBS.   35, VALUE REPLACED BY ZERO    0.00000E+00
|_GENR LNTM=LOG(TM+15)
|_GENR LNTD=LOG(TD+1)
|_GENR DP=0.
|_IF(PRC.GT.0.0) DP=1.0
|_GENR LNPRC=0.
|_IF(PRC.GT.0) LNPRC=LOG(PRC)
|_SKIPIF ((Y.LE.0))
OBSERVATION    22 WILL BE SKIPPED
OBSERVATION    23 WILL BE SKIPPED
OBSERVATION    24 WILL BE SKIPPED
OBSERVATION    25 WILL BE SKIPPED
OBSERVATION    26 WILL BE SKIPPED
OBSERVATION    27 WILL BE SKIPPED
OBSERVATION    28 WILL BE SKIPPED
OBSERVATION    29 WILL BE SKIPPED
OBSERVATION    30 WILL BE SKIPPED
OBSERVATION    31 WILL BE SKIPPED
OBSERVATION    32 WILL BE SKIPPED
OBSERVATION    33 WILL BE SKIPPED
OBSERVATION    34 WILL BE SKIPPED
```

```
OBSERVATION    35 WILL BE SKIPPED
|_STAT   LNTD LNTM LNPRC / PCOR
NAME          N    MEAN          ST. DEV        VARIANCE      MINIMUM       MAXIMUM
LNTD         42    1.8471        0.61279        0.37551       0.40547        2.6247
LNTM         42    2.7792        0.16603        0.27567E-01   2.4596         3.0634
LNPRC        42  0.67973E-02     0.48032        0.23071      -1.3863         1.6253

 CORRELATION MATRIX OF VARIABLES -       42 OBSERVATIONS


LNTD       1.00000
LNTM       0.58901      1.00000
LNPRC     -0.43129E-01 -0.18633      1.00000
             LNTD         LNTM         LNPRC


|_OLS Y  TD TM DP /GF RSTAT LM

REQUIRED MEMORY IS PAR=     9 CURRENT PAR=  250
OLS ESTIMATION
     42 OBSERVATIONS      DEPENDENT VARIABLE = Y
...NOTE..SAMPLE RANGE SET TO:     1,    56

 R-SQUARE =  0.4758      R-SQUARE ADJUSTED =  0.4344
VARIANCE OF THE ESTIMATE =   2.5374
STANDARD ERROR OF THE ESTIMATE =    1.5929
LOG OF THE LIKELIHOOD FUNCTION = -77.0473


VARIABLE    ESTIMATED   STANDARD    T-RATIO     PARTIAL STANDARDIZED ELASTICITY
  NAME     COEFFICIENT    ERROR      38 DF        CORR.  COEFFICIENT  AT MEANS

TD          0.15258     0.81501E-01  1.8721      0.2906  0.28047      0.28723
TM          0.36260     0.11463      3.1632      0.4565  0.46645      0.13992
DP         -0.21257     0.56614     -0.37548    -0.0608 -0.46958E-01 -0.19161E-01
CONSTANT    2.0328      0.58877      3.4527      0.4887  0.00000E+00  0.59201

DURBIN-WATSON = 2.1998     VON NEUMAN RATIO = 2.2535     RHO = -0.12279
RESIDUAL SUM =  0.19318E-13  RESIDUAL VARIANCE =    2.5374
SUM OF ABSOLUTE ERRORS=    52.031
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.4758
RUNS TEST:    26 RUNS,    21 POSITIVE,    21 NEGATIVE, NORMAL STATISTIC =    1.2498
COEFFICIENT OF SKEWNESS =  -0.0239 WITH STANDARD DEVIATION OF 0.3654
COEFFICIENT OF EXCESS KURTOSIS =  -0.4282 WITH STANDARD DEVIATION OF 0.7166

     GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 10 GROUPS
OBSERVED  0.0  1.0  2.0 10.0  8.0  9.0  7.0  4.0  1.0  0.0
EXPECTED  0.3  1.2  3.3  6.7  9.5  9.5  6.7  3.3  1.2  0.3
CHI-SQUARE =     3.3120 WITH  4 DEGREES OF FREEDOM

JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
CHI-SQUARE =     0.4741 WITH  2 DEGREES OF FREEDOM
|_* DELETE SKIP$
|_SET NOSKIP
|_FC /BEG=22 END=35 LIST

REQUIRED MEMORY IS PAR=     7 CURRENT PAR=  250
DEPENDENT VARIABLE = Y                   14 OBSERVATIONS
FORECAST COEFFICIENTS
  0.152577643416      0.362604905950      -0.212571620909       2.03284852067

 OBSERVATION             OBSERVED          PREDICTED        CALCULATED
     NO.                   VALUE             VALUE            RESIDUAL
     22                 0.00000E+00        1.9574           -1.9574
                                           *    I
     23                 0.00000E+00        3.2893           -3.2893
                                      *         I
     24                 0.00000E+00        6.0939           -6.0939
                             *                  I
```

```
     25              0.00000E+00       5.9220          -5.9220
                               *           I
     26              0.00000E+00       5.3085          -5.3085
                                *          I
     27              0.00000E+00       3.3177          -3.3177
                                   *       I
     28              0.00000E+00       3.7022          -3.7022
                                  *        I
     29              0.00000E+00       3.0083          -3.0083
                                   *       I
     30              0.00000E+00       3.4954          -3.4954
                                   *       I
     31              0.00000E+00       2.7753          -2.7753
                                    *      I
     32              0.00000E+00       2.9594          -2.9594
                                   *       I
     33              0.00000E+00       2.5922          -2.5922
                                    *      I
     34              0.00000E+00       2.1700          -2.1700
                                     *     I
     35              0.00000E+00       3.2893          -3.2893
                                   *       I
SUM OF ABSOLUTE ERRORS=   49.881
R-SQUARE BETWEEN OBSERVEO ANO PREOICTEO = 0.0000
MEAN ERROR =  -3.5629
SUM-SQUAREO ERRORS =    199.73
MEAN SQUARE ERROR =    14.266
MEAN ABSOLUTE ERROR=   3.5629
ROOT MEAN SQUARE ERROR =    3.7771
THEIL INEQUALITY COEFFICIENT U = 0.000
  OECOMPOSITION
     PROPORTION OUE TO BIAS =  0.88983
     PROPORTION DUE TO VARIANCE =  0.11017
     PROPORTION OUE TO COVARIANCE =  0.56921E-17
  OECOMPOSITION
     PROPORTION OUE TO BIAS =  0.88983
     PROPORTION OUE TO REGRESSION =  0.11017
     PROPORTION OUE TO OISTURBANCE = -0.19516E-17
|_PRINT Y TO /BEG=22 END=35
      Y              TO
  0.0000000E+00   2.800000
  0.0000000E+00   4.400000
  0.0000000E+00   12.80000
  0.0000000E+00   12.30000
  0.0000000E+00   12.20000
  0.0000000E+00   4.500000
  0.0000000E+00   5.000000
  0.0000000E+00   7.700000
  0.0000000E+00   12.20000
  0.0000000E+00   9.500000
  0.0000000E+00   9.400000
  0.0000000E+00   8.300000
  0.0000000E+00   2.800000
  0.0000000E+00   4.400000
|_SET SKIP
|_SKIPIF ((Y.LE.0))
|_OLS LNY LNTO  LNTM OP /GF RSTAT LOGLOG LM

REQUIREO MEMORY IS PAR=    9 CURRENT PAR=  250
OLS ESTIMATION
      42 OBSERVATIONS     OEPENOENT VARIABLE = LNY
...NOTE..SAMPLE RANGE SET TO:    1,    56

 R-SQUARE =  0.4039     R-SQUARE AOJUSTEO =  0.3569
VARIANCE OF THE ESTIMATE =  0.25553
STANOARO ERROR OF THE ESTIMATE =  0.50550
LOG OF THE LIKELIHOOD FUNCTION(IF OEPVAR LOG) = -72.7779
```

VARIABLE NAME	ESTIMATED COEFFICIENT	STANDARD ERROR	T-RATIO 38 DF	PARTIAL CORR.	STANDARDIZED COEFFICIENT	ELASTICITY AT MEANS
LNTD	0.32903	0.16064	2.0482	0.3153	0.31987	0.32903
LNTM	1.4849	0.59579	2.4923	0.3748	0.39113	1.4849
DP	-0.43436E-02	0.17679	-0.24568E-01	-0.0040	-0.32243E-02	-0.43436E-02
CONSTANT	-3.6871	1.5242	-2.4191	-0.3653	0.00000E+00	-3.6871

```
DURBIN-WATSON = 2.2671     VON NEUMAN RATIO = 2.3224     RHO = -0.15516
RESIDUAL SUM =  0.69833E-13  RESIDUAL VARIANCE =  0.25553
SUM OF ABSOLUTE ERRORS=   16.762
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.4039
RUNS TEST:   22 RUNS,   23 POSITIVE,   19 NEGATIVE, NORMAL STATISTIC =  0.60071E-01
COEFFICIENT OF SKEWNESS =  -0.3290 WITH STANDARD DEVIATION OF 0.3654
COEFFICIENT OF EXCESS KURTOSIS =   0.0467 WITH STANDARD DEVIATION OF 0.7166

     GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 10 GROUPS
OBSERVED  0.0  2.0  2.0  8.0  7.0  9.0 12.0  1.0  1.0  0.0
EXPECTED  0.3  1.2  3.3  6.7  9.5  9.5  6.7  3.3  1.2  0.3
CHI-SQUARE =     8.6227 WITH  4 DEGREES OF FREEDOM

JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
CHI-SQUARE =     0.7209 WITH  2 DEGREES OF FREEDOM
|_SET NOSKIP
|_* DELETE SKIP$


|_FC /BEG=22 END=35  LIST

REQUIRED MEMORY IS PAR=    7 CURRENT PAR=  250
DEPENDENT VARIABLE = LNY              14 OBSERVATIONS
FORECAST COEFFICIENTS
  0.329029064887       1.48490440482      -0.434357106510E-02  -3.68714901287

 OBSERVATION           OBSERVED          PREDICTED        CALCULATED
     NO.                 VALUE             VALUE           RESIDUAL
     22              0.00000E+00        0.68757          -0.68757
                                          *     I
     23              0.00000E+00         1.0878           -1.0878
                                      *         I
     24              0.00000E+00         1.7209           -1.7209
                               *                I
     25              0.00000E+00         1.6530           -1.6530
                                *               I
     26              0.00000E+00         1.5262           -1.5262
                                  *             I
     27              0.00000E+00         1.0499           -1.0499
                                      *         I
     28              0.00000E+00         1.1525           -1.1525
                                     *          I
     29              0.00000E+00        0.99037          -0.99037
                                      *         I
     30              0.00000E+00         1.0699           -1.0699
                                      *         I
     31              0.00000E+00        0.90093          -0.90093
                                       *        I
     32              0.00000E+00        0.95908          -0.95908
                                       *        I
     33              0.00000E+00        0.86100          -0.86100
                                       *        I
     34              0.00000E+00        0.69192          -0.69192
                                          *     I
     35              0.00000E+00         1.0878           -1.0878
                                      *         I
SUM OF ABSOLUTE ERRORS=   15.439
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.0000
MEAN ERROR =  -1.1028
SUM-SQUARED ERRORS =   18.370
MEAN SQUARE ERROR =   1.3122
```

```
MEAN ABSOLUTE ERROR=   1.1028
ROOT MEAN SQUARE ERROR =   1.1455
THEIL INEQUALITY COEFFICIENT U = 0.000
  DECOMPOSITION
     PROPORTION DUE TO BIAS =  0.92681
     PROPORTION DUE TO VARIANCE =  0.73194E-01
     PROPORTION DUE TO COVARIANCE =  0.76436E-17
  DECOMPOSITION
     PROPORTION DUE TO BIAS =  0.92681
     PROPORTION DUE TO REGRESSION =  0.73194E-01
     PROPORTION DUE TO DISTURBANCE =  0.36321E-17
|_PRINT LNY LNTD  LNTM LNPRC/BEG=22 END=35
      LNY              LNTD           LNTM           LNPRC
  0.0000000E+00   1.335001       2.653242        1.720979
  0.0000000E+00   1.686399       2.844909        2.457878
  0.0000000E+00   2.624669       3.063391       -1.386294
  0.0000000E+00   2.587764       3.022861       0.0000000E+00
  0.0000000E+00   2.580217       2.939162       0.0000000E+00
  0.0000000E+00   1.704748       2.812410       0.0000000E+00
  0.0000000E+00   1.791759       2.862201       0.0000000E+00
  0.0000000E+00   2.163323       2.670694       0.0000000E+00
  0.0000000E+00   2.580217       2.631889       0.0000000E+00
  0.0000000E+00   2.351375       2.568788       0.0000000E+00
  0.0000000E+00   2.341806       2.610070       0.0000000E+00
  0.0000000E+00   2.230014       2.568788       0.0000000E+00
  0.0000000E+00   1.335001       2.653242       0.0000000E+00
  0.0000000E+00   1.686399       2.844909       0.5766134
|_STOP
```

CERES Weather File for 1979-80

ORHE	45.83	119.28	0.00	0.00	
79	275	14.12	24.4	4.4	.0
79	276	16.05	24.4	1.7	.0
79	277	15.04	23.9	.6	.0
79	278	14.95	26.7	5.6	.0
79	279	11.30	27.8	5.0	.0
79	280	10.79	25.6	9.4	.0
79	281	13.53	25.6	6.1	.0
79	282	14.64	25.6	2.8	.0
79	283	14.32	21.1	1.1	.0
79	284	14.25	23.9	1.7	.0
79	285	12.69	25.6	1.7	.0
79	286	8.77	24.4	3.3	.0
79	287	7.27	22.2	5.0	.0
79	288	13.53	22.8	11.7	1.8
79	289	6.13	22.8	4.4	.0
79	290	13.08	19.4	1.7	.0
79	291	1.56	17.8	2.8	.0
79	292	6.75	10.0	5.0	16.3
79	293	6.28	15.6	1.1	.0
79	294	10.07	13.3	3.3	8.1
79	295	1.91	15.6	5.6	.0
79	296	4.31	17.2	7.2	.0
79	297	2.51	16.1	6.1	.5
79	298	4.94	12.8	8.9	3.0
79	299	10.34	18.9	5.0	1.3
79	300	9.86	20.6	6.1	3.6
79	301	8.33	17.2	3.3	.0
79	302	11.13	15.6	4.4	.0
79	303	4.08	15.0	1.1	.0
79	304	8.22	10.6	3.9	.0
79	305	9.95	13.3	-5.0	.0
79	306	3.75	11.7	-2.8	.0
79	307	5.39	7.8	-1.1	1.5
79	308	4.84	10.0	2.2	2.8
79	309	7.10	12.2	6.1	.5
79	310	5.07	12.8	1.1	.3
79	311	9.04	13.3	-2.8	.0
79	312	7.64	11.7	-3.9	.0
79	313	5.59	10.0	-.6	.0
79	314	7.11	10.0	-3.9	.3
79	315	2.20	9.4	-3.9	.0
79	316	1.12	4.4	1.1	.0
79	317	1.12	3.9	2.2	.0
79	318	.90	3.9	1.1	.0
79	319	1.42	2.8	.6	.0
79	320	1.75	3.3	.6	5.3
79	321	5.90	3.3	.6	8.4
79	322	7.38	12.8	2.2	.3
79	323	8.59	10.0	-3.9	.0
79	324	8.39	9.4	-6.7	.0
79	325	2.67	6.1	-4.4	.0
79	326	.67	2.2	-2.2	.0
79	327	6.48	2.8	-1.7	7.6
79	328	4.16	9.4	-1.7	5.6
79	329	2.89	6.1	-.6	1.0
79	330	1.78	6.1	-1.1	6.4
79	331	1.40	3.3	-3.3	.0
79	332	1.31	-.6	-3.3	.0
79	333	2.34	-1.7	-5.0	.0
79	334	2.23	-1.7	-5.0	.0
79	335	.99	.0	-6.1	.0
79	336	1.91	.6	-3.3	.8
79	337	1.84	6.7	.0	3.6
79	338	2.02	9.4	2.8	1.3
79	339	1.87	11.7	4.4	.8

79	340	2.16	9.4	2.2	.0
79	341	6.17	11.1	.6	.0
79	342	5.76	11.7	-1.1	.0
79	343	3.71	10.0	-1.1	.0
79	344	6.68	14.4	.6	.0
79	345	4.89	7.8	-5.6	.0
79	346	5.44	8.3	-3.9	.0
79	347	1.49	10.0	.0	.0
79	348	2.53	10.6	1.7	.3
79	349	.56	13.3	6.7	.0
79	350	3.79	11.1	-3.9	1.0
79	351	1.44	1.7	-3.9	.0
79	352	1.81	2.8	-.6	.5
79	353	2.23	6.7	2.2	.3
79	354	3.08	9.4	-2.8	.5
79	355	3.10	10.0	-1.7	.0
79	356	6.13	7.8	.0	.0
79	357	.86	7.8	-5.0	.0
79	358	3.00	4.4	-1.1	1.0
79	359	5.64	5.6	-1.7	3.3
79	360	4.62	6.7	-4.4	.0
79	361	.91	3.9	-3.9	.0
79	362	2.55	.6	-1.7	.3
79	363	1.05	2.2	-1.1	.0
79	364	1.07	1.7	-1.1	.3
79	365	1.54	1.7	-.6	1.0
80	1	5.14	2.2	-1.7	1.3
80	2	1.22	8.3	-2.8	.5
80	3	2.93	2.2	-1.1	1.0
80	4	1.07	4.4	-.6	2.5
80	5	2.79	1.7	-1.1	10.4
80	6	5.14	6.7	-7.8	.0
80	7	2.74	-2.8	-11.7	.0
80	8	.69	-3.9	-10.0	9.7
80	9	.56	-5.0	-8.9	9.9
80	10	7.62	-6.7	-18.3	5.1
80	11	3.76	1.7	-14.4	.0
80	12	3.60	10.6	-7.8	2.5
80	13	2.91	11.7	.0	7.1
80	14	2.46	5.6	-.6	2.0
80	15	4.81	7.2	-2.8	2.8
80	16	2.05	6.1	-2.8	.0
80	17	6.45	4.4	-1.7	1.8
80	18	3.02	7.8	-3.3	.0
80	19	8.34	1.7	-8.9	.0
80	20	4.74	.6	-9.4	.0
80	21	7.45	-.6	-6.7	.0
80	22	2.32	1.7	-9.4	.0
80	23	1.48	.0	-6.1	.0
80	24	5.74	.0	-2.8	.0
80	25	3.13	1.1	-3.9	.0
80	26	7.24	.6	-8.9	.0
80	27	9.03	-3.3	-16.1	.3
80	28	8.15	-5.6	-19.4	.0
80	29	9.11	-6.7	-20.0	.0
80	30	6.51	-6.1	-19.4	.0
80	31	3.97	-5.6	-16.7	.0
80	32	3.27	-3.9	-9.4	2.0
80	33	1.38	-1.7	-5.0	1.3
80	34	7.87	.6	-2.2	.0
80	35	9.50	6.7	-1.7	.0
80	36	4.57	10.6	-2.2	.0
80	37	7.12	3.3	-1.1	3.6
80	38	9.49	12.2	-1.7	.0
80	39	3.55	8.3	-.6	.0
80	40	3.50	4.4	.0	.0
80	41	2.11	4.4	.6	.0
80	42	1.66	3.9	.0	.0
80	43	2.57	2.8	-.6	.0

80	44	1.62	3.3	-1.1	.0
80	45	4.55	1.1	-6.1	1.3
80	46	5.15	-3.3	-6.7	1.8
80	47	4.85	.6	-5.0	.0
80	48	4.13	.6	-2.8	1.0
80	49	2.79	1.7	-1.1	5.8
80	50	6.28	3.9	-.6	.8
80	51	7.48	11.1	1.1	3.3
80	52	10.08	11.7	-3.3	.0
80	53	6.89	10.6	-2.8	.0
80	54	10.24	5.6	-1.7	2.3
80	55	7.43	11.1	-1.1	.0
80	56	5.48	10.0	1.1	.8
80	57	2.37	8.3	2.8	3.3
80	58	3.83	8.3	5.0	2.0
80	59	9.34	12.8	6.1	1.3
80	60	13.47	15.0	.6	.5
80	61	9.13	15.6	2.2	.0
80	62	10.86	12.2	2.8	.0
80	63	8.06	15.0	2.8	.0
80	64	13.77	15.0	5.6	.0
80	65	4.26	15.6	-2.2	4.1
80	66	8.51	1.7	-7.8	5.1
80	67	13.24	5.6	-2.8	.0
80	68	13.27	11.1	1.1	.0
80	69	9.68	14.4	2.8	.0
80	70	13.05	13.3	-1.1	.0
80	71	10.68	16.7	3.9	5.8
80	72	6.82	10.6	1.1	.0
80	73	8.80	11.7	4.4	.0
80	74	16.16	12.8	2.8	2.5
80	75	16.67	11.1	-1.7	.0
80	76	15.56	10.6	-2.2	.0
80	77	4.84	12.2	3.9	.0
80	78	17.35	15.0	3.9	.0
80	79	16.09	15.0	4.4	.0
80	80	5.30	16.7	3.9	1.5
80	81	11.59	11.7	5.0	.0
80	82	17.88	16.1	4.4	.0
80	83	15.16	16.1	3.3	.0
80	84	17.03	13.9	.6	.0
80	85	19.54	12.8	-5.0	.0
80	86	9.20	13.9	-.6	.5
80	87	14.68	13.3	3.3	2.0
80	88	13.06	14.4	-2.8	.0
80	89	4.79	16.1	6.7	.0
80	90	15.67	12.8	1.1	.0
80	91	13.67	14.4	-1.7	.0
80	92	17.70	12.8	-2.2	.0
80	93	18.25	15.0	-4.4	.0
80	94	20.40	13.3	-2.2	.0
80	95	17.76	17.2	3.9	.0
80	96	14.51	20.0	3.9	.5
80	97	16.31	17.8	3.3	.3
80	98	19.74	12.8	-.6	.0
80	99	8.02	13.9	2.8	.0
80	100	18.31	16.1	7.2	1.0
80	101	19.82	17.2	3.3	.0
80	102	23.08	15.6	-1.7	.0
80	103	22.63	19.4	1.7	.0
80	104	22.19	22.8	1.7	.0
80	105	13.02	25.6	11.1	.0
80	106	23.49	21.7	6.1	.0
80	107	23.03	18.3	.6	.0
80	108	17.28	23.9	4.4	.0
80	109	21.73	23.9	2.8	.0
80	110	18.18	25.0	8.3	.0
80	111	7.45	25.0	9.4	2.0
80	112	7.21	13.9	7.2	.8

80	113	4.32	15.0	8.3	.3
80	114	21.11	20.0	10.0	.0
80	115	25.11	21.7	9.4	.0
80	116	25.57	20.0	.6	.0
80	117	25.25	21.7	5.0	.0
80	118	25.34	26.7	7.8	.0
80	119	17.52	30.0	13.3	.0
80	120	26.45	27.2	6.1	.8
80	121	20.71	18.3	5.0	.3
80	122	25.20	17.8	5.0	.0
80	123	18.76	25.0	12.2	.0
80	124	26.80	23.3	2.8	.0
80	125	26.49	25.6	6.1	.0
80	126	18.60	30.0	12.2	.0
80	127	14.61	28.3	8.9	4.1
80	128	26.39	19.4	6.1	.3
80	129	24.00	22.2	7.2	.0
80	130	22.01	21.1	6.7	2.5
80	131	7.73	18.9	9.4	.5
80	132	27.90	15.6	3.3	1.8
80	133	22.73	23.9	11.1	.0
80	134	27.39	23.3	8.9	.0
80	135	11.00	23.9	10.6	.0
80	136	26.32	17.8	6.7	2.8
80	137	28.67	18.9	6.1	.0
80	138	27.50	21.7	7.8	.0
80	139	19.71	23.9	5.6	.0
80	140	25.68	25.6	7.2	.0
80	141	27.18	26.7	8.3	.0
80	142	26.53	29.4	5.0	.0
80	143	24.07	26.7	7.8	5.8
80	144	26.87	18.9	4.4	.0
80	145	14.26	18.9	8.3	.0
80	146	8.05	18.3	9.4	.0
80	147	9.94	17.8	6.7	14.0
80	148	19.45	12.8	7.2	3.0
80	149	22.58	17.8	8.3	.0
80	150	26.51	21.7	8.3	.0
80	151	28.34	23.9	7.2	.0
80	152	28.03	23.9	10.6	.0
80	153	23.85	26.1	11.7	.8
80	154	27.44	19.4	6.7	.0
80	155	27.02	18.9	6.7	.0
80	156	29.70	19.4	4.4	.0
80	157	23.76	22.8	7.2	.0
80	158	22.90	22.2	9.4	.0
80	159	20.44	21.7	9.4	.0
80	160	27.98	25.0	7.8	.3
80	161	23.95	28.9	15.0	.0
80	162	25.70	25.0	11.1	.0
80	163	19.89	25.6	12.8	.0
80	164	5.14	23.9	13.9	.0
80	165	20.42	15.6	10.6	6.1
80	166	12.46	18.9	8.9	1.3
80	167	21.33	20.6	11.1	.0
80	168	28.15	24.4	10.6	.0
80	169	30.38	28.9	11.1	.0
80	170	29.21	24.4	8.9	.0
80	171	28.75	27.2	10.0	.0
80	172	26.31	29.4	11.7	.0
80	173	26.81	28.9	14.4	.0
80	174	15.49	28.3	12.8	.3
80	175	30.48	22.2	10.6	.5
80	176	21.06	23.3	8.3	.3
80	177	19.52	26.7	12.8	1.3
80	178	11.00	20.0	10.0	.3
80	179	30.26	19.4	8.9	4.8
80	180	30.17	25.0	6.7	.0
80	181	31.17	27.8	12.8	.0

80	182	30.66	25.6	7.2	.0
80	183	30.02	27.2	6.7	.0
80	184	14.69	31.1	13.9	.0
80	185	20.63	26.1	10.0	1.5
80	186	19.88	21.1	11.7	.3
80	187	28.71	23.9	8.3	.0
80	188	29.27	26.1	11.1	.0
80	189	26.76	27.2	9.4	.0
80	190	23.64	32.8	13.9	.0
80	191	27.50	34.4	15.0	.0
80	192	28.80	31.1	12.8	.5
80	193	24.55	26.7	9.4	.0
80	194	27.69	22.8	10.6	.0
80	195	28.01	20.6	12.8	.0
80	196	26.20	30.0	16.7	.0
80	197	29.68	28.9	14.4	.0
80	198	24.07	31.1	12.8	.0
80	199	29.13	30.0	12.2	.0
80	200	25.62	29.4	12.2	.0
80	201	28.33	30.6	15.6	.0
80	202	28.29	30.0	12.8	.0
80	203	28.39	33.3	12.8	.0
80	204	27.66	37.8	17.2	.0
80	205	27.62	36.7	18.3	.0
80	206	27.39	31.7	13.3	.0
80	207	26.62	31.7	16.7	.0
80	208	27.12	33.3	13.3	.0
80	209	27.85	35.0	13.9	.0
80	210	27.32	36.1	13.3	.0
80	211	27.58	36.7	16.7	.0
80	212	28.16	31.7	13.9	.0
80	213	24.05	33.3	13.9	.0
80	214	27.89	35.6	17.8	.0
80	215	23.07	31.7	17.8	.0
80	216	27.68	28.9	12.2	.0
80	217	27.33	26.7	8.3	.0
80	218	27.44	30.0	10.6	.0
80	219	26.46	25.6	10.0	.0
80	220	26.61	27.2	8.9	.0
80	221	23.75	30.0	9.4	.0
80	222	25.37	30.6	11.7	.0
80	223	23.07	31.1	10.6	.0
80	224	21.65	33.9	16.7	.0
80	225	24.41	34.4	18.3	.0
80	226	24.39	32.2	15.0	.0
80	227	23.03	32.2	17.2	.0
80	228	25.03	29.4	13.9	.0
80	229	24.43	27.8	13.9	.0
80	230	11.71	22.2	14.4	.0
80	231	12.06	24.4	12.2	.0
80	232	24.47	22.2	12.2	.0
80	233	24.91	28.3	15.6	.0
80	234	24.58	28.3	7.2	.0
80	235	23.68	28.3	8.9	.0
80	236	24.02	29.4	14.4	.0
80	237	23.55	30.0	16.1	.0
80	238	23.42	27.8	5.6	.0
80	239	22.38	27.2	7.2	.0
80	240	23.76	29.4	13.9	.0
80	241	23.57	23.9	8.3	.0
80	242	21.87	21.7	3.3	.0
80	243	15.20	19.4	7.2	.0
80	244	20.79	16.7	12.2	.0
80	245	19.08	23.9	9.4	.0
80	246	20.85	27.2	9.4	2.3
80	247	22.32	22.8	5.0	.0
80	248	22.03	23.3	3.9	.0
80	249	21.12	28.3	7.8	.0
80	250	18.08	30.6	12.8	.0

80	251	19.49	33.3	15.6	.0
80	252	18.47	28.3	7.2	.0
80	253	18.85	27.8	9.4	.0
80	254	9.30	28.9	13.3	.0
80	255	19.70	26.7	15.6	.0
80	256	10.46	30.6	15.0	.0
80	257	10.22	24.4	10.6	13.2
80	258	17.89	18.9	10.0	3.0
80	259	19.39	23.9	8.3	.0
80	260	19.35	26.7	8.3	.0
80	261	19.53	31.1	13.3	.0
80	262	7.05	31.1	15.0	.0
80	263	12.94	22.2	12.8	.5
80	264	15.81	22.2	12.8	.0
80	265	18.56	20.6	8.9	.0
80	266	14.09	21.1	3.9	.0
80	267	17.90	22.8	8.9	.0
80	268	17.87	23.9	5.6	.0
80	269	16.64	23.9	3.3	.0
80	270	15.03	23.3	6.7	.0
80	271	14.88	24.4	6.1	.0
80	272	16.41	26.7	9.4	.0
80	273	16.43	25.6	7.8	.0
80	274	13.49	28.9	12.2	.0

CERES Weather File for 1985-86

ORHE	45.83	119.28	0.00	0.00	
85	275	13.23	18.3	5.6	.0
85	276	15.67	24.4	10.6	.0
85	277	15.22	21.1	.0	.0
85	278	14.61	20.0	2.2	.0
85	279	8.58	23.9	9.4	.0
85	280	8.44	20.0	5.0	19.6
85	281	14.90	9.4	-2.8	.0
85	282	14.70	8.9	-3.9	.0
85	283	12.59	11.7	-2.2	.0
85	284	8.70	17.2	3.3	.8
85	285	14.34	17.2	4.4	.0
85	286	13.07	16.1	.6	.0
85	287	4.07	16.7	2.8	.0
85	288	12.67	16.7	8.3	.0
85	289	12.15	23.3	11.7	.0
85	290	12.85	18.3	3.3	1.8
85	291	12.01	19.4	2.8	.0
85	292	4.37	19.4	3.9	.0
85	293	5.06	15.6	4.4	.0
85	294	4.86	16.1	5.6	.0
85	295	3.77	14.4	5.6	.5
85	296	4.66	16.1	9.4	.0
85	297	5.01	15.6	7.2	.0
85	298	9.29	22.2	8.9	.0
85	299	7.93	17.2	1.1	.0
85	300	10.98	16.1	3.9	.0
85	301	10.91	21.1	5.6	.0
85	302	10.74	12.8	-2.8	.0
85	303	8.28	11.7	-3.3	.0
85	304	2.44	16.1	2.8	.0
85	305	6.20	10.0	2.8	.0
85	306	3.36	18.3	8.3	.0
85	307	5.89	17.2	6.7	.0
85	308	1.55	17.8	8.9	.0
85	309	3.87	12.2	2.8	9.4
85	310	5.30	11.1	6.1	.0
85	311	2.55	13.9	9.4	.3
85	312	6.12	17.8	3.9	5.6
85	313	4.87	18.3	-1.1	2.0
85	314	2.11	10.0	-1.7	.0
85	315	8.13	.6	-3.3	1.8
85	316	8.56	1.1	-12.2	.0
85	317	8.78	-1.1	-11.7	.0
85	318	8.30	.6	-11.1	.0
85	319	1.99	.6	-10.0	1.3
85	320	5.68	.0	-3.9	4.6
85	321	4.55	7.2	-.6	3.6
85	322	8.24	6.7	-2.8	1.5
85	323	2.65	5.0	-5.0	.0
85	324	3.71	-3.3	-5.6	4.8
85	325	4.89	-2.8	-11.1	2.5
85	326	6.82	-4.4	-8.9	3.0
85	327	5.48	-3.3	-23.9	.0
85	328	4.79	-12.2	-23.9	.0
85	329	4.14	-12.2	-20.0	1.3
85	330	8.60	-7.8	-15.6	.8
85	331	2.75	-1.7	-15.6	.0
85	332	3.20	-9.4	-13.3	1.3
85	333	3.59	-11.1	-13.3	1.8
85	334	4.32	-7.2	-12.2	.0
85	335	3.91	-7.8	-21.7	.5
85	336	2.41	-11.7	-20.6	7.6
85	337	6.88	-2.2	-11.7	1.5
85	338	4.67	6.7	-5.6	.0
85	339	4.54	3.9	-7.8	.0

85	340	2.57	1.7	-5.0	1.8
85	341	2.79	1.1	-1.1	4.1
85	342	2.28	1.1	.0	.0
85	343	5.65	1.1	-3.9	.0
85	344	5.57	.0	-7.8	.0
85	345	5.39	1.7	-12.8	.0
85	346	5.45	-1.1	-8.9	.0
85	347	3.67	-.6	-11.7	.0
85	348	2.34	-5.0	-8.9	.0
85	349	3.01	-5.6	-7.8	.0
85	350	2.26	-5.0	-7.2	.0
85	351	2.22	-5.6	-8.3	.0
85	352	2.30	-6.7	-8.3	.0
85	353	2.38	-6.1	-8.3	.0
85	354	2.43	-5.6	-6.7	.0
85	355	1.76	-4.4	-6.1	.0
85	356	1.83	-5.0	-6.1	.0
85	357	1.67	-5.0	-6.1	.0
85	358	1.60	-3.9	-5.6	.0
85	359	1.92	-4.4	-6.7	.0
85	360	2.22	-5.0	-6.7	.0
85	361	2.76	-5.0	-6.7	.3
85	362	3.13	-4.4	-7.8	.3
85	363	3.93	-4.4	-7.8	.0
85	364	2.41	-2.8	-6.7	.0
85	365	2.84	-4.4	-6.7	.0
86	1	3.54	-3.3	-6.7	3.6
86	2	4.14	5.6	-5.0	.0
86	3	5.53	1.7	-5.0	.0
86	4	2.71	1.7	-3.3	.0
86	5	2.28	-1.1	-5.6	2.5
86	6	6.92	6.1	-2.2	3.0
86	7	5.32	7.8	-5.6	.0
86	8	6.74	2.2	-5.6	.0
86	9	3.54	6.7	-1.7	1.3
86	10	1.78	3.9	.0	.8
86	11	6.89	5.6	-1.7	.0
86	12	2.57	6.7	-5.0	.0
86	13	1.47	.0	-3.9	.0
86	14	2.38	.0	-3.9	.0
86	15	4.05	-.6	-3.9	.0
86	16	2.95	2.2	-3.3	.8
86	17	3.95	6.7	-.6	4.6
86	18	3.21	7.2	.0	.8
86	19	2.12	13.3	.6	.0
86	20	6.78	8.3	3.9	.0
86	21	5.05	9.4	-2.2	.0
86	22	1.76	6.1	-1.1	.3
86	23	4.99	4.4	.6	7.6
86	24	8.28	12.2	1.1	.0
86	25	8.17	10.6	-2.8	.0
86	26	5.00	5.6	-4.4	.0
86	27	2.49	2.2	-2.2	1.0
86	28	2.08	3.3	-.6	1.3
86	29	1.66	2.2	.6	4.3
86	30	3.28	2.8	1.1	4.8
86	31	1.89	6.1	2.2	3.3
86	32	5.99	6.7	3.3	.5
86	33	3.54	12.8	3.3	3.6
86	34	6.95	7.8	1.1	.5
86	35	5.08	8.3	2.2	1.5
86	36	7.74	10.0	3.3	2.5
86	37	4.14	10.6	2.2	.0
86	38	6.44	6.7	-4.4	.0
86	39	10.85	5.6	-6.1	.0
86	40	8.16	6.1	-5.6	.0
86	41	3.81	5.6	-2.8	.0
86	42	5.85	2.2	-1.1	.0
86	43	3.25	3.9	-1.7	10.2

86	44	6.62	3.9	-6.7	2.8
86	45	3.67	1.7	-4.4	1.5
86	46	8.18	3.9	-5.6	10.7
86	47	7.44	4.4	-4.4	.0
86	48	6.36	8.3	1.1	4.6
86	49	2.84	5.0	1.1	4.3
86	50	8.42	1.1	-1.7	.3
86	51	10.31	1.1	-3.9	.0
86	52	4.32	9.4	-1.7	.0
86	53	4.26	8.9	3.3	4.6
86	54	3.66	11.7	5.0	13.0
86	55	11.62	16.7	7.2	.0
86	56	5.01	22.8	8.9	.0
86	57	8.86	17.2	6.1	.0
86	58	10.69	16.7	1.7	.0
86	59	11.81	14.4	.0	.0
86	60	7.66	15.6	2.8	.0
86	61	12.21	16.7	1.7	.0
86	62	12.55	13.9	.0	.0
86	63	13.86	13.3	1.7	.0
86	64	11.13	18.3	.0	.0
86	65	7.30	16.1	3.9	.0
86	66	5.90	17.2	7.8	2.0
86	67	4.69	16.7	3.9	.3
86	68	14.33	10.0	5.6	1.5
86	69	9.62	16.7	6.1	.5
86	70	13.53	15.6	2.8	1.0
86	71	15.46	16.1	5.0	1.3
86	72	6.46	15.0	.6	.0
86	73	15.91	11.7	2.2	2.5
86	74	6.96	12.8	.6	.0
86	75	8.45	10.6	3.3	3.0
86	76	15.52	12.8	5.0	1.0
86	77	10.11	15.0	3.9	.0
86	78	17.60	15.6	4.4	.5
86	79	16.04	19.4	1.1	.0
86	80	13.77	18.9	5.6	.0
86	81	14.11	16.7	-1.1	.0
86	82	6.28	13.9	1.1	.0
86	83	18.59	10.0	5.0	12.4
86	84	17.14	14.4	1.7	.0
86	85	14.16	15.6	6.7	.0
86	86	15.12	19.4	3.9	.0
86	87	15.73	21.1	7.8	.0
86	88	17.66	22.2	9.4	.0
86	89	14.20	21.1	10.0	2.0
86	90	17.05	15.0	-1.7	.0
86	91	18.03	15.0	3.3	.0
86	92	18.08	13.3	2.8	.0
86	93	18.04	16.7	-1.1	.0
86	94	15.95	16.7	6.1	.0
86	95	21.11	16.7	.6	.0
86	96	21.65	17.8	-.6	.0
86	97	21.45	20.6	1.1	.0
86	98	21.62	22.8	6.1	.0
86	99	20.35	21.7	9.4	.0
86	100	22.92	18.3	4.4	.0
86	101	7.84	16.1	1.1	.0
86	102	17.18	12.2	3.9	.3
86	103	22.57	13.9	5.6	4.8
86	104	15.79	15.0	2.8	.0
86	105	9.50	17.8	5.6	.0
86	106	13.69	18.9	1.1	.5
86	107	20.45	16.1	8.9	.0
86	108	22.20	16.7	5.0	.0
86	109	17.36	16.7	2.8	.0
86	110	23.47	21.7	2.8	.0
86	111	24.56	28.3	7.8	.0
86	112	4.96	28.3	10.0	.0

86	113	23.61	11.7	1.7	.0
86	114	16.34	13.9	-2.2	.0
86	115	23.68	14.4	3.9	.0
86	116	17.34	13.9	2.2	.0
86	117	20.75	15.6	7.2	3.8
86	118	24.71	17.8	3.9	.0
86	119	26.68	14.4	3.9	.0
86	120	22.58	15.0	-1.7	.0
86	121	14.18	18.9	3.3	.0
86	122	13.26	19.4	8.9	.0
86	123	11.18	17.2	8.3	.5
86	124	23.62	15.6	6.7	.0
86	125	16.31	18.3	3.9	.0
86	126	16.52	17.8	3.3	13.7
86	127	25.85	13.9	5.6	.0
86	128	28.12	18.9	6.7	.0
86	129	20.35	20.0	7.2	.0
86	130	19.59	18.3	6.1	.0
86	131	25.83	15.0	4.4	.0
86	132	18.50	17.2	6.1	.0
86	133	24.30	18.9	10.0	.0
86	134	25.85	15.6	5.0	.0
86	135	26.10	17.2	1.1	.0
86	136	25.03	18.9	1.7	.0
86	137	26.79	22.2	8.9	.0
86	138	20.14	26.7	12.8	.0
86	139	24.44	26.1	10.6	.0
86	140	8.73	27.2	11.7	.0
86	141	16.57	17.8	6.7	13.5
86	142	28.67	16.7	5.6	.0
86	143	22.16	18.3	4.4	.0
86	144	26.10	21.7	7.8	.0
86	145	28.20	27.8	7.8	.0
86	146	27.96	31.7	18.3	.0
86	147	27.84	31.1	16.1	.0
86	148	27.57	30.0	17.2	.0
86	149	27.41	32.2	17.2	.0
86	150	27.78	35.6	18.3	.0
86	151	27.94	37.8	17.8	.0
86	152	26.66	38.9	20.6	.0
86	153	25.03	37.8	18.9	.0
86	154	26.22	34.4	20.0	.0
86	155	26.87	32.8	18.3	.0
86	156	27.01	29.4	16.1	.0
86	157	25.60	30.0	12.8	.0
86	158	26.35	25.6	13.3	.0
86	159	29.93	25.0	10.6	.0
86	160	29.73	23.9	9.4	.0
86	161	29.30	28.3	10.0	.0
86	162	29.67	32.8	13.3	.0
86	163	28.94	33.3	13.9	.0
86	164	28.83	32.2	11.7	.0
86	165	18.55	35.0	17.8	.0
86	166	27.21	26.1	10.0	.0
86	167	29.61	25.0	13.3	.0
86	168	28.69	27.8	9.4	.0
86	169	20.60	31.1	14.4	.0
86	170	26.80	21.7	7.2	.0
86	171	29.72	22.8	12.2	.0
86	172	30.15	23.9	9.4	.0
86	173	27.94	26.7	8.3	.0
86	174	29.75	31.1	10.6	.0
86	175	27.94	35.0	18.9	.0
86	176	28.45	32.8	18.3	.0
86	177	14.75	32.2	12.8	.0
86	178	24.22	29.4	13.3	.3
86	179	16.02	33.3	16.1	.0
86	180	28.99	30.0	14.4	.0
86	181	29.18	25.0	11.1	.0

86	182	24.73	30.0	12.8	.0
86	183	11.44	31.7	18.9	.0
86	184	21.79	23.9	14.4	.3
86	185	13.74	22.2	8.9	6.4
86	186	29.94	18.9	10.0	1.3
86	187	29.94	23.9	6.7	.0
86	188	26.31	29.4	9.4	.0
86	189	26.14	31.7	16.7	.0
86	190	20.78	29.4	17.8	.0
86	191	12.23	25.6	15.6	.0
86	192	29.46	24.4	14.4	.5
86	193	29.13	26.1	12.8	.0
86	194	29.15	26.1	11.7	.0
86	195	29.38	28.3	13.9	.0
86	196	27.48	27.2	11.1	.0
86	197	16.05	23.9	11.7	.0
86	198	28.32	22.8	10.6	1.0
86	199	24.56	25.6	9.4	.0
86	200	27.98	30.0	11.1	.0
86	201	27.86	35.0	12.8	.0
86	202	27.87	35.0	13.9	.0
86	203	27.79	35.6	18.3	.0
86	204	26.95	31.7	15.0	.0
86	205	27.29	27.8	14.4	.0
86	206	23.24	30.6	16.7	.0
86	207	24.14	30.0	14.4	.0
86	208	26.94	28.3	11.7	.0
86	209	26.91	26.1	12.8	.0
86	210	23.99	28.3	13.3	.0
86	211	25.71	26.7	9.4	.0
86	212	26.32	28.3	7.8	.0
86	213	26.47	31.1	9.4	.0
86	214	18.72	35.0	12.8	.0
86	215	26.21	33.9	13.9	.0
86	216	26.38	35.6	15.6	.0
86	217	26.01	32.2	16.7	.0
86	218	25.95	32.2	12.2	.0
86	219	24.60	33.3	12.2	.0
86	220	24.53	36.1	15.0	.0
86	221	24.29	37.8	16.1	.0
86	222	24.42	38.3	21.7	.0
86	223	24.27	33.9	16.7	.0
86	224	24.66	28.9	16.7	.0
86	225	24.17	30.0	13.9	.0
86	226	24.36	32.8	15.0	.0
86	227	24.07	36.7	16.1	.0
86	228	21.18	32.2	10.0	.0
86	229	22.47	31.7	14.4	.0
86	230	23.51	33.9	13.9	.0
86	231	23.32	35.0	17.2	.0
86	232	20.72	31.7	11.1	.0
86	233	21.51	31.7	15.0	.0
86	234	21.80	34.4	13.9	.0
86	235	22.27	32.2	17.8	.0
86	236	20.54	31.1	17.2	.0
86	237	18.60	31.1	12.2	.0
86	238	22.44	31.7	12.2	.0
86	239	19.64	34.4	14.4	.0
86	240	10.11	38.3	18.9	.0
86	241	18.76	31.1	17.2	.5
86	242	18.06	30.6	15.6	.0
86	243	21.61	26.7	14.4	.0
86	244	20.93	28.3	13.3	.0
86	245	21.45	30.0	15.0	.0
86	246	21.41	30.0	12.8	.0
86	247	21.16	30.6	11.7	.0
86	248	20.33	33.3	11.7	.0
86	249	20.34	30.0	11.1	.0
86	250	19.83	25.6	8.9	.0

86	251	19.25	28.3	13.9	.0
86	252	20.32	23.3	11.1	.0
86	253	17.55	24.4	12.8	.0
86	254	20.50	24.4	5.0	.0
86	255	13.61	21.7	4.4	.0
86	256	15.65	21.1	6.7	.8
86	257	16.74	21.1	5.0	.0
86	258	13.08	20.6	9.4	.0
86	259	16.33	21.7	6.1	5.6
86	260	7.58	20.0	8.9	.3
86	261	19.36	21.1	10.6	3.3
86	262	15.58	20.6	6.1	.0
86	263	15.75	20.6	7.8	2.5
86	264	17.61	21.1	6.7	.0
86	265	18.48	21.1	4.4	.0
86	266	3.95	23.3	6.7	.0
86	267	14.42	17.2	6.7	5.1
86	268	9.68	17.2	2.8	.0
86	269	18.30	18.3	6.1	2.5
86	270	12.98	17.8	6.1	.0
86	271	14.19	18.9	6.7	.3
86	272	5.63	19.4	10.6	.5
86	273	10.68	17.8	9.4	4.6
86	274	13.99	18.9	8.3	.5

CERES Weather File for 1987-88

ORHE	45.83	119.28	0.00	0.00	
1987	274	15.86	28.3	6.7	0.00
	275	14.94	30.0	6.7	0.00
	276	13.01	25.0	15.0	0.00
	277	14.64	25.0	8.3	0.00
	278	15.52	27.2	5.0	0.00
	279	15.06	26.7	5.0	0.00
	280	13.51	30.0	6.7	0.00
	281	13.51	25.6	10.0	0.00
	282	14.23	21.1	5.0	0.00
	283	14.85	19.4	0.6	0.00
	284	14.56	19.4	0.6	0.00
	285	11.92	21.1	2.8	0.00
	286	13.77	21.7	2.2	0.00
	287	6.82	16.7	1.7	0.00
	288	12.93	17.8	2.8	0.00
	289	12.89	19.4	-2.2	0.00
	290	6.15	20.6	1.7	0.00
	291	12.51	18.3	0.6	0.00
	292	12.51	17.8	0.0	0.00
	293	12.38	17.8	-2.2	0.00
	294	11.76	18.9	-2.2	0.00
	295	11.21	18.9	-1.1	0.00
	296	7.66	17.22	-1.67	0.00
	297	7.53	17.78	-0.56	0.00
	298	6.57	22.22	2.78	0.00
	299	5.73	21.11	1.67	0.00
	300	7.70	18.89	-1.11	0.00
	301	7.70	18.33	-2.22	0.00
	302	7.49	18.89	-0.56	0.00
	303	5.19	16.67	4.44	0.00
	304	2.85	16.11	8.89	0.00
	305	4.44	17.78	6.11	1.52
	306	3.39	15.56	7.78	0.00
	307	1.30	14.44	3.33	0.00
	308	6.53	17.22	2.22	0.00
	309	6.49	16.11	0.00	0.00
	310	6.07	13.89	0.00	0.00
	311	3.22	13.89	3.33	0.00
	312	4.27	16.67	0.00	0.00
	313	4.35	11.11	2.22	0.00
	314	4.02	17.22	0.56	0.00
	315	4.35	13.33	2.22	0.00
	316	2.80	16.11	7.22	3.05
	317	2.80	15.56	8.33	2.54
	318	2.64	15.56	3.89	0.00
	319	5.36	11.67	3.33	0.00
	320	2.05	10.00	2.78	0.00
	321	6.03	12.78	-6.67	0.00
	322	5.15	7.78	-5.56	0.00
	323	4.31	7.22	-3.89	0.00
	324	4.02	8.33	-3.89	0.00
	325	2.51	10.00	-2.22	0.00
	326	3.01	12.22	-1.67	0.00
	327	2.30	12.22	0.56	0.25
	328	4.81	13.33	2.22	0.00
	329	0.63	11.67	2.22	0.00
	330	4.52	11.11	-6.11	0.00
	331	3.77	7.22	-3.89	0.00
	332	2.76	5.00	-5.00	0.00
	333	1.26	6.11	-1.67	0.00
	334	1.46	3.89	-3.89	1.02
	335	1.21	2.22	-1.67	1.27
	336	0.42	10.00	1.67	6.86
	337	3.01	13.89	2.78	3.81
	338	1.34	12.22	1.67	1.52

	339	2.30	10.56	5.00	2.79
	340	0.59	16.11	5.00	1.27
	341	1.55	19.44	3.89	0.00
	342	2.64	11.67	0.56	0.00
	343	1.84	11.67	1.11	2.03
	344	2.89	18.89	5.56	5.33
	345	3.97	10.56	2.78	0.00
	346	3.05	8.33	-1.11	0.00
	347	3.72	6.67	-5.56	0.00
	348	3.81	4.44	-5.00	0.00
	349	1.80	1.67	-3.89	0.00
	350	0.88	1.11	-1.11	0.25
	351	0.63	1.67	-0.56	2.54
	352	2.05	1.11	-3.89	0.00
	353	2.38	3.33	-2.78	0.00
	354	0.79	-1.11	-3.89	0.00
	355	0.38	3.89	-3.33	0.00
	356	2.26	6.67	-1.11	0.00
	357	1.59	5.00	-6.11	0.00
	358	5.02	0.56	-7.78	0.00
	359	5.02	2.78	-7.78	0.00
	360	0.50	-3.33	-5.56	0.00
	361	0.50	-2.78	-4.44	0.00
	362	0.46	-3.89	-6.11	0.00
	363	0.46	-3.89	-6.67	3.05
	364	1.88	-3.89	-6.11	2.54
	365	2.30	-0.56	-8.33	0.00
1988	1	6.36	2.2	-6.1	0.00
	2	3.97	1.7	-6.1	0.00
	3	3.22	-3.3	-6.7	0.00
	4	3.26	-5.0	-7.2	0.51
	5	3.93	-3.3	-6.7	4.32
	6	4.14	-0.6	-4.4	0.00
	7	2.64	-1.1	-5.6	0.00
	8	3.26	3.9	-4.4	1.78
	9	2.85	-1.1	-6.1	0.00
	10	2.93	4.4	-1.1	6.35
	11	6.90	3.9	-0.6	2.54
	12	5.27	6.1	-1.1	0.00
	13	2.51	2.2	-1.1	1.52
	14	3.93	5.6	-0.6	2.79
	15	6.86	8.3	1.7	5.33
	16	3.93	5.6	-0.6	0.00
	17	7.91	5.6	-2.8	0.00
	18	2.01	0.6	-2.8	0.00
	19	6.78	5.0	-2.8	0.00
	20	5.90	7.8	-3.3	0.00
	21	7.91	9.4	-1.7	0.00
	22	3.68	8.9	-2.8	0.00
	23	8.91	11.7	0.6	0.00
	24	6.69	5.6	-1.1	0.00
	25	7.24	6.7	-3.3	0.00
	26	5.56	5.0	-3.3	0.00
	27	4.39	4.4	-1.1	0.00
	28	4.73	6.1	-1.1	0.00
	29	4.85	11.1	0.0	0.25
	30	7.36	7.2	0.6	0.00
	31	4.18	0.6	-4.4	0.00
	32	10.33	0.0	-11.7	0.00
	33	9.92	1.7	-12.8	0.00
	34	6.40	8.9	-2.2	0.00
	35	9.96	6.1	-5.6	0.00
	36	7.49	4.4	-6.7	0.00
	37	7.07	7.2	-2.8	0.00
	38	6.53	12.2	1.1	0.00
	39	5.02	12.2	3.9	0.00
	40	3.51	10.6	7.8	0.00
	41	7.82	14.4	4.4	0.00
	42	10.50	17.2	3.3	0.00

43	8.16	15.0	-1.1	0.00
44	8.16	15.0	-1.1	0.00
45	4.27	10.6	2.2	0.00
46	10.33	10.0	4.4	0.00
47	12.64	12.2	0.6	0.00
48	6.40	11.7	-0.6	0.00
49	12.68	12.8	0.0	0.00
50	12.80	16.7	0.0	0.00
51	13.05	18.9	-2.2	0.00
52	12.93	19.4	-1.1	0.00
53	13.81	12.8	-2.2	0.00
54	12.05	10.0	-6.7	0.00
55	13.60	12.8	-5.0	0.00
56	12.13	12.8	-5.0	0.00
57	12.13	15.0	-4.4	0.00
58	13.39	16.7	-2.2	0.00
59	12.34	16.1	-0.6	0.00
60	14.14	20.0	3.9	0.00
61	4.73	15.0	6.1	0.76
62	10.25	15.0	3.3	0.00
63	14.56	12.2	0.0	0.00
64	7.20	12.8	0.6	1.78
65	5.94	8.3	1.1	0.00
66	16.61	11.1	2.8	0.00
67	16.57	15.6	-1.1	0.00
68	7.24	12.2	0.6	1.78
69	13.43	10.6	2.2	1.52
70	15.98	12.8	0.0	0.00
71	17.82	12.8	-3.3	0.00
72	18.20	15.6	-4.4	0.00
73	16.74	17.2	-3.3	0.00
74	12.51	13.3	0.0	0.00
75	18.24	13.9	-3.9	0.00
76	18.91	15.0	-3.3	0.00
77	18.08	17.2	-4.4	0.00
78	18.24	18.3	-2.8	0.00
79	14.14	20.0	0.0	0.00
80	7.82	16.7	7.2	0.00
81	7.49	12.2	2.8	0.00
82	13.64	17.2	2.2	1.02
83	9.04	11.1	3.3	0.00
84	3.89	10.0	3.3	0.00
85	13.72	17.8	7.8	0.00
86	8.49	15.0	2.8	9.65
87	8.83	8.9	0.0	0.00
88	20.59	11.7	-0.6	2.79
89	16.65	11.1	2.2	1.27
90	21.05	15.0	0.6	0.00
91	24.02	18.9	1.1	0.51
92	21.42	22.8	2.8	0.00
93	9.21	17.2	10.6	2.54
94	20.79	13.9	3.9	0.51
95	17.57	11.7	1.1	0.00
96	13.51	16.7	1.1	0.00
97	11.42	18.3	5.0	0.51
98	19.62	12.8	0.6	0.00
99	21.46	16.7	0.6	0.00
100	21.38	18.3	-2.2	0.00
101	21.55	24.4	0.0	0.00
102	21.05	26.1	2.2	0.00
103	22.38	27.2	4.4	0.00
104	13.26	26.7	12.8	0.00
105	8.74	20.6	11.1	0.00
106	10.96	22.8	10.0	0.00
107	15.82	21.1	7.8	0.00
108	4.35	12.8	10.0	3.05
109	16.74	20.6	8.3	0.00
110	9.58	17.8	4.4	0.00
111	4.60	13.3	10.0	11.68

112	4.64	11.7	8.9	11.43
113	14.39	14.4	6.7	7.11
114	14.48	16.1	7.2	0.00
115	16.32	15.0	6.7	0.00
116	17.95	17.2	3.9	0.00
117	20.92	20.6	0.6	0.00
118	20.92	22.8	3.9	0.00
119	14.64	21.1	9.4	0.25
120	22.97	17.2	5.6	4.06
121	25.69	13.9	2.2	0.00
122	23.85	13.9	3.3	0.00
123	11.80	13.3	1.1	0.00
124	22.18	16.7	3.3	0.00
125	18.87	14.4	5.0	0.00
126	23.97	20.0	8.3	0.00
127	24.31	17.8	7.8	0.00
128	28.95	20.6	2.8	0.00
129	19.25	22.8	7.8	0.25
130	24.98	23.9	6.7	0.00
131	22.30	32.2	10.6	0.00
132	22.30	31.1	11.1	0.00
133	22.38	32.8	12.2	0.51
134	19.96	21.1	7.2	0.00
135	24.69	22.2	7.2	0.00
136	25.31	27.8	5.0	0.00
137	11.97	18.3	8.3	0.51
138	25.52	20.0	5.6	0.00
139	24.73	21.1	9.4	0.51
140	26.15	22.8	8.3	0.00
141	32.30	26.7	5.0	0.00
142	32.01	31.1	5.0	0.00
143	27.32	30.0	11.7	0.00
144	20.50	21.7	7.2	0.00
145	31.42	23.3	9.4	0.00
146	28.70	25.6	11.1	0.00
147	26.69	25.6	9.4	0.00
148	25.44	26.1	11.1	0.00
149	8.62	15.6	9.4	19.81
150	21.92	17.8	7.8	0.00
151	20.92	19.4	7.2	0.00
152	10.46	18.9	9.4	1.52
153	16.74	19.4	10.0	1.78
154	15.61	21.7	10.6	0.00
155	11.09	16.1	10.0	4.57
156	16.99	17.8	9.4	0.00
157	11.09	12.8	8.9	3.56
158	21.51	18.3	7.2	0.00
159	14.64	19.4	7.2	0.25
160	16.74	21.1	5.0	0.51
161	14.73	21.1	7.2	0.51
162	27.74	21.7	8.9	0.00
163	29.21	26.1	5.6	0.00
164	30.00	27.2	8.9	0.00
165	29.87	28.9	10.0	0.00
166	30.00	32.2	8.9	0.00
167	28.83	34.4	13.3	0.00
168	21.72	33.9	15.6	0.00
169	25.40	28.3	16.7	0.00
170	29.33	28.9	15.0	0.00
171	29.67	32.2	10.6	0.00
172	29.71	33.3	16.1	0.00
173	28.91	33.3	16.1	0.00
174	29.29	33.3	17.8	0.00
175	33.01	28.9	15.6	0.00
176	22.38	30.0	13.3	0.00
177	8.45	27.2	14.4	0.00
178	26.82	28.3	16.7	0.00
179	27.57	25.0	13.3	0.76
180	26.65	22.2	11.7	0.00

181	29.33	23.3	10.6	0.00
182	28.24	28.3	6.7	0.00
183	28.12	31.7	15.0	0.00
184	27.28	30.6	16.1	0.00
185	18.66	23.9	12.8	0.00
186	18.45	23.3	11.1	0.00
187	21.42	21.7	11.1	0.00
188	28.62	25.0	8.9	0.00
189	29.33	30.6	7.2	0.00
190	29.16	35.0	10.0	0.00
191	28.03	36.1	15.6	0.00
192	27.41	34.4	16.1	0.00
193	22.51	25.6	15.6	0.00
194	11.21	23.3	13.9	0.00
195	16.95	27.2	15.6	0.00
196	26.15	26.7	12.8	0.25
197	27.70	29.4	15.0	0.00
198	28.33	28.9	12.8	0.00
199	28.20	32.2	17.2	0.00
200	28.49	33.3	11.7	0.00
201	28.41	36.7	8.9	0.00
202	28.03	39.4	11.7	0.00
203	28.20	38.3	21.1	0.00
204	27.41	36.1	19.4	0.00
205	25.36	32.8	16.7	0.00
206	27.78	36.7	13.3	0.00
207	28.08	38.9	11.1	0.00
208	27.24	38.9	14.4	0.00
209	26.23	36.7	22.2	0.00
210	25.40	33.9	18.3	0.00
211	26.40	35.6	16.7	0.00
212	26.95	36.1	18.3	0.00
213	26.40	32.8	19.4	0.00
214	26.57	27.2	13.9	0.00
215	23.43	28.3	10.0	0.00
216	25.94	31.7	8.3	0.00
217	25.94	36.1	8.9	0.00
218	13.93	33.9	16.7	0.00
219	25.73	26.7	13.9	0.00
220	25.52	28.3	11.7	0.00
221	24.64	32.8	10.0	0.00
222	24.98	36.1	15.6	0.00
223	25.06	32.2	17.2	0.00
224	24.27	31.7	15.0	0.00
225	24.23	32.8	16.1	0.00
226	16.03	28.3	17.8	0.00
227	24.23	31.1	12.8	0.00
228	23.89	26.7	16.1	0.00
229	22.22	28.3	12.2	0.00
230	21.67	26.7	15.6	0.00
231	23.68	26.1	11.1	0.00
232	23.72	32.2	6.1	0.00
233	22.05	26.7	12.8	0.00
234	24.06	27.8	7.2	0.00
235	23.51	32.2	5.6	0.00
236	23.39	35.6	9.4	0.00
237	21.09	37.2	10.6	0.00
238	22.59	35.0	18.9	0.00
239	21.00	30.6	15.0	0.00
240	21.46	33.3	10.6	0.00
241	21.55	36.1	11.1	0.00
242	19.92	33.9	13.9	0.00
243	20.04	28.3	11.7	0.00
244	20.13	30.0	8.9	0.00
245	19.71	33.3	8.9	0.00
246	14.60	35.6	14.4	0.00
247	18.87	29.4	14.4	0.00
248	19.08	27.8	12.2	0.00
249	18.91	30.6	7.2	0.00

250	18.58	28.3	8.3	0.00
251	12.85	22.2	9.4	0.00
252	18.16	22.8	5.6	0.00
253	18.37	26.1	4.4	0.00
254	18.08	29.4	7.2	0.00
255	17.91	32.8	8.3	0.00
256	14.73	25.6	15.0	0.00
257	17.41	19.4	11.7	0.00
258	13.10	18.3	6.7	0.00
259	15.65	20.6	3.9	0.00
260	11.80	16.7	10.0	9.40
261	11.92	20.0	8.9	2.54
262	16.74	24.4	5.0	0.00
263	16.11	24.4	7.8	0.00
264	11.46	22.2	11.7	0.00
265	15.02	23.9	7.8	0.00
266	7.66	20.6	12.2	0.00
267	11.21	23.9	12.2	0.00
268	14.48	19.4	9.4	0.51
269	15.31	22.8	5.6	0.00
270	15.23	26.1	10.6	0.00
271	15.27	28.3	7.2	0.00
272	14.52	31.1	8.9	0.00
273	16.00	17.78	-1.1	0.00
274	5.26	19.44	1.7	0.00
275	13.23	18.3	5.6	0.00

CERES Expected Weather File for Wheat

ORHE	45.83	119.28	0.00	0.00			
ORHE	10	1	1.62	5.3	-1.7	.0	.00
ORHE	10	2	1.63	2.5	-4.2	.0	.00
ORHE	10	3	1.64	1.5	-9.3	.0	.00
ORHE	10	4	1.65	-2.8	-7.5	.0	.00
ORHE	10	5	1.66	.7	-9.4	.0	.00
ORHE	10	6	1.68	-3.7	-10.2	.0	.00
ORHE	10	7	1.69	-1.6	-12.9	.0	.00
ORHE	10	8	1.70	.7	-15.8	.0	.00
ORHE	10	9	1.72	5.4	-4.3	.0	.00
ORHE	10	10	1.73	4.1	-9.5	.0	.00
ORHE	10	11	1.75	6.1	-3.8	.0	.00
ORHE	10	12	1.76	.8	-4.7	.0	.00
ORHE	10	13	1.78	3.2	-7.3	1.7	.00
ORHE	10	14	1.80	-1.3	-11.9	.0	.00
ORHE	10	15	1.82	1.9	-11.6	.0	.00
ORHE	10	16	1.84	-.2	-12.7	.0	.00
ORHE	10	17	1.86	4.2	-4.4	.0	.00
ORHE	10	18	1.88	4.5	-2.1	.0	.00
ORHE	10	19	1.90	11.7	3.6	.0	.00
ORHE	10	20	1.92	1.6	-1.3	1.2	.00
ORHE	10	21	1.94	2.5	1.6	.0	.00
ORHE	10	22	1.97	6.4	4.5	4.4	.00
ORHE	10	23	1.99	11.4	1.8	.0	.00
ORHE	10	24	2.01	15.6	3.4	.0	.00
ORHE	10	25	2.04	8.9	3.7	.0	.00
ORHE	10	26	2.06	8.4	-2.1	.0	.00
ORHE	10	27	2.09	7.3	-1.4	.0	.00
ORHE	10	28	2.12	4.3	-7.1	.0	.00
ORHE	10	29	2.15	-1.3	-6.8	.0	.00
ORHE	10	30	2.17	-.8	-12.0	.0	.00
ORHE	10	31	2.20	7.9	-4.5	.0	.00
ORHE	10	32	2.23	2.4	-5.4	.4	.00
ORHE	10	33	2.26	5.5	-3.1	.2	.00
ORHE	10	34	2.29	6.3	-.5	6.5	.00
ORHE	10	35	2.33	2.7	-2.6	4.1	.00
ORHE	10	36	2.36	3.7	-2.6	.1	.00
ORHE	10	37	2.39	3.5	-.9	.0	.00
ORHE	10	38	2.42	.0	-3.1	.5	.00
ORHE	10	39	2.46	2.7	-3.1	.0	.00
ORHE	10	40	2.49	5.6	-7.1	.0	.00
ORHE	10	41	2.53	7.7	-7.4	.0	.00
ORHE	10	42	2.56	6.7	-2.4	.0	.00
ORHE	10	43	2.60	4.9	2.6	.0	.00
ORHE	10	44	2.63	9.0	1.4	.0	.00
ORHE	10	45	2.67	5.5	-3.5	2.7	.00
ORHE	10	46	2.71	3.4	-5.5	12.5	.00
ORHE	10	47	2.75	1.1	-.3	8.2	.00
ORHE	10	48	2.79	4.0	-4.0	5.5	.00
ORHE	10	49	2.82	5.3	-1.7	.0	.00
ORHE	10	50	2.86	4.9	1.1	.0	.00
ORHE	10	51	2.90	5.4	-2.7	.0	.00
ORHE	10	52	2.94	1.2	-4.3	.0	.00
ORHE	10	53	2.98	5.6	-4.9	.0	.00
ORHE	10	54	3.02	-.1	-8.6	1.0	.00
ORHE	10	55	3.07	2.8	-9.0	.0	.00
ORHE	10	56	3.11	-4.0	-10.1	.0	.00
ORHE	10	57	3.15	-5.1	-13.6	.1	.00
ORHE	10	58	3.19	-6.6	-8.8	.8	.00
ORHE	10	59	3.23	-3.2	-3.5	5.9	.00
ORHE	10	60	3.28	4.6	4.3	.3	.00
ORHE	10	61	3.32	.5	-2.0	.5	.00
ORHE	10	62	3.36	-1.0	-1.9	4.7	.00
ORHE	10	63	3.41	6.5	.5	2.9	.00
ORHE	10	64	3.45	12.2	4.2	.0	.00
ORHE	10	65	3.50	17.0	.8	.0	.00

ORHE	10	66	3.54	9.2	-4.2	.0	.00
ORHE	10	67	3.58	10.3	1.1	.0	.00
ORHE	10	68	3.63	5.1	-6.4	.0	.00
ORHE	10	69	3.67	3.9	-6.4	.0	.00
ORHE	10	70	3.72	1.7	-6.1	10.6	.00
ORHE	10	71	3.76	10.8	.8	.0	.00
ORHE	10	72	3.81	11.0	-1.6	.0	.00
ORHE	10	73	3.85	3.8	-4.6	.5	.00
ORHE	10	74	3.90	10.2	-2.0	.0	.00
ORHE	10	75	3.95	2.6	-7.1	.0	.00
ORHE	10	76	3.99	5.4	-7.9	8.6	.00
ORHE	10	77	4.04	9.7	-3.7	1.4	.00
ORHE	10	78	4.08	11.9	2.7	.4	.00
ORHE	10	79	4.13	5.7	1.2	2.5	.00
ORHE	10	80	4.17	10.5	.2	.0	.00
ORHE	10	81	4.22	13.2	4.1	.0	.00
ORHE	10	82	4.26	12.3	4.3	.0	.00
ORHE	10	83	4.31	8.8	2.4	3.4	.00
ORHE	10	84	4.35	7.6	-4.6	.0	.00
ORHE	10	85	4.40	9.7	-4.9	.0	.00
ORHE	10	86	4.44	10.2	.5	.0	.00
ORHE	10	87	4.49	10.1	2.9	.0	.00
ORHE	10	88	4.53	15.3	7.6	.0	.00
ORHE	10	89	4.58	14.6	8.8	.0	.00
ORHE	10	90	4.62	17.8	10.7	8.1	.00
ORHE	10	91	4.67	12.5	4.0	.0	.00
ORHE	10	92	4.71	14.6	2.4	2.9	.00
ORHE	10	93	4.75	11.0	-2.2	.0	.00
ORHE	10	94	4.80	12.0	.1	.0	.00
ORHE	10	95	4.84	6.5	-.8	6.1	.00
ORHE	10	96	4.88	6.2	2.4	.0	.00
ORHE	10	97	4.92	7.2	1.9	.0	.00
ORHE	10	98	4.97	2.6	-1.0	2.2	.00
ORHE	10	99	5.01	13.0	-2.1	.0	.00
ORHE	10	100	5.05	17.0	1.9	.0	.00
ORHE	10	101	5.09	12.3	-.6	2.3	.00
ORHE	10	102	5.13	11.5	-1.8	7.5	.00
ORHE	10	103	5.17	11.8	-2.1	.0	.00
ORHE	10	104	5.21	20.5	2.2	.0	.00
ORHE	10	105	5.25	18.1	3.2	.0	.00
ORHE	10	106	5.29	15.1	6.9	3.6	.00
ORHE	10	107	5.33	18.7	9.3	.0	.00
ORHE	10	108	5.37	20.6	10.7	.0	.00
ORHE	10	109	5.41	24.6	6.1	.0	.00
ORHE	10	110	5.45	24.3	8.1	.0	.00
ORHE	10	111	5.48	23.5	7.9	.0	.00
ORHE	10	112	5.52	21.9	3.8	3.3	.00
ORHE	10	113	5.56	18.8	6.4	5.7	.00
ORHE	10	114	5.59	21.6	9.3	.0	.00
ORHE	10	115	5.63	21.2	4.6	3.5	.00
ORHE	10	116	5.66	22.9	5.3	.0	.00
ORHE	10	117	5.70	22.2	4.4	.0	.00
ORHE	10	118	5.73	18.0	5.5	.0	.00
ORHE	10	119	5.76	15.7	5.8	4.6	.00
ORHE	10	120	5.80	12.7	1.1	.0	.00
ORHE	10	121	5.83	19.9	7.0	5.4	.00
ORHE	10	122	5.86	22.4	2.8	.0	.00
ORHE	10	123	5.89	20.6	3.2	.0	.00
ORHE	10	124	5.92	20.1	3.0	.0	.00
ORHE	10	125	5.95	14.9	3.2	.0	.00
ORHE	10	126	5.98	25.5	8.0	.0	.00
ORHE	10	127	6.01	25.3	9.5	.0	.00
ORHE	10	128	6.04	23.7	8.8	.0	.00
ORHE	10	129	6.07	24.2	7.8	3.7	.00
ORHE	10	130	6.09	31.4	12.9	.0	.00
ORHE	10	131	6.12	31.1	13.2	.0	.00
ORHE	10	132	6.14	26.9	13.0	.9	.00
ORHE	10	133	6.17	18.7	13.1	.0	.00
ORHE	10	134	6.19	16.5	12.4	17.3	.00

ORHE	10	135	6.22	24.4	11.3	.0	.00
ORHE	10	136	6.24	15.6	8.2	16.7	.00
ORHE	10	137	6.27	20.3	9.2	.0	.00
ORHE	10	138	6.29	24.5	7.4	.0	.00
ORHE	10	139	6.31	23.6	11.7	.0	.00
ORHE	10	140	6.33	27.0	14.5	.0	.00
ORHE	10	141	6.35	33.0	16.1	.0	.00
ORHE	10	142	6.37	33.7	16.1	.0	.00
ORHE	10	143	6.39	24.6	10.9	.0	.00
ORHE	10	144	6.41	22.0	9.3	.0	.00
ORHE	10	145	6.42	24.1	7.3	.0	.00
ORHE	10	146	6.44	24.6	7.8	.0	.00
ORHE	10	147	6.46	23.5	10.7	.8	.00
ORHE	10	148	6.47	31.3	7.9	.0	.00
ORHE	10	149	6.49	29.5	10.6	.0	.00
ORHE	10	150	6.50	33.7	14.5	.0	.00
ORHE	10	151	6.52	39.1	13.8	.0	.00
ORHE	10	152	6.53	27.6	8.8	.0	.00
ORHE	10	153	6.54	30.9	11.1	.2	.00
ORHE	10	154	6.55	30.1	13.4	.8	.00
ORHE	10	155	6.56	30.3	13.6	.0	.00
ORHE	10	156	6.57	30.3	13.8	.0	.00
ORHE	10	157	6.58	29.9	10.6	.0	.00
ORHE	10	158	6.59	33.5	12.7	.0	.00
ORHE	10	159	6.60	29.1	11.0	.0	.00
ORHE	10	160	6.61	31.0	10.0	.0	.00
ORHE	10	161	6.61	26.8	9.1	.5	.00
ORHE	10	162	6.62	27.4	9.5	.3	.00
ORHE	10	163	6.63	29.7	9.2	.0	.00
ORHE	10	164	6.63	26.7	7.2	.0	.00
ORHE	10	165	6.63	28.2	9.8	.0	.00
ORHE	10	166	6.64	27.6	10.3	.0	.00
ORHE	10	167	6.64	28.9	10.1	.0	.00
ORHE	10	168	6.64	32.9	10.6	.0	.00
ORHE	10	169	6.64	31.5	10.7	1.1	.00
ORHE	10	170	6.64	33.1	11.9	.0	.00
ORHE	10	171	6.64	27.0	11.1	.0	.00
ORHE	10	172	6.64	30.5	10.8	.0	.00
ORHE	10	173	6.64	31.0	12.9	.0	.00
ORHE	10	174	6.64	33.4	14.8	.3	.00
ORHE	10	175	6.64	32.5	11.8	4.9	.00
ORHE	10	176	6.63	32.1	13.9	.2	.00
ORHE	10	177	6.63	31.9	13.7	.0	.00
ORHE	10	178	6.62	33.7	13.4	.0	.00
ORHE	10	179	6.62	30.6	10.8	.0	.00
ORHE	10	180	6.61	29.9	9.7	.0	.00
ORHE	10	181	6.60	27.1	8.1	.0	.00
ORHE	10	182	6.60	25.6	6.7	.0	.00
ORHE	10	183	6.59	26.3	8.4	.0	.00
ORHE	10	184	6.58	30.8	9.5	.0	.00
ORHE	10	185	6.57	27.2	10.2	.0	.00
ORHE	10	186	6.56	26.4	12.1	.0	.00
ORHE	10	187	6.55	29.7	10.2	.0	.00
ORHE	10	188	6.53	27.9	10.5	.0	.00
ORHE	10	189	6.52	25.8	13.2	.0	.00
ORHE	10	190	6.51	28.5	10.1	.0	.00
ORHE	10	191	6.50	29.7	9.4	.0	.00
ORHE	10	192	6.48	27.2	10.6	.0	.00
ORHE	10	193	6.47	26.8	11.1	.0	.00
ORHE	10	194	6.45	32.0	13.0	.0	.00
ORHE	10	195	6.43	33.0	14.8	.0	.00
ORHE	10	196	6.42	33.7	13.3	.0	.00
ORHE	10	197	6.40	30.4	15.7	.0	.00
ORHE	10	198	6.38	28.4	12.9	1.7	.00
ORHE	10	199	6.36	25.2	11.8	.8	.00
ORHE	10	200	6.34	25.3	11.8	.4	.00
ORHE	10	201	6.32	27.9	13.1	.0	.00
ORHE	10	202	6.30	25.8	10.6	.0	.00
ORHE	10	203	6.28	28.7	11.5	.0	.00

ORHE	10	204	6.26	28.1	10.5	.0	.00
ORHE	10	205	6.23	32.6	12.3	.0	.00
ORHE	10	206	6.21	34.0	14.9	.0	.00
ORHE	10	207	6.19	34.5	13.3	.0	.00
ORHE	10	208	6.16	33.2	14.4	5.3	.00
ORHE	10	209	6.14	35.8	15.2	.0	.00
ORHE	10	210	6.11	33.8	13.5	.0	.00
ORHE	10	211	6.09	29.8	12.5	.0	.00
ORHE	10	212	6.06	35.7	15.2	.0	.00
ORHE	10	213	6.03	32.4	15.4	.0	.00
ORHE	10	214	6.00	32.8	15.1	.0	.00
ORHE	10	215	5.97	29.0	13.4	.0	.00
ORHE	10	216	5.95	32.2	15.7	.0	.00
ORHE	10	217	5.92	33.7	14.8	.0	.00
ORHE	10	218	5.89	33.1	11.5	.0	.00
ORHE	10	219	5.85	30.2	9.3	.0	.00
ORHE	10	220	5.82	28.3	9.4	.0	.00
ORHE	10	221	5.79	27.1	9.2	.0	.00
ORHE	10	222	5.76	26.7	13.0	.0	.00
ORHE	10	223	5.73	24.9	9.0	.0	.00
ORHE	10	224	5.69	23.9	8.1	.0	.00
ORHE	10	225	5.66	25.3	7.2	.0	.00
ORHE	10	226	5.63	29.7	10.4	.0	.00
ORHE	10	227	5.59	29.4	10.0	.0	.00
ORHE	10	228	5.56	27.2	10.5	.0	.00
ORHE	10	229	5.52	27.5	10.7	.0	.00
ORHE	10	230	5.48	26.9	10.2	.0	.00
ORHE	10	231	5.45	28.5	12.7	.0	.00
ORHE	10	232	5.41	26.7	11.1	.0	.00
ORHE	10	233	5.37	29.6	13.4	.0	.00
ORHE	10	234	5.34	30.4	11.4	.0	.00
ORHE	10	235	5.30	32.1	11.8	.0	.00
ORHE	10	236	5.26	24.4	10.9	.1	.00
ORHE	10	237	5.22	24.7	13.9	.0	.00
ORHE	10	238	5.18	32.0	13.4	.0	.00
ORHE	10	239	5.14	31.6	15.1	.0	.00
ORHE	10	240	5.10	29.5	13.9	.0	.00
ORHE	10	241	5.06	21.5	15.4	.1	.00
ORHE	10	242	5.02	29.6	13.7	.0	.00
ORHE	10	243	4.98	28.5	16.8	.0	.00
ORHE	10	244	4.94	19.9	11.1	1.1	.00
ORHE	10	245	4.90	19.5	7.4	17.9	.00
ORHE	10	246	4.85	19.0	10.3	2.7	.00
ORHE	10	247	4.81	26.5	9.1	.0	.00
ORHE	10	248	4.77	26.7	9.1	.0	.00
ORHE	10	249	4.73	25.1	11.8	3.5	.00
ORHE	10	250	4.68	23.7	8.0	2.4	.00
ORHE	10	251	4.64	23.6	6.6	.0	.00
ORHE	10	252	4.60	19.2	5.9	.0	.00
ORHE	10	253	4.55	19.4	6.9	5.8	.00
ORHE	10	254	4.51	23.1	10.1	5.8	.00
ORHE	10	255	4.47	23.8	11.7	2.5	.00
ORHE	10	256	4.42	27.5	10.5	.0	.00
ORHE	10	257	4.38	34.3	15.4	.0	.00
ORHE	10	258	4.33	31.3	15.2	.0	.00
ORHE	10	259	4.29	28.5	11.4	.0	.00
ORHE	10	260	4.25	23.7	6.7	2.2	.00
ORHE	10	261	4.20	20.2	3.8	.0	.00
ORHE	10	262	4.16	17.0	5.5	.0	.00
ORHE	10	263	4.11	21.2	2.6	6.1	.00
ORHE	10	264	4.07	20.7	3.9	.8	.00
ORHE	10	265	4.02	23.6	2.7	.0	.00
ORHE	10	266	3.98	19.0	2.7	3.6	.00
ORHE	10	267	3.93	25.2	7.4	3.7	.00
ORHE	10	268	3.89	20.1	2.3	1.0	.00
ORHE	10	269	3.84	21.4	1.4	.0	.00
ORHE	10	270	3.80	12.8	.1	.0	.00
ORHE	10	271	3.76	13.7	.4	.0	.00
ORHE	10	272	3.71	11.8	-.3	11.9	.00

ORHE	10	273	3.67	21.3	1.5	6.4	.00
ORHE	10	274	3.62	28.8	9.0	.9	.00
ORHE	10	275	3.58	28.4	10.2	.0	.00
ORHE	22	276	3.54	26.4	14.1	.0	.00
ORHE	22	277	3.49	24.5	13.4	.0	.00
ORHE	22	278	3.45	26.0	18.2	.0	.00
ORHE	22	279	3.41	25.8	18.6	.0	.00
ORHE	22	280	3.36	19.7	11.6	.0	.00
ORHE	22	281	3.32	13.4	9.1	.0	.00
ORHE	22	282	3.28	14.2	4.4	.0	.00
ORHE	22	283	3.23	16.4	2.0	.0	.00
ORHE	22	284	3.19	16.9	-.2	2.0	.00
ORHE	22	285	3.15	15.7	3.8	.0	.00
ORHE	22	286	3.11	10.9	-2.8	.0	.00
ORHE	22	287	3.07	15.3	.5	.0	.00
ORHE	22	288	3.03	12.2	-1.8	.0	.00
ORHE	22	289	2.99	12.5	3.3	.0	.00
ORHE	22	290	2.95	15.6	7.5	.0	.00
ORHE	22	291	2.91	16.8	4.9	.0	.00
ORHE	22	292	2.87	19.4	5.0	.0	.00
ORHE	22	293	2.83	18.8	7.9	.0	.00
ORHE	22	294	2.79	13.7	8.5	3.3	.00
ORHE	22	295	2.75	14.1	10.6	.0	.00
ORHE	22	296	2.72	18.1	11.1	.0	.00
ORHE	22	297	2.68	25.1	9.7	.0	.00
ORHE	22	298	2.64	19.1	7.1	.0	.00
ORHE	22	299	2.61	22.8	9.4	.0	.00
ORHE	22	300	2.57	21.7	6.2	.0	.00
ORHE	22	301	2.54	22.0	7.1	.0	.00
ORHE	22	302	2.50	11.2	5.9	.0	.00
ORHE	22	303	2.47	11.5	2.9	.0	.00
ORHE	22	304	2.43	13.3	5.0	.0	.00
ORHE	22	305	2.40	16.8	4.6	.0	.00
ORHE	22	306	2.37	24.0	2.3	.0	.00
ORHE	22	307	2.34	12.2	-1.1	.0	.00
ORHE	22	308	2.30	15.3	3.7	.0	.00
ORHE	22	309	2.27	14.7	5.4	.0	.00
ORHE	22	310	2.24	21.7	2.1	.0	.00
ORHE	22	311	2.21	11.2	3.7	2.9	.00
ORHE	22	312	2.18	11.9	.6	.0	.00
ORHE	22	313	2.16	14.7	-.5	.0	.00
ORHE	22	314	2.13	14.2	4.5	4.7	.00
ORHE	22	315	2.10	20.7	5.7	.0	.00
ORHE	22	316	2.08	14.8	9.1	.2	.00
ORHE	22	317	2.05	19.1	7.4	1.1	.00
ORHE	22	318	2.02	20.8	14.2	.8	.00
ORHE	22	319	2.00	15.7	10.5	.1	.00
ORHE	22	320	1.98	10.4	1.1	.0	.00
ORHE	22	321	1.95	8.4	-4.1	.0	.00
ORHE	22	322	1.93	15.1	4.6	.0	.00
ORHE	22	323	1.91	9.0	-1.3	.0	.00
ORHE	22	324	1.89	15.3	6.1	.0	.00
ORHE	22	325	1.87	10.1	8.1	1.6	.00
ORHE	22	326	1.85	13.5	4.6	4.1	.00
ORHE	22	327	1.83	17.9	6.1	.0	.00
ORHE	22	328	1.81	16.0	-1.6	.0	.00
ORHE	22	329	1.79	6.5	-4.3	.2	.00
ORHE	22	330	1.77	3.3	1.1	1.1	.00
ORHE	22	331	1.76	.2	-7.5	1.7	.00
ORHE	22	332	1.74	1.5	-8.4	3.9	.00
ORHE	22	333	1.72	-4.1	-13.5	.2	.00
ORHE	22	334	1.71	3.1	-13.2	.0	.00
ORHE	22	335	1.70	2.8	-5.0	.0	.00
ORHE	22	336	1.68	3.7	-9.0	.0	.00
ORHE	22	337	1.67	5.3	-11.3	.0	.00
ORHE	22	338	1.66	5.2	-9.9	2.8	.00
ORHE	22	339	1.65	11.6	-.3	6.5	.00
ORHE	22	340	1.64	7.4	-3.2	4.2	.00
ORHE	22	341	1.63	8.9	-.2	.0	.00

ORHE	22	342	1.62	8.8	-1.6	.0	.00
ORHE	22	343	1.61	12.0	-1.0	.0	.00
ORHE	22	344	1.60	8.8	-3.9	.0	.00
ORHE	22	345	1.60	.4	-3.5	.0	.00
ORHE	22	346	1.59	-2.7	-3.3	1.3	.00
ORHE	22	347	1.59	4.3	-2.1	3.6	.00
ORHE	22	348	1.58	3.7	-7.4	.0	.00
ORHE	22	349	1.58	1.6	-9.9	.0	.00
ORHE	22	350	1.57	7.6	-3.1	.0	.00
ORHE	22	351	1.57	3.8	-.5	.0	.00
ORHE	22	352	1.57	-.3	-8.7	.0	.00
ORHE	22	353	1.57	9.6	-4.5	.0	.00
ORHE	22	354	1.57	7.7	-6.5	1.3	.00
ORHE	22	355	1.57	-.5	-7.2	7.4	.00
ORHE	22	356	1.57	-.5	-4.4	.0	.00
ORHE	22	357	1.57	5.6	-7.3	.0	.00
ORHE	22	358	1.58	2.1	-4.8	.0	.00
ORHE	22	359	1.58	-.9	-8.2	.2	.00
ORHE	22	360	1.58	4.8	-7.7	3.2	.00
ORHE	22	361	1.59	3.3	-3.8	5.9	.00
ORHE	22	362	1.59	.0	-6.7	.0	.00
ORHE	22	363	1.60	-3.8	-7.8	.0	.00
ORHE	22	364	1.61	5.5	-8.4	.0	.00
ORHE	22	365	1.61	-1.4	-9.2	.0	.00
ORHE	23	366	1.62	5.4	-7.8	.3	.00

CERES Expected Weather File for Corn

ORHE	45.83	119.28	0.00	0.00			
ORHE	10	1	1.62	5.3	-1.7	.0	.00
ORHE	10	2	1.63	2.5	-4.2	.0	.00
ORHE	10	3	1.64	1.5	-9.3	.0	.00
ORHE	10	4	1.65	-2.8	-7.5	.0	.00
ORHE	10	5	1.66	.7	-9.4	.0	.00
ORHE	10	6	1.68	-3.7	-10.2	.0	.00
ORHE	10	7	1.69	-1.6	-12.9	.0	.00
ORHE	10	8	1.70	.7	-15.8	.0	.00
ORHE	10	9	1.72	5.4	-4.3	.0	.00
ORHE	10	10	1.73	4.1	-9.5	.0	.00
ORHE	10	11	1.75	6.1	-3.8	.0	.00
ORHE	10	12	1.76	.8	-4.7	.0	.00
ORHE	10	13	1.78	3.2	-7.3	1.7	.00
ORHE	10	14	1.80	-1.3	-11.9	.0	.00
ORHE	10	15	1.82	1.9	-11.6	.0	.00
ORHE	10	16	1.84	-.2	-12.7	.0	.00
ORHE	10	17	1.86	4.2	-4.4	.0	.00
ORHE	10	18	1.88	4.5	-2.1	.0	.00
ORHE	10	19	1.90	11.7	3.6	.0	.00
ORHE	10	20	1.92	1.6	-1.3	1.2	.00
ORHE	10	21	1.94	2.5	1.6	.0	.00
ORHE	10	22	1.97	6.4	4.5	4.4	.00
ORHE	10	23	1.99	11.4	1.8	.0	.00
ORHE	10	24	2.01	15.6	3.4	.0	.00
ORHE	10	25	2.04	8.9	3.7	.0	.00
ORHE	10	26	2.06	8.4	-2.1	.0	.00
ORHE	10	27	2.09	7.3	-1.4	.0	.00
ORHE	10	28	2.12	4.3	-7.1	.0	.00
ORHE	10	29	2.15	-1.3	-6.8	.0	.00
ORHE	10	30	2.17	-.8	-12.0	.0	.00
ORHE	10	31	2.20	7.9	-4.5	.0	.00
ORHE	10	32	2.23	2.4	-5.4	.4	.00
ORHE	10	33	2.26	5.5	-3.1	.2	.00
ORHE	10	34	2.29	6.3	-.5	6.5	.00
ORHE	10	35	2.33	2.7	-2.6	4.1	.00
ORHE	10	36	2.36	3.7	-2.6	.1	.00
ORHE	10	37	2.39	3.5	-.9	.0	.00
ORHE	10	38	2.42	.0	-3.1	.5	.00
ORHE	10	39	2.46	2.7	-3.1	.0	.00
ORHE	10	40	2.49	5.6	-7.1	.0	.00
ORHE	10	41	2.53	7.7	-7.4	.0	.00
ORHE	10	42	2.56	6.7	-2.4	.0	.00
ORHE	10	43	2.60	4.9	2.6	.0	.00
ORHE	10	44	2.63	9.0	1.4	.0	.00
ORHE	10	45	2.67	5.5	-3.5	2.7	.00
ORHE	10	46	2.71	3.4	-5.5	12.5	.00
ORHE	10	47	2.75	1.1	-.3	8.2	.00
ORHE	10	48	2.79	4.0	-4.0	5.5	.00
ORHE	10	49	2.82	5.3	-1.7	.0	.00
ORHE	10	50	2.86	4.9	1.1	.0	.00
ORHE	10	51	2.90	5.4	-2.7	.0	.00
ORHE	10	52	2.94	1.2	-4.3	.0	.00
ORHE	10	53	2.98	5.6	-4.9	.0	.00
ORHE	10	54	3.02	-.1	-8.6	1.0	.00
ORHE	10	55	3.07	2.8	-9.0	.0	.00
ORHE	10	56	3.11	-4.0	-10.1	.0	.00
ORHE	10	57	3.15	-5.1	-13.6	.1	.00
ORHE	10	58	3.19	-6.6	-8.8	.8	.00
ORHE	10	59	3.23	-3.2	-3.5	5.9	.00
ORHE	10	60	3.28	4.6	4.3	.3	.00
ORHE	10	61	3.32	.5	-2.0	.5	.00
ORHE	10	62	3.36	-1.0	-1.9	4.7	.00
ORHE	10	63	3.41	6.5	.5	2.9	.00
ORHE	10	64	3.45	12.2	4.2	.0	.00
ORHE	10	65	3.50	17.0	.8	.0	.00

ORHE	10	66	3.54	9.2	-4.2	.0	.00
ORHE	10	67	3.58	10.3	1.1	.0	.00
ORHE	10	68	3.63	5.1	-6.4	.0	.00
ORHE	10	69	3.67	3.9	-6.4	.0	.00
ORHE	10	70	3.72	1.7	-6.1	10.6	.00
ORHE	10	71	3.76	10.8	.8	.0	.00
ORHE	10	72	3.81	11.0	-1.6	.0	.00
ORHE	10	73	3.85	3.8	-4.6	.5	.00
ORHE	10	74	3.90	10.2	-2.0	.0	.00
ORHE	10	75	3.95	2.6	-7.1	.0	.00
ORHE	10	76	3.99	5.4	-7.9	8.6	.00
ORHE	10	77	4.04	9.7	-3.7	1.4	.00
ORHE	10	78	4.08	11.9	2.7	.4	.00
ORHE	10	79	4.13	5.7	1.2	2.5	.00
ORHE	10	80	4.17	10.5	.2	.0	.00
ORHE	10	81	4.22	13.2	4.1	.0	.00
ORHE	10	82	4.26	12.3	4.3	.0	.00
ORHE	10	83	4.31	8.8	2.4	3.4	.00
ORHE	10	84	4.35	7.6	-4.6	.0	.00
ORHE	10	85	4.40	9.7	-4.9	.0	.00
ORHE	10	86	4.44	10.2	.5	.0	.00
ORHE	10	87	4.49	10.1	2.9	.0	.00
ORHE	10	88	4.53	15.3	7.6	.0	.00
ORHE	10	89	4.58	14.6	8.8	.0	.00
ORHE	10	90	4.62	17.8	10.7	8.1	.00
ORHE	10	91	4.67	12.5	4.0	.0	.00
ORHE	10	92	4.71	14.6	2.4	2.9	.00
ORHE	10	93	4.75	11.0	-2.2	.0	.00
ORHE	10	94	4.80	12.0	.1	.0	.00
ORHE	10	95	4.84	6.5	-.8	6.1	.00
ORHE	10	96	4.88	6.2	2.4	.0	.00
ORHE	10	97	4.92	7.2	1.9	.0	.00
ORHE	10	98	4.97	2.6	-1.0	2.2	.00
ORHE	10	99	5.01	13.0	-2.1	.0	.00
ORHE	10	100	5.05	17.0	1.9	.0	.00
ORHE	10	101	5.09	12.3	-.6	2.3	.00
ORHE	10	102	5.13	11.5	-1.8	7.5	.00
ORHE	10	103	5.17	11.8	-2.1	.0	.00
ORHE	10	104	5.21	20.5	2.2	.0	.00
ORHE	10	105	5.25	18.1	3.2	.0	.00
ORHE	10	106	5.29	15.1	6.9	3.6	.00
ORHE	10	107	5.33	18.7	9.3	.0	.00
ORHE	10	108	5.37	20.6	10.7	.0	.00
ORHE	10	109	5.41	24.6	6.1	.0	.00
ORHE	10	110	5.45	24.3	8.1	.0	.00
ORHE	10	111	5.48	23.5	7.9	.0	.00
ORHE	10	112	5.52	21.9	3.8	3.3	.00
ORHE	10	113	5.56	18.8	6.4	5.7	.00
ORHE	10	114	5.59	21.6	9.3	.0	.00
ORHE	10	115	5.63	21.2	4.6	3.5	.00
ORHE	10	116	5.66	22.9	5.3	.0	.00
ORHE	10	117	5.70	22.2	4.4	.0	.00
ORHE	10	118	5.73	18.0	5.5	.0	.00
ORHE	10	119	5.76	15.7	5.8	4.6	.00
ORHE	10	120	5.80	12.7	1.1	.0	.00
ORHE	10	121	5.83	19.9	7.0	5.4	.00
ORHE	10	122	5.86	22.4	2.8	.0	.00
ORHE	10	123	5.89	20.6	3.2	.0	.00
ORHE	10	124	5.92	20.1	3.0	.0	.00
ORHE	10	125	5.95	14.9	3.2	.0	.00
ORHE	10	126	5.98	25.5	8.0	.0	.00
ORHE	10	127	6.01	25.3	9.5	.0	.00
ORHE	10	128	6.04	23.7	8.8	.0	.00
ORHE	10	129	6.07	24.2	7.8	3.7	.00
ORHE	10	130	6.09	31.4	12.9	.0	.00
ORHE	10	131	6.12	31.1	13.2	.0	.00
ORHE	10	132	6.14	26.9	13.0	.9	.00
ORHE	10	133	6.17	18.7	13.1	.0	.00
ORHE	10	134	6.19	16.5	12.4	17.3	.00

ORHE	10	135	6.22	24.4	11.3	.0	.00
ORHE	10	136	6.24	15.6	8.2	16.7	.00
ORHE	10	137	6.27	20.3	9.2	.0	.00
ORHE	10	138	6.29	24.5	7.4	.0	.00
ORHE	10	139	6.31	23.6	11.7	.0	.00
ORHE	10	140	6.33	27.0	14.5	.0	.00
ORHE	10	141	6.35	33.0	16.1	.0	.00
ORHE	10	142	6.37	33.7	16.1	.0	.00
ORHE	10	143	6.39	24.6	10.9	.0	.00
ORHE	10	144	6.41	22.0	9.3	.0	.00
ORHE	10	145	6.42	24.1	7.3	.0	.00
ORHE	10	146	6.44	24.6	7.8	.0	.00
ORHE	10	147	6.46	23.5	10.7	.8	.00
ORHE	10	148	6.47	31.3	7.9	.0	.00
ORHE	10	149	6.49	29.5	10.6	.0	.00
ORHE	10	150	6.50	33.7	14.5	.0	.00
ORHE	10	151	6.52	39.1	13.8	.0	.00
ORHE	10	152	6.53	27.6	8.8	.0	.00
ORHE	10	153	6.54	30.9	11.1	.2	.00
ORHE	10	154	6.55	30.1	13.4	.8	.00
ORHE	10	155	6.56	30.3	13.6	.0	.00
ORHE	10	156	6.57	30.3	13.8	.0	.00
ORHE	10	157	6.58	29.9	10.6	.0	.00
ORHE	10	158	6.59	33.5	12.7	.0	.00
ORHE	10	159	6.60	29.1	11.0	.0	.00
ORHE	10	160	6.61	31.0	10.0	.0	.00
ORHE	10	161	6.61	26.8	9.1	.5	.00
ORHE	10	162	6.62	27.4	9.5	.3	.00
ORHE	10	163	6.63	29.7	9.2	.0	.00
ORHE	10	164	6.63	26.7	7.2	.0	.00
ORHE	10	165	6.63	28.2	9.8	.0	.00
ORHE	10	166	6.64	27.6	10.3	.0	.00
ORHE	10	167	6.64	28.9	10.1	.0	.00
ORHE	10	168	6.64	32.9	10.6	.0	.00
ORHE	10	169	6.64	31.5	10.7	1.1	.00
ORHE	10	170	6.64	33.1	11.9	.0	.00
ORHE	10	171	6.64	27.0	11.1	.0	.00
ORHE	10	172	6.64	30.5	10.8	.0	.00
ORHE	10	173	6.64	31.0	12.9	.0	.00
ORHE	10	174	6.64	33.4	14.8	.3	.00
ORHE	10	175	6.64	32.5	11.8	4.9	.00
ORHE	10	176	6.63	32.1	13.9	.2	.00
ORHE	10	177	6.63	31.9	13.7	.0	.00
ORHE	10	178	6.62	33.7	13.4	.0	.00
ORHE	10	179	6.62	30.6	10.8	.0	.00
ORHE	10	180	6.61	29.9	9.7	.0	.00
ORHE	10	181	6.60	27.1	8.1	.0	.00
ORHE	10	182	6.60	25.6	6.7	.0	.00
ORHE	10	183	6.59	26.3	8.4	.0	.00
ORHE	10	184	6.58	30.8	9.5	.0	.00
ORHE	10	185	6.57	27.2	10.2	.0	.00
ORHE	10	186	6.56	26.4	12.1	.0	.00
ORHE	10	187	6.55	29.7	10.2	.0	.00
ORHE	10	188	6.53	27.9	10.5	.0	.00
ORHE	10	189	6.52	25.8	13.2	.0	.00
ORHE	10	190	6.51	28.5	10.1	.0	.00
ORHE	10	191	6.50	29.7	9.4	.0	.00
ORHE	10	192	6.48	27.2	10.6	.0	.00
ORHE	10	193	6.47	26.8	11.1	.0	.00
ORHE	10	194	6.45	32.0	13.0	.0	.00
ORHE	10	195	6.43	33.0	14.8	.0	.00
ORHE	10	196	6.42	33.7	13.3	.0	.00
ORHE	10	197	6.40	30.4	15.7	.0	.00
ORHE	10	198	6.38	28.4	12.9	1.7	.00
ORHE	10	199	6.36	25.2	11.8	.8	.00
ORHE	10	200	6.34	25.3	11.8	.4	.00
ORHE	10	201	6.32	27.9	13.1	.0	.00
ORHE	10	202	6.30	25.8	10.6	.0	.00
ORHE	10	203	6.28	28.7	11.5	.0	.00

ORHE	10	204	6.26	28.1	10.5	.0	.00
ORHE	10	205	6.23	32.6	12.3	.0	.00
ORHE	10	206	6.21	34.0	14.9	.0	.00
ORHE	10	207	6.19	34.5	13.3	.0	.00
ORHE	10	208	6.16	33.2	14.4	5.3	.00
ORHE	10	209	6.14	35.8	15.2	.0	.00
ORHE	10	210	6.11	33.8	13.5	.0	.00
ORHE	10	211	6.09	29.8	12.5	.0	.00
ORHE	10	212	6.06	35.7	15.2	.0	.00
ORHE	10	213	6.03	32.4	15.4	.0	.00
ORHE	10	214	6.00	32.8	15.1	.0	.00
ORHE	10	215	5.97	29.0	13.4	.0	.00
ORHE	10	216	5.95	32.2	15.7	.0	.00
ORHE	10	217	5.92	33.7	14.8	.0	.00
ORHE	10	218	5.89	33.1	11.5	.0	.00
ORHE	10	219	5.85	30.2	9.3	.0	.00
ORHE	10	220	5.82	28.3	9.4	.0	.00
ORHE	10	221	5.79	27.1	9.2	.0	.00
ORHE	10	222	5.76	26.7	13.0	.0	.00
ORHE	10	223	5.73	24.9	9.0	.0	.00
ORHE	10	224	5.69	23.9	8.1	.0	.00
ORHE	10	225	5.66	25.3	7.2	.0	.00
ORHE	10	226	5.63	29.7	10.4	.0	.00
ORHE	10	227	5.59	29.4	10.0	.0	.00
ORHE	10	228	5.56	27.2	10.5	.0	.00
ORHE	10	229	5.52	27.5	10.7	.0	.00
ORHE	10	230	5.48	26.9	10.2	.0	.00
ORHE	10	231	5.45	28.5	12.7	.0	.00
ORHE	10	232	5.41	26.7	11.1	.0	.00
ORHE	10	233	5.37	29.6	13.4	.0	.00
ORHE	10	234	5.34	30.4	11.4	.0	.00
ORHE	10	235	5.30	32.1	11.8	.0	.00
ORHE	10	236	5.26	24.4	10.9	.1	.00
ORHE	10	237	5.22	24.7	13.9	.0	.00
ORHE	10	238	5.18	32.0	13.4	.0	.00
ORHE	10	239	5.14	31.6	15.1	.0	.00
ORHE	10	240	5.10	29.5	13.9	.0	.00
ORHE	10	241	5.06	21.5	15.4	.1	.00
ORHE	10	242	5.02	29.6	13.7	.0	.00
ORHE	10	243	4.98	28.5	16.8	.0	.00
ORHE	10	244	4.94	19.9	11.1	1.1	.00
ORHE	10	245	4.90	19.5	7.4	17.9	.00
ORHE	10	246	4.85	19.0	10.3	2.7	.00
ORHE	10	247	4.81	26.5	9.1	.0	.00
ORHE	10	248	4.77	26.7	9.1	.0	.00
ORHE	10	249	4.73	25.1	11.8	3.5	.00
ORHE	10	250	4.68	23.7	8.0	2.4	.00
ORHE	10	251	4.64	23.6	6.6	.0	.00
ORHE	10	252	4.60	19.2	5.9	.0	.00
ORHE	10	253	4.55	19.4	6.9	5.8	.00
ORHE	10	254	4.51	23.1	10.1	5.8	.00
ORHE	10	255	4.47	23.8	11.7	2.5	.00
ORHE	10	256	4.42	27.5	10.5	.0	.00
ORHE	10	257	4.38	34.3	15.4	.0	.00
ORHE	10	258	4.33	31.3	15.2	.0	.00
ORHE	10	259	4.29	28.5	11.4	.0	.00
ORHE	10	260	4.25	23.7	6.7	2.2	.00
ORHE	10	261	4.20	20.2	3.8	.0	.00
ORHE	10	262	4.16	17.0	5.5	.0	.00
ORHE	10	263	4.11	21.2	2.6	6.1	.00
ORHE	10	264	4.07	20.7	3.9	.8	.00
ORHE	10	265	4.02	23.6	2.7	.0	.00
ORHE	10	266	3.98	19.0	2.7	3.6	.00
ORHE	10	267	3.93	25.2	7.4	3.7	.00
ORHE	10	268	3.89	20.1	2.3	1.0	.00
ORHE	10	269	3.84	21.4	1.4	.0	.00
ORHE	10	270	3.80	12.8	.1	.0	.00
ORHE	10	271	3.76	13.7	.4	.0	.00
ORHE	10	272	3.71	11.8	-.3	11.9	.00

ORHE	10	273	3.67	21.3	1.5	6.4	.00
ORHE	10	274	3.62	28.8	9.0	.9	.00
ORHE	10	275	3.58	28.4	10.2	.0	.00
ORHE	10	276	3.54	25.3	9.7	.0	.00
ORHE	10	277	3.49	27.5	12.2	.0	.00
ORHE	10	278	3.45	24.5	9.4	.0	.00
ORHE	10	279	3.41	22.5	11.4	.0	.00
ORHE	10	280	3.36	17.6	13.0	.0	.00
ORHE	10	281	3.32	16.7	5.5	.0	.00
ORHE	10	282	3.28	13.4	4.7	.0	.00
ORHE	10	283	3.23	11.8	4.6	.0	.00
ORHE	10	284	3.19	19.2	6.7	1.4	.00
ORHE	10	285	3.15	12.7	2.6	.4	.00
ORHE	10	286	3.11	19.1	5.3	.0	.00
ORHE	10	287	3.07	18.1	6.6	.0	.00
ORHE	10	288	3.03	19.7	10.0	.0	.00
ORHE	10	289	2.99	24.3	6.7	.0	.00
ORHE	10	290	2.95	19.8	6.5	.0	.00
ORHE	10	291	2.91	18.5	7.7	.0	.00
ORHE	10	292	2.87	8.9	2.1	.0	.00
ORHE	10	293	2.83	12.2	.5	.0	.00
ORHE	10	294	2.79	8.8	.5	1.0	.00
ORHE	10	295	2.75	13.9	5.3	.0	.00
ORHE	10	296	2.72	14.7	5.7	.0	.00
ORHE	10	297	2.68	19.5	5.5	.0	.00
ORHE	10	298	2.64	24.4	8.2	.0	.00
ORHE	10	299	2.61	16.2	8.0	3.9	.00
ORHE	10	300	2.57	14.2	9.1	.6	.00
ORHE	10	301	2.54	19.4	4.6	.0	.00
ORHE	10	302	2.50	9.8	-4.7	.0	.00
ORHE	10	303	2.47	17.7	-3.1	.0	.00
ORHE	10	304	2.43	13.0	-3.5	.0	.00
ORHE	10	305	2.40	9.7	-3.9	.0	.00
ORHE	10	306	2.37	13.6	-.2	.0	.00
ORHE	10	307	2.34	12.9	2.0	.0	.00
ORHE	10	308	2.30	16.5	1.9	.0	.00
ORHE	10	309	2.27	17.2	1.9	4.7	.00
ORHE	10	310	2.24	12.2	1.5	1.0	.00
ORHE	10	311	2.21	13.3	-3.3	2.0	.00
ORHE	10	312	2.18	6.5	-4.7	1.2	.00
ORHE	10	313	2.16	2.4	-2.2	1.4	.00
ORHE	10	314	2.13	10.7	-3.3	.0	.00
ORHE	10	315	2.10	7.8	-3.0	2.6	.00
ORHE	10	316	2.08	7.6	-1.3	.0	.00
ORHE	10	317	2.05	9.0	-1.6	3.0	.00
ORHE	10	318	2.02	12.5	2.6	.0	.00
ORHE	10	319	2.00	13.5	3.4	.0	.00
ORHE	10	320	1.98	9.4	-1.2	.6	.00
ORHE	10	321	1.95	9.4	-3.8	.0	.00
ORHE	10	322	1.93	6.6	-5.8	1.1	.00
ORHE	10	323	1.91	4.6	-4.4	.0	.00
ORHE	10	324	1.89	6.3	-4.7	.0	.00
ORHE	10	325	1.87	10.2	.2	.0	.00
ORHE	10	326	1.85	2.4	-4.9	.0	.00
ORHE	10	327	1.83	7.0	-2.9	.0	.00
ORHE	10	328	1.81	4.3	.6	.0	.00
ORHE	10	329	1.79	6.6	-3.6	.8	.00
ORHE	10	330	1.77	2.8	-1.8	1.1	.00
ORHE	10	331	1.76	6.3	-6.1	.0	.00
ORHE	10	332	1.74	12.8	-7.5	.0	.00
ORHE	10	333	1.72	9.5	.5	1.2	.00
ORHE	10	334	1.71	10.8	-.2	2.3	.00
ORHE	10	335	1.70	5.9	-2.8	.0	.00
ORHE	10	336	1.68	6.0	-4.8	.0	.00
ORHE	10	337	1.67	-2.6	-9.9	1.8	.00
ORHE	10	338	1.66	-.7	-10.5	2.1	.00
ORHE	10	339	1.65	3.8	-8.1	1.5	.00
ORHE	10	340	1.64	10.5	-9.0	.0	.00
ORHE	10	341	1.63	7.0	-2.2	.0	.00

ORHE	10	342	1.62	8.0	-3.4	.0	.00
ORHE	10	343	1.61	11.7	-2.2	.0	.00
ORHE	10	344	1.60	14.8	-1.5	.0	.00
ORHE	10	345	1.60	6.8	-2.0	.0	.00
ORHE	10	346	1.59	8.1	-1.0	.0	.00
ORHE	10	347	1.59	1.9	-1.9	5.2	.00
ORHE	10	348	1.58	7.4	-1.7	.0	.00
ORHE	10	349	1.58	5.5	-5.4	.0	.00
ORHE	10	350	1.57	7.7	-.1	.0	.00
ORHE	10	351	1.57	3.2	1.7	2.2	.00
ORHE	10	352	1.57	8.6	-2.3	5.4	.00
ORHE	10	353	1.57	8.4	1.2	2.4	.00
ORHE	10	354	1.57	7.2	-5.0	8.1	.00
ORHE	10	355	1.57	5.9	4.0	1.0	.00
ORHE	10	356	1.57	8.8	2.9	.5	.00
ORHE	10	357	1.57	2.7	1.2	1.1	.00
ORHE	10	358	1.58	7.4	.8	.0	.00
ORHE	10	359	1.58	8.0	3.9	3.0	.00
ORHE	10	360	1.58	5.9	3.7	.1	.00
ORHE	10	361	1.59	7.8	7.1	1.1	.00
ORHE	10	362	1.59	5.0	3.2	.0	.00
ORHE	10	363	1.60	-.9	-1.0	.0	.00
ORHE	10	364	1.61	5.0	.7	.0	.00
ORHE	10	365	1.61	12.6	5.6	.0	.00
ORHE	11	366	1.62	5.7	-1.8	.0	.00

CERES Expected Weather File for Potatoes

ORHE	45.83	119.28	0.00	0.00			
ORHE	23	1	1.62	5.4	-7.8	.3	.00
ORHE	23	2	1.63	6.5	-9.3	.9	.00
ORHE	23	3	1.64	7.8	-3.6	1.8	.00
ORHE	23	4	1.65	2.5	-3.5	.2	.00
ORHE	23	5	1.66	7.4	-6.6	.4	.00
ORHE	23	6	1.68	4.5	-6.0	.0	.00
ORHE	23	7	1.69	3.0	-2.7	2.1	.00
ORHE	23	8	1.70	3.3	2.2	4.4	.00
ORHE	23	9	1.72	8.9	-2.3	.9	.00
ORHE	23	10	1.73	4.2	-4.7	1.7	.00
ORHE	23	11	1.75	4.9	-2.0	6.9	.00
ORHE	23	12	1.76	4.2	-3.2	5.0	.00
ORHE	23	13	1.78	.3	-1.1	3.3	.00
ORHE	23	14	1.80	2.1	1.9	5.0	.00
ORHE	23	15	1.82	8.9	-.6	.0	.00
ORHE	23	16	1.84	8.0	-.4	.0	.00
ORHE	23	17	1.86	9.3	-2.6	.0	.00
ORHE	23	18	1.88	-.1	-7.8	.0	.00
ORHE	23	19	1.90	-7.3	-13.3	.0	.00
ORHE	23	20	1.92	2.7	-10.0	.0	.00
ORHE	23	21	1.94	1.6	-10.7	.0	.00
ORHE	23	22	1.97	2.9	-2.6	.0	.00
ORHE	23	23	1.99	4.7	-.1	.0	.00
ORHE	23	24	2.01	3.9	-7.8	.0	.00
ORHE	23	25	2.04	3.2	-9.3	.0	.00
ORHE	23	26	2.06	11.4	-2.9	.0	.00
ORHE	23	27	2.09	2.9	1.6	.0	.00
ORHE	23	28	2.12	8.6	-.8	.0	.00
ORHE	23	29	2.15	15.7	.4	.0	.00
ORHE	23	30	2.17	8.1	7.9	6.3	.00
ORHE	23	31	2.20	15.0	8.1	.0	.00
ORHE	23	32	2.23	7.8	6.5	.0	.00
ORHE	23	33	2.26	8.5	4.3	.0	.00
ORHE	23	34	2.29	4.8	2.9	.0	.00
ORHE	23	35	2.33	5.1	2.7	.0	.00
ORHE	23	36	2.36	-3.1	-4.5	2.8	.00
ORHE	23	37	2.39	2.3	-3.6	.0	.00
ORHE	23	38	2.42	1.4	-3.9	.0	.00
ORHE	23	39	2.46	5.8	-4.2	.0	.00
ORHE	23	40	2.49	5.3	-5.6	4.3	.00
ORHE	23	41	2.53	.0	-.1	.7	.00
ORHE	23	42	2.56	1.3	-7.0	.0	.00
ORHE	23	43	2.60	4.7	-3.8	.0	.00
ORHE	23	44	2.63	13.1	-1.9	.0	.00
ORHE	23	45	2.67	10.6	5.4	.0	.00
ORHE	23	46	2.71	18.0	8.8	.0	.00
ORHE	23	47	2.75	13.2	6.7	.0	.00
ORHE	23	48	2.79	8.9	6.0	.0	.00
ORHE	23	49	2.82	5.5	.4	.0	.00
ORHE	23	50	2.86	1.5	-3.5	.0	.00
ORHE	23	51	2.90	3.9	-8.5	1.6	.00
ORHE	23	52	2.94	11.3	-6.5	.0	.00
ORHE	23	53	2.98	10.5	1.8	8.2	.00
ORHE	23	54	3.02	11.8	.2	.0	.00
ORHE	23	55	3.07	12.4	2.4	.0	.00
ORHE	23	56	3.11	10.8	3.0	.0	.00
ORHE	23	57	3.15	8.3	.4	.0	.00
ORHE	23	58	3.19	8.1	-2.9	.0	.00
ORHE	23	59	3.23	5.2	-1.7	.0	.00
ORHE	23	60	3.28	7.0	-4.3	.0	.00
ORHE	23	61	3.32	9.2	-4.3	.0	.00
ORHE	23	62	3.36	9.8	2.5	7.2	.00
ORHE	23	63	3.41	5.8	-3.9	5.0	.00
ORHE	23	64	3.45	11.6	1.0	.0	.00
ORHE	23	65	3.50	10.8	-1.3	.0	.00

ORHE	23	66	3.54	8.2	-2.4	.0	.00
ORHE	23	67	3.58	5.1	.2	3.2	.00
ORHE	23	68	3.63	6.8	-5.5	.2	.00
ORHE	23	69	3.67	7.5	-7.3	.0	.00
ORHE	23	70	3.72	10.2	-.9	.0	.00
ORHE	23	71	3.76	6.6	-3.7	2.3	.00
ORHE	23	72	3.81	11.7	-2.5	.0	.00
ORHE	23	73	3.85	15.1	5.7	.0	.00
ORHE	23	74	3.90	16.8	9.4	1.9	.00
ORHE	23	75	3.95	15.7	9.4	.0	.00
ORHE	23	76	3.99	18.7	10.1	.0	.00
ORHE	23	77	4.04	20.4	5.8	.0	.00
ORHE	23	78	4.08	10.0	1.1	5.2	.00
ORHE	23	79	4.13	5.0	-3.9	.0	.00
ORHE	23	80	4.17	3.0	-1.1	.0	.00
ORHE	23	81	4.22	4.6	-8.3	.0	.00
ORHE	23	82	4.26	8.5	-4.3	.0	.00
ORHE	23	83	4.31	13.8	1.4	.0	.00
ORHE	23	84	4.35	12.6	1.4	.0	.00
ORHE	23	85	4.40	16.9	.4	.0	.00
ORHE	23	86	4.44	15.5	5.2	.0	.00
ORHE	23	87	4.49	18.5	3.8	.0	.00
ORHE	23	88	4.53	13.5	-2.8	.0	.00
ORHE	23	89	4.58	15.8	3.0	.0	.00
ORHE	23	90	4.62	15.1	-1.6	.0	.00
ORHE	23	91	4.67	17.7	1.4	.0	.00
ORHE	23	92	4.71	19.2	1.7	.0	.00
ORHE	23	93	4.75	20.0	5.5	.0	.00
ORHE	23	94	4.80	16.5	4.2	.0	.00
ORHE	23	95	4.84	19.5	5.3	.0	.00
ORHE	23	96	4.88	16.1	7.0	.0	.00
ORHE	23	97	4.92	10.0	4.6	.0	.00
ORHE	23	98	4.97	16.6	4.0	.0	.00
ORHE	23	99	5.01	9.5	2.2	.0	.00
ORHE	23	100	5.05	7.7	1.3	.0	.00
ORHE	23	101	5.09	19.9	5.5	.0	.00
ORHE	23	102	5.13	9.7	6.9	.1	.00
ORHE	23	103	5.17	19.5	8.8	.0	.00
ORHE	23	104	5.21	16.1	5.5	9.8	.00
ORHE	23	105	5.25	19.5	9.3	3.2	.00
ORHE	23	106	5.29	21.1	5.4	1.0	.00
ORHE	23	107	5.33	17.1	4.8	.1	.00
ORHE	23	108	5.37	16.0	4.9	.0	.00
ORHE	23	109	5.41	13.9	1.9	2.4	.00
ORHE	23	110	5.45	21.7	3.3	.0	.00
ORHE	23	111	5.48	23.5	7.8	.0	.00
ORHE	23	112	5.52	22.2	9.9	.0	.00
ORHE	23	113	5.56	17.2	10.7	.0	.00
ORHE	23	114	5.59	23.4	11.1	.0	.00
ORHE	23	115	5.63	21.7	13.8	2.6	.00
ORHE	23	116	5.66	24.2	12.4	3.2	.00
ORHE	23	117	5.70	22.2	10.6	.0	.00
ORHE	23	118	5.73	29.0	14.3	.0	.00
ORHE	23	119	5.76	18.6	7.9	.0	.00
ORHE	23	120	5.80	20.7	4.5	.0	.00
ORHE	23	121	5.83	25.2	4.3	.0	.00
ORHE	23	122	5.86	23.3	11.8	.0	.00
ORHE	23	123	5.89	22.6	9.4	.0	.00
ORHE	23	124	5.92	29.3	15.5	.0	.00
ORHE	23	125	5.95	30.7	16.4	.0	.00
ORHE	23	126	5.98	27.3	13.6	.3	.00
ORHE	23	127	6.01	24.9	11.9	.0	.00
ORHE	23	128	6.04	20.9	10.2	.0	.00
ORHE	23	129	6.07	26.6	13.7	8.7	.00
ORHE	23	130	6.09	29.6	8.3	.0	.00
ORHE	23	131	6.12	30.5	11.5	.0	.00
ORHE	23	132	6.14	25.8	10.9	.0	.00
ORHE	23	133	6.17	25.2	11.1	.0	.00
ORHE	23	134	6.19	20.3	9.7	.0	.00

ORHE	23	135	6.22	21.6	10.6	.0	.00
ORHE	23	136	6.24	18.3	7.5	.0	.00
ORHE	23	137	6.27	19.3	7.1	.0	.00
ORHE	23	138	6.29	16.3	8.1	.0	.00
ORHE	23	139	6.31	18.4	6.5	.0	.00
ORHE	23	140	6.33	17.0	1.7	.0	.00
ORHE	23	141	6.35	26.1	8.0	4.4	.00
ORHE	23	142	6.37	23.0	9.3	.0	.00
ORHE	23	143	6.39	26.2	6.9	.0	.00
ORHE	23	144	6.41	30.2	14.3	.0	.00
ORHE	23	145	6.42	27.1	7.9	.1	.00
ORHE	23	146	6.44	20.1	6.3	.0	.00
ORHE	23	147	6.46	19.4	5.9	5.7	.00
ORHE	23	148	6.47	21.2	6.7	.0	.00
ORHE	23	149	6.49	22.1	8.4	.0	.00
ORHE	23	150	6.50	22.7	9.7	.0	.00
ORHE	23	151	6.52	26.7	12.2	.0	.00
ORHE	23	152	6.53	25.3	10.6	.0	.00
ORHE	23	153	6.54	29.3	8.5	.0	.00
ORHE	23	154	6.55	26.8	13.3	.0	.00
ORHE	23	155	6.56	31.3	13.0	.0	.00
ORHE	23	156	6.57	28.5	9.5	.0	.00
ORHE	23	157	6.58	24.7	13.1	.0	.00
ORHE	23	158	6.59	28.8	11.3	.0	.00
ORHE	23	159	6.60	29.3	13.0	1.8	.00
ORHE	23	160	6.61	24.5	11.3	3.0	.00
ORHE	23	161	6.61	22.6	11.4	4.6	.00
ORHE	23	162	6.62	21.6	5.1	1.7	.00
ORHE	23	163	6.63	23.4	5.8	.0	.00
ORHE	23	164	6.63	23.7	8.0	.0	.00
ORHE	23	165	6.63	27.3	9.7	.0	.00
ORHE	23	166	6.64	25.5	5.6	.0	.00
ORHE	23	167	6.64	23.1	9.2	.0	.00
ORHE	23	168	6.64	28.5	9.5	.0	.00
ORHE	23	169	6.64	21.2	7.3	.0	.00
ORHE	23	170	6.64	26.2	9.5	.0	.00
ORHE	23	171	6.64	28.9	11.8	.0	.00
ORHE	23	172	6.64	28.2	15.4	.0	.00
ORHE	23	173	6.64	28.2	10.4	.0	.00
ORHE	23	174	6.64	34.3	10.8	.0	.00
ORHE	23	175	6.64	29.3	13.2	.0	.00
ORHE	23	176	6.63	30.0	10.4	.0	.00
ORHE	23	177	6.63	33.1	13.6	.0	.00
ORHE	23	178	6.62	29.2	15.6	4.4	.00
ORHE	23	179	6.62	26.9	13.3	.0	.00
ORHE	23	180	6.61	30.7	13.1	.0	.00
ORHE	23	181	6.60	31.7	16.9	.0	.00
ORHE	23	182	6.60	29.9	14.4	.0	.00
ORHE	23	183	6.59	28.4	13.9	.0	.00
ORHE	23	184	6.58	26.7	9.4	.0	.00
ORHE	23	185	6.57	29.5	11.0	.0	.00
ORHE	23	186	6.56	27.1	10.6	.0	.00
ORHE	23	187	6.55	26.6	11.6	.0	.00
ORHE	23	188	6.53	31.1	16.2	.0	.00
ORHE	23	189	6.52	31.2	12.9	.0	.00
ORHE	23	190	6.51	32.4	13.8	.0	.00
ORHE	23	191	6.50	32.1	16.6	.0	.00
ORHE	23	192	6.48	30.4	14.2	5.1	.00
ORHE	23	193	6.47	28.4	12.0	3.7	.00
ORHE	23	194	6.45	27.4	13.2	2.7	.00
ORHE	23	195	6.43	29.7	14.0	.0	.00
ORHE	23	196	6.42	26.7	13.5	.0	.00
ORHE	23	197	6.40	30.2	13.2	.0	.00
ORHE	23	198	6.38	33.2	14.5	.0	.00
ORHE	23	199	6.36	30.1	14.4	6.8	.00
ORHE	23	200	6.34	34.2	13.9	.0	.00
ORHE	23	201	6.32	34.5	13.7	.0	.00
ORHE	23	202	6.30	33.7	13.9	.0	.00
ORHE	23	203	6.28	32.2	12.0	.0	.00

ORHE	23	204	6.26	27.6	11.8	6.0	.00
ORHE	23	205	6.23	22.2	9.2	1.2	.00
ORHE	23	206	6.21	25.2	8.4	.0	.00
ORHE	23	207	6.19	28.7	9.3	.0	.00
ORHE	23	208	6.16	28.0	8.7	8.2	.00
ORHE	23	209	6.14	25.3	5.3	.0	.00
ORHE	23	210	6.11	30.9	9.9	.0	.00
ORHE	23	211	6.09	28.4	12.3	.0	.00
ORHE	23	212	6.06	32.6	12.3	.0	.00
ORHE	23	213	6.03	30.2	9.7	.0	.00
ORHE	23	214	6.00	30.2	10.0	.0	.00
ORHE	23	215	5.97	31.5	9.0	.0	.00
ORHE	23	216	5.95	31.7	10.7	.0	.00
ORHE	23	217	5.92	28.3	9.8	.0	.00
ORHE	23	218	5.89	29.7	9.9	.0	.00
ORHE	23	219	5.85	26.3	10.3	.0	.00
ORHE	23	220	5.82	30.3	10.7	.0	.00
ORHE	23	221	5.79	30.6	11.1	.0	.00
ORHE	23	222	5.76	36.0	12.8	.0	.00
ORHE	23	223	5.73	31.8	10.7	.0	.00
ORHE	23	224	5.69	27.1	10.6	.0	.00
ORHE	23	225	5.66	31.1	14.8	.5	.00
ORHE	23	226	5.63	35.3	14.3	.0	.00
ORHE	23	227	5.59	32.6	15.7	.0	.00
ORHE	23	228	5.56	32.6	17.4	.0	.00
ORHE	23	229	5.52	32.9	14.3	.0	.00
ORHE	23	230	5.48	28.7	13.6	.1	.00
ORHE	23	231	5.45	29.9	14.9	1.2	.00
ORHE	23	232	5.41	28.1	14.5	2.8	.00
ORHE	23	233	5.37	25.5	9.8	.0	.00
ORHE	23	234	5.34	31.1	7.6	.0	.00
ORHE	23	235	5.30	35.0	15.5	.0	.00
ORHE	23	236	5.26	32.7	17.2	.0	.00
ORHE	23	237	5.22	31.7	18.6	.0	.00
ORHE	23	238	5.18	33.8	18.2	.0	.00
ORHE	23	239	5.14	32.8	18.0	.0	.00
ORHE	23	240	5.10	25.9	13.7	.0	.00
ORHE	23	241	5.06	29.0	16.1	.0	.00
ORHE	23	242	5.02	25.8	14.2	.0	.00
ORHE	23	243	4.98	28.2	12.0	.0	.00
ORHE	23	244	4.94	33.5	13.6	.0	.00
ORHE	23	245	4.90	33.2	15.9	2.6	.00
ORHE	23	246	4.85	36.8	19.0	.0	.00
ORHE	23	247	4.81	29.7	17.6	.3	.00
ORHE	23	248	4.77	25.7	12.7	4.8	.00
ORHE	23	249	4.73	26.6	12.9	2.3	.00
ORHE	23	250	4.68	27.0	16.2	1.0	.00
ORHE	23	251	4.64	25.1	12.1	5.0	.00
ORHE	23	252	4.60	21.1	12.5	3.2	.00
ORHE	23	253	4.55	21.8	6.2	.0	.00
ORHE	23	254	4.51	20.8	7.5	.0	.00
ORHE	23	255	4.47	18.4	5.4	.0	.00
ORHE	23	256	4.42	17.4	4.4	.0	.00
ORHE	23	257	4.38	20.8	3.2	.0	.00
ORHE	23	258	4.33	22.3	5.4	.0	.00
ORHE	23	259	4.29	22.8	10.9	.0	.00
ORHE	23	260	4.25	22.1	8.3	.0	.00
ORHE	23	261	4.20	20.5	7.2	.0	.00
ORHE	23	262	4.16	25.5	9.8	.0	.00
ORHE	23	263	4.11	25.8	8.5	.0	.00
ORHE	23	264	4.07	19.8	7.1	.0	.00
ORHE	23	265	4.02	23.8	7.7	.0	.00
ORHE	23	266	3.98	21.9	11.5	.0	.00
ORHE	23	267	3.93	22.3	8.3	.0	.00
ORHE	23	268	3.89	18.8	3.7	.0	.00
ORHE	23	269	3.84	21.0	4.4	.0	.00
ORHE	23	270	3.80	19.3	7.6	.0	.00
ORHE	23	271	3.76	16.9	6.9	.0	.00
ORHE	23	272	3.71	22.7	7.3	.0	.00

ORHE	23	273	3.67	21.6	2.1	.0	.00
ORHE	23	274	3.62	18.1	8.7	.4	.00
ORHE	23	275	3.58	22.6	8.0	.0	.00
ORHE	23	276	3.54	14.3	4.3	.0	.00
ORHE	23	277	3.49	18.8	4.7	.0	.00
ORHE	23	278	3.45	19.5	5.7	.0	.00
ORHE	23	279	3.41	15.5	6.4	.0	.00
ORHE	23	280	3.36	10.9	1.4	.0	.00
ORHE	23	281	3.32	12.6	.2	.0	.00
ORHE	23	282	3.28	17.5	1.9	.0	.00
ORHE	23	283	3.23	12.3	2.4	.0	.00
ORHE	23	284	3.19	15.2	-1.5	.0	.00
ORHE	23	285	3.15	17.7	-.5	.0	.00
ORHE	23	286	3.11	18.4	3.0	.0	.00
ORHE	23	287	3.07	17.7	-1.3	.0	.00
ORHE	23	288	3.03	16.4	5.2	.0	.00
ORHE	23	289	2.99	17.5	5.8	.0	.00
ORHE	23	290	2.95	21.1	6.0	.0	.00
ORHE	23	291	2.91	21.0	10.4	.0	.00
ORHE	23	292	2.87	20.8	9.2	.0	.00
ORHE	23	293	2.83	29.2	11.1	.0	.00
ORHE	23	294	2.79	24.6	10.1	.0	.00
ORHE	23	295	2.75	18.6	5.5	4.2	.00
ORHE	23	296	2.72	19.9	2.7	.0	.00
ORHE	23	297	2.68	11.3	2.6	.0	.00
ORHE	23	298	2.64	15.2	5.0	.0	.00
ORHE	23	299	2.61	19.6	7.0	.0	.00
ORHE	23	300	2.57	10.2	5.5	2.4	.00
ORHE	23	301	2.54	16.5	2.7	3.4	.00
ORHE	23	302	2.50	13.4	7.2	2.1	.00
ORHE	23	303	2.47	21.2	7.0	.0	.00
ORHE	23	304	2.43	15.3	6.6	.7	.00
ORHE	23	305	2.40	12.6	3.2	.0	.00
ORHE	23	306	2.37	12.0	3.4	.0	.00
ORHE	23	307	2.34	17.6	5.4	.0	.00
ORHE	23	308	2.30	16.8	2.1	5.4	.00
ORHE	23	309	2.27	14.9	2.5	1.5	.00
ORHE	23	310	2.24	22.1	8.1	.0	.00
ORHE	23	311	2.21	21.0	1.9	.0	.00
ORHE	23	312	2.18	25.1	6.6	.0	.00
ORHE	23	313	2.16	16.6	9.2	.0	.00
ORHE	23	314	2.13	16.1	11.3	.0	.00
ORHE	23	315	2.10	8.0	3.9	.9	.00
ORHE	23	316	2.08	6.5	1.8	.1	.00
ORHE	23	317	2.05	10.4	4.1	.0	.00
ORHE	23	318	2.02	5.3	-2.2	.0	.00
ORHE	23	319	2.00	10.1	-5.3	.0	.00
ORHE	23	320	1.98	4.2	-4.3	.0	.00
ORHE	23	321	1.95	-1.5	-9.4	7.1	.00
ORHE	23	322	1.93	.3	-12.0	4.6	.00
ORHE	23	323	1.91	4.6	-4.1	.0	.00
ORHE	23	324	1.89	4.6	-1.2	.0	.00
ORHE	23	325	1.87	8.9	2.2	.0	.00
ORHE	23	326	1.85	9.2	-2.6	.2	.00
ORHE	23	327	1.83	9.1	-.5	.0	.00
ORHE	23	328	1.81	11.8	-3.9	.0	.00
ORHE	23	329	1.79	6.8	-9.9	.7	.00
ORHE	23	330	1.77	9.9	-4.1	3.8	.00
ORHE	23	331	1.76	6.8	-5.4	.4	.00
ORHE	23	332	1.74	9.1	-6.1	3.3	.00
ORHE	23	333	1.72	4.1	-7.4	.0	.00
ORHE	23	334	1.71	-2.3	-9.1	6.6	.00
ORHE	23	335	1.70	1.0	-10.0	.0	.00
ORHE	23	336	1.68	.7	-10.8	.0	.00
ORHE	23	337	1.67	8.2	-10.1	.0	.00
ORHE	23	338	1.66	7.6	-3.4	.0	.00
ORHE	23	339	1.65	2.4	-5.2	.0	.00
ORHE	23	340	1.64	10.5	-4.6	.0	.00
ORHE	23	341	1.63	6.4	-1.4	.0	.00

ORHE	23	342	1.62	12.3	4.2	.0	.00
ORHE	23	343	1.61	14.0	4.8	.0	.00
ORHE	23	344	1.60	14.6	9.5	1.0	.00
ORHE	23	345	1.60	5.6	1.6	.7	.00
ORHE	23	346	1.59	6.8	.6	.4	.00
ORHE	23	347	1.59	5.5	-2.9	2.3	.00
ORHE	23	348	1.58	10.2	-2.4	1.5	.00
ORHE	23	349	1.58	7.7	-2.2	10.1	.00
ORHE	23	350	1.57	2.8	-2.6	.0	.00
ORHE	23	351	1.57	.6	-.5	.0	.00
ORHE	23	352	1.57	-5.1	-6.6	.0	.00
ORHE	23	353	1.57	-2.9	-5.3	.0	.00
ORHE	23	354	1.57	-3.4	-3.7	1.8	.00
ORHE	23	355	1.57	7.2	-3.7	.0	.00
ORHE	23	356	1.57	7.5	-1.9	.0	.00
ORHE	23	357	1.57	7.3	-2.2	.0	.00
ORHE	23	358	1.58	-1.8	-7.2	9.1	.00
ORHE	23	359	1.58	-.1	-4.4	.0	.00
ORHE	23	360	1.58	4.5	-8.8	.0	.00
ORHE	23	361	1.59	3.6	-8.6	.0	.00
ORHE	23	362	1.59	9.9	-6.0	.0	.00
ORHE	23	363	1.60	3.0	-3.8	.0	.00
ORHE	23	364	1.61	.1	-5.7	.0	.00
ORHE	23	365	1.61	1.8	-7.1	1.1	.00
ORHE	24	1	1.62	1.2	-1.2	.0	.00

Input Parameter File Used for WGEN

.573	.586	.478	.345	.283	.421	.261	.250	.426	.452	.496	.596
.205	.212	.249	.184	.159	.150	.070	.046	.126	.101	.379	.259
.998	.998	.998	.852	.836	.864	.998	.859	.919	.955	.998	.998
.117	.111	.103	.113	.173	.126	.079	.094	.151	.162	.107	.121

64.194	23.564	.145	-.074
60.960			
40.511	14.721	.201	-.119
.356	.280		
.297			

Example Input Files for LAMB.FOR

File #1:

```
c:\qu\c20.prn
C20001.0
36.0
```

File #2:

```
 90 0.00    0.00
104 0.00    0.00
111 0.01    0.40
118 0.00    0.00
125 0.41   23.20
132 0.00    0.00
139 0.00    0.00
146 0.53   30.20
153 0.36   20.70
160 0.00    0.00
167 0.99   56.00
174 1.52   85.70
181 1.81  102.80
188 2.13  121.80
195 2.48  140.30
202 2.53  143.00
216 2.99  169.00
209 2.96  167.50
223 2.69  152.40
237 1.76   99.60
244 2.28  129.10
258 0.75   42.40
```

Solution File for the Base Wheat Optimization Analysis

THIS IS RUN NUMBER: 1

RUN TIME REPORT:
THE PROFIT MAXIMIZING FINAL Sa IS 25 mm & N IS 20 kg/ha YIELDING $1253.41 IN NET REVENUE
THE AVARAGE TIME IN CERES WAS .00 SECONDS IN 67999 CALLS OF CERES

PERIOD	JULIAN DATE	POINTER STATE mm/m	TRUE STATE mm/m	IRRI- GATION mm@	CURRENT SUM $	ETa mm	MARGINAL YIELD kg/ha	WATER COSTS $	ROOT DEPTH m	MOSI- TURE* mm	N USED kg	POINTER N kg/ha/m	TRUE N kg/ha/m	FERTIL- IZER kg/ha	N LEACH kg/ha	WATER LEACH mm	NITR. COSTS $
1	88	50	38	0	142.55	3.0	1716.38	13.80	1.00	2.79	0	120	99	88	.0	.0	118.30
2	89	45	47	11	240.21	2.6	2118.80	15.20	1.00	1.27	1	80	98	0	.0	.0	83.60
3	90	50	49	6	256.23	4.2	2240.43	19.00	1.00	.00	1	80	97	0	.0	.0	83.30
4	91	55	55	11	285.42	5.1	2496.11	29.50	1.00	.51	3	80	94	0	.0	.0	84.50
5	92	60	61	11	339.22	4.9	2881.24	37.60	1.00	.00	3	80	91	0	.0	.0	84.20
6	93	55	61	0	302.07	1.7	2597.07	29.10	1.00	2.54	3	80	88	0	.0	.0	84.40
7	94	60	58	0	399.58	3.4	3274.58	41.40	1.00	.51	4	80	84	0	.0	.0	82.90
8	95	50	55	0	273.51	2.7	2310.98	22.70	1.00	.00	3	60	81	0	.0	.0	73.60
9	96	50	53	0	243.78	2.2	2139.20	24.30	1.00	.00	3	60	78	0	.0	.0	74.20
10	97	50	51	0	286.61	2.0	2412.62	25.30	1.00	.51	4	60	74	0	.0	.0	74.10
11	98	60	58	11	383.40	4.0	3181.12	43.20	1.00	.00	4	60	70	0	.0	.0	82.40
12	99	50	55	0	299.96	3.5	2550.70	25.80	1.00	.00	4	60	66	0	.0	.0	82.40
13	100	60	59	9	414.54	4.5	3374.94	42.90	1.00	.00	4	60	62	0	.0	.0	82.50
14	101	65	65	11	660.97	5.0	5471.61	138.70	1.00	.00	6	40	56	0	.0	.0	75.70
15	102	55	61	0	273.77	4.4	2439.59	31.60	1.00	.00	6	60	50	0	.0	.0	85.00
16	103	55	56	0	286.93	5.1	2461.55	32.30	1.00	.00	4	40	46	0	.0	.0	74.70
17	104	55	57	5	286.67	4.2	2468.70	32.10	1.00	.00	5	40	41	0	.0	.0	76.30
18	105	60	62	8	450.13	2.7	3616.59	44.90	1.00	.00	5	60	60	24	.0	.0	83.70
19	106	55	60	0	333.72	2.2	2850.10	34.50	1.00	.00	5	60	55	0	.0	.0	87.70
20	107	55	57	0	331.34	3.0	2838.27	34.20	1.00	.00	7	60	48	0	.0	.0	88.50
21	108	60	63	4	439.18	.7	3503.46	42.70	1.00	3.05	1	40	47	0	.0	.0	78.60
22	109	65	60	0	781.26	3.2	6226.08	134.30	1.00	.00	8	40	39	0	.0	.0	80.60
23	110	55	58	0	288.53	1.7	2307.81	33.00	1.00	.00	2	20	37	0	.0	.0	47.70
24	111	65	69	0	551.06	.8	4560.83	131.00	1.00	11.68	1	20	36	0	.0	.0	47.70
25	112	75	70	0	492.33	.8	4381.59	161.00	1.00	11.43	1	20	35	0	.0	.0	47.70
26	113	85	85	11	767.46	2.5	6365.63	162.90	1.00	7.11	5	60	56	26	.0	.0	88.10
27	114	80	81	0	794.26	3.6	6535.53	161.00	1.00	.00	11	60	45	0	.0	.5	90.40
28	115	75	78	0	753.02	2.8	6234.39	159.10	1.00	.00	8	40	37	0	.0	.8	85.40
29	116	75	73	0	623.71	5.1	5239.05	157.20	1.00	.00	4	20	33	0	.1	1.1	57.40
30	117	80	78	11	834.96	5.7	6772.07	157.20	1.00	.00	13	60	51	31	.1	1.1	91.40
31	118	70	73	0	807.56	4.9	6567.64	154.90	1.00	.00	14	40	37	0	.1	1.0	88.40
32	119	65	70	0	743.29	2.8	5870.46	127.10	1.00	.25	6	20	31	0	.1	.7	68.90
33	120	70	70	0	748.33	4.1	6053.02	151.30	1.00	4.06	4	20	27	0	.0	.3	68.90
34	121	70	70	5	864.88	5.2	6906.81	150.10	1.00	.00	14	40	30	17	.0	.1	90.10
35	122	70	72	6	888.94	3.9	7056.94	149.50	1.00	.00	14	40	40	24	.0	.1	90.70
36	123	65	70	0	837.45	1.9	6524.42	122.30	1.00	.00	1	20	39	0	.0	.0	84.20
37	124	75	73	8	812.70	4.8	6537.31	149.10	1.00	.00	7	20	32	0	.0	.0	84.20
38	125	75	77	8	850.03	4.2	6767.43	148.60	1.00	.00	3	20	29	0	.0	.0	84.20
39	126	80	80	8	855.81	4.5	6943.80	148.10	1.00	.00	13	60	48	32	.0	.6	107.10
40	127	85	84	11	890.02	7.4	7088.38	148.00	1.00	.00	8	20	40	0	.1	1.0	96.10
41	128	80	81	4	867.70	7.2	6995.49	146.90	1.00	.00	13	40	35	8	.1	1.2	104.70
42	129	85	86	11	871.72	5.8	7027.58	146.80	1.00	.25	7	40	46	18	.1	1.5	105.90
43	130	90	88	11	886.56	8.9	7154.70	146.80	1.00	.00	8	40	38	0	.1	2.4	111.40
44	131	80	80	0	911.37	7.8	7323.48	146.80	1.00	.00	5	40	33	0	.1	2.1	113.60
45	132	80	79	9	915.02	9.5	7358.56	146.50	1.00	.00	3	40	42	12	.1	1.9	115.90
46	133	65	71	0	903.29	8.1	7119.05	125.40	1.00	.51	1	20	41	0	.1	1.4	110.40
47	134	70	74	8	909.83	4.8	7227.97	136.30	1.00	.00	4	20	37	0	.1	.7	110.40
48	135	70	69	0	912.01	4.7	7266.07	140.20	1.00	.00	7	20	30	0	.0	.5	110.40
49	136	75	72	11	904.50	8.0	7205.94	138.10	1.00	.00	3	20	27	0	.0	.2	110.40
50	137	65	70	0	922.05	2.2	7209.59	121.10	1.00	.51	0	20	28	0	.0	.1	110.40
51	138	65	66	0	915.31	4.7	7155.73	119.30	1.00	.00	3	20	25	0	.0	.1	110.40
52	139	60	61	0	659.14	4.8	5204.20	63.20	1.00	.51	0	20	25	0	.0	.0	110.40
53	140	60	60	4	653.83	5.1	5186.99	65.70	1.00	.00	1	20	24	0	.0	.0	110.40
54	141	55	53	0	642.21	7.3	5069.47	58.60	1.00	.00	0	20	24	0	.0	.0	110.40
55	142	50	48	5	580.35	9.9	4661.23	55.10	1.00	.00	0	20	24	0	.0	.0	110.40
56	143	50	51	11	544.83	7.6	4454.04	57.50	1.00	.00	1	20	23	0	.0	.0	110.40
57	144	55	57	11	636.02	4.9	5075.92	65.80	1.00	.00	0	20	23	0	.0	.0	110.40
58	145	55	50	0	637.69	7.2	5105.70	68.90	1.00	.00	0	20	24	0	.0	.0	110.40
59	146	55	54	11	635.74	7.4	5084.69	67.50	1.00	.00	1	20	23	0	.0	.0	110.40
60	147	55	56	9	647.47	6.9	5170.96	69.50	1.00	.00	0	20	23	0	.0	.0	110.40
61	148	45	50	0	610.27	5.8	4880.91	60.30	1.00	.00	0	20	23	0	.0	.0	110.40
62	149	70	79	11	954.95	1.5	7458.03	128.00	1.00	19.81	0	20	24	0	.0	.0	110.40
63	150	75	75	0	971.94	4.0	7564.22	128.00	1.00	.00	0	20	24	0	.0	.0	110.40
64	151	70	71	0	990.96	3.9	7671.12	126.10	1.00	.00	0	20	24	0	.0	.0	110.40
65	152	65	70	0	1018.54	2.0	7751.13	111.30	1.00	1.52	0	20	24	0	.0	.0	110.40
66	153	75	76	8	1002.27	3.2	7738.63	125.60	1.00	1.78	0	20	24	0	.0	.0	110.40
67	154	75	73	0	924.40	3.1	7239.95	123.60	1.00	.00	0	20	24	0	.0	.0	110.40
68	155	80	82	7	923.94	2.0	7232.84	123.00	1.00	4.57	0	20	24	0	.0	.0	110.40
69	156	75	79	0	935.04	3.1	7302.24	123.00	1.00	.00	0	20	24	0	.0	.7	110.40
70	157	85	86	7	942.94	1.9	7347.41	122.30	1.00	3.56	0	20	24	0	.1	1.1	110.40
71	158	85	80	0	876.04	5.9	6917.31	120.40	1.00	.00	0	20	24	0	.1	1.2	110.40
72	159	70	77	0	975.18	2.7	7536.96	120.40	1.00	.25	0	20	24	0	.1	1.1	110.40
73	160	70	73	0	960.09	4.1	7430.62	118.50	1.00	.51	0	20	24	0	.1	.9	110.40
74	161	80	80	11	881.13	3.8	6936.99	118.40	1.00	.51	0	20	24	0	.0	.8	110.40
75	162	85	82	10	887.34	8.4	6978.63	118.90	1.00	.00	0	20	24	0	.1	1.0	110.40
76	163	80	81	7	927.84	8.4	7227.57	118.20	1.00	.00	0	20	24	0	.1	1.1	110.40
77	164	85	82	11	937.76	10.1	7297.33	119.50	1.00	.00	0	20	24	0	.1	1.3	110.40
78	165	80	81	9	1029.36	9.8	7867.67	119.10	1.00	.00	0	20	24	0	.1	1.3	110.40
79	166	80	80	10	1037.66	11.1	7918.37	118.90	1.00	.00	0	20	24	0	.1	1.2	110.40
80	167	80	78	11	1057.95	.2	8044.99	118.90	1.00	.00	0	20	24	0	.1	1.0	110.40
81	168	75	70	0	1041.77	8.4	7931.86	117.00	1.00	.00	0	20	24	0	.0	.5	110.40
82	169	65	67	4	1077.60	6.8	8084.32	105.50	1.00	.00	0	20	24	0	.0	.2	110.40
83	170	70	68	11	1102.53	10.0	8304.30	115.80	1.00	.00	0	20	24	0	.0	.1	110.40
84	171	70	69	11	1129.75	10.1	8474.21	115.80	1.00	.00	0	20	25	0	.0	.0	110.40
85	172	70	69	11	1084.01	10.9	8176.17	113.80	1.00	.00	0	20	25	0	.0	.0	110.40
86	173	70	70	11	1071.74	9.7	8099.29	113.80	1.00	.00	0	20	25	0	.0	.0	110.40
87	174	70	69	11	1054.46	11.9	7991.15	113.80	1.00	.00	0	20	25	0	.0	.0	110.40
88	175	65	68	9	1076.95	10.0	8070.28	103.90	1.00	.00	0	20	25	0	.0	.0	110.40
89	176	70	72	11	1079.84	7.3	8147.38	113.40	1.00	.00	0	20	25	0	.0	.0	110.40
90	177	60	70	0	1105.35	2.1	8148.59	88.10	1.00	.00	0	20	25	0	.0	.0	110.40
91	178	80	72	11	1068.81	9.2	8066.27	111.40	1.00	.00	0	20	25	0	.0	.0	110.40
92	179	75	77	11	1075.13	6.1	8105.58	111.40	1.00	.76	0	20	25	0	.0	.0	110.40
93	180	75	76	5	1092.08	6.3	8205.38	110.40	1.00	.00	0	20	25	0	.0	.0	110.40
94	181	80	79	11	1120.18	7.9	8380.79	110.40	1.00	.00	0	20	25	0	.0	.1	110.40
95	182	80	81	10	1139.34	8.0	8511.38	112.10	1.00	.00	0	20	25	0	.0	.8	110.40
96	183	75	71	0	1152.97	9.7	8572.58	108.30	1.00	.00	0	20	26	0	.1	.8	110.40
97	184	65	67	4	1155.45	8.1	8547.73	101.80	1.00	.00	0	20	26	0	.0	.3	110.40
98	185	70	72	11	1148.86	5.8	8539.49	107.10	1.00	.00	0	20	26	0	.0	.1	110.40
99	186	75	77	10	1147.97	4.7	8532.79	106.90	1.00	.00	0	20	26	0	.0	.1	110.40
100	187	75	73	0	1155.19	4.2	8565.88	105.00	1.00	.00	0	20	26	0	.0	.2	110.40
101	188	65	67	0	1178.58	6.0	8675.68	99.20	1.00	.00	0	20	26	0	.0	.0	110.40
102	189	60	59	0	1209.63	8.0	8847.90	95.70	1.00	.00	0	20	26	0	.0	.0	110.40
103	190	50	49	0	1231.73	9.8	8968.25	92.80	1.00	.00	0	20	26	0	.0	.0	110.40
104	191	45	45	6	1233.23	10.2	8983.77	93.80	1.00	.00	0	20	26	0	.0	.0	110.40
105	192	45	45	11	1228.42	11.2	8958.27	94.50	1.00	.00	0	20	26	0	.0	.0	110.40
106	193	30	40	0	1230.86	4.9	8967.19	93.50	1.00	.00	0	20	26	0	.0	.0	110.40
107	194	35	38	0	1241.00	2.1	9036.87	94.50	1.00	.00	0	20	26	0	.0	.0	110.40
108	195	35	34	0	1249.10	4.4	9075.52	92.60	1.00	.00	0	20	26	0	.0	.0	110.40
109	196	25	32	0	1253.41	2.3	9102.48	92.60	1.00	.25	0	20	26	0	.0	.0	110.40
AVERAGE:			67mm	9mm		5.4mm					2.5kg		37kg	28kg			
TOTAL:				531mm		584.9mm				81.01mm	270kg			280kg	3kg@	45mm@	

* Rainfall plus snow pack melt
@ Total for full growing season

Solution File for the Base Corn Optimization Analysis

THIS IS RUN NUMBER: 1

RUN TIME REPORT:
THE PROFIT MAXIMIZING FINAL Sa IS 20 mm & N IS 20 kg/ha YIELDING $1066.90 IN NET REVENUE
THE AVARAGE TIME IN CERES WAS 0.27 SECONDS IN 217097 CALLS OF CERES

PERIOD	JULIAN DATE	POINTER STATE mm/m	TRUE STATE mm/m	IRRI-GATION mm	CURRENT SUM $	ETa mm	MARGINAL YIELD kg/ha	WATER COSTS $	ROOT DEPTH m	MOSI-TURE* mm	N USED kg	POINTER N kg/ha/m	TRUE N kg/ha/m	FERTIL-IZER kg/ha	N LEACH kg/ha	WATER LEACH mm	NITR. COSTS $
1	121	50	50	0	118.09	3.3	3875.32	178.70	0.30	0.00	0	40	37	0	0.0	0.0	129.50
2	122	40	43	0	-184.05	2.5	7.88	184.90	0.30	0.00	0	20	37	0	0.0	0.0	0.00
3	123	30	40	0	-183.93	1.4	7.75	184.80	0.30	0.00	0	20	37	0	0.0	0.0	0.00
4	124	35	37	0	-183.40	1.1	7.76	184.30	0.30	0.00	0	20	37	0	0.0	0.0	0.00
5	125	30	33	0	-184.53	0.9	7.97	185.40	0.30	0.00	1	20	33	0	0.0	0.0	0.00
6	126	30	30	0	-184.97	0.8	7.96	185.80	0.30	0.00	0	20	33	0	0.0	0.0	0.00
7	127	25	27	0	-186.27	0.7	8.11	187.20	0.30	0.00	0	20	33	0	0.0	0.0	0.00
8	128	20	23	0	-186.79	0.7	8.12	187.70	0.30	0.00	0	20	33	0	0.0	0.0	0.00
9	129	20	23	0	-188.53	0.9	8.01	189.40	0.30	0.25	0	20	33	0	0.0	0.0	0.00
10	130	20	20	0	-190.60	1.4	8.03	191.50	0.30	0.00	0	20	33	0	0.0	0.0	0.00
11	131	20	20	0	210.35	0.4	4742.10	188.40	0.30	0.00	0	40	33	0	0.0	0.0	122.90
12	132	20	20	0	-191.63	0.4	8.98	192.60	0.30	0.00	0	20	33	0	0.0	0.0	0.00
13	133	50	33	10	171.65	6.0	4316.97	185.80	0.30	0.51	0	40	33	0	0.0	0.0	117.40
14	134	20	33	0	-187.91	0.8	8.61	188.90	0.30	0.00	0	20	33	0	0.0	0.0	0.00
15	135	30	30	0	-189.25	0.8	8.72	190.20	0.30	0.00	0	20	33	0	0.0	0.0	0.00
16	136	25	27	0	-188.00	0.7	8.81	189.00	0.30	0.00	0	20	33	0	0.0	0.0	0.00
17	137	20	23	0	-183.81	1.2	9.48	184.90	0.30	0.51	0	20	33	0	0.0	0.0	0.00
18	138	20	23	0	-181.69	0.6	9.46	182.70	0.30	0.00	0	20	33	0	0.0	0.0	0.00
19	139	20	20	0	-179.87	1.1	9.26	180.90	0.30	0.51	0	20	33	0	0.0	0.0	0.00
20	140	50	37	11	-181.28	6.0	9.60	182.30	0.30	0.00	0	20	33	0	0.0	0.0	0.00
21	141	20	33	0	195.32	0.9	4363.06	175.10	0.30	0.00	0	40	33	0	0.0	0.0	109.60
22	142	55	43	8	-179.23	5.0	9.24	180.30	0.30	0.00	0	20	33	0	0.0	0.0	0.00
23	143	60	57	11	-175.89	6.9	9.68	177.00	0.30	0.00	0	20	33	0	0.0	0.0	0.00
24	144	55	67	7	397.94	3.8	6446.27	170.70	0.30	0.00	3	100	90	20	0.0	0.2	140.40
25	145	85	70	10	384.98	9.1	6304.90	173.90	0.30	0.00	2	80	83	0	0.0	0.3	134.60
26	146	35	57	0	332.78	3.5	5802.19	174.80	0.30	0.00	2	60	77	0	0.0	0.3	130.70
27	147	80	68	11	432.83	7.3	7053.24	174.30	0.31	0.00	2	140	137	21	0.0	0.5	168.80
28	148	40	57	0	462.42	3.5	7409.52	178.10	0.32	0.00	2	140	126	0	0.0	0.5	174.50
29	149	95	100	0	451.83	1.5	7144.51	177.20	0.33	19.81	1	100	118	0	0.1	0.9	156.80
30	150	95	81	0	454.74	4.9	7161.54	175.10	0.34	0.00	2	100	107	0	0.1	1.1	157.90
31	151	65	70	0	450.21	2.9	7076.38	174.20	0.37	0.00	1	100	96	0	0.1	1.2	154.00
32	152	60	68	0	430.69	1.8	6835.06	172.90	0.38	1.52	1	80	91	0	0.1	1.2	148.30
33	153	85	81	9	431.12	3.1	6846.67	173.40	0.39	1.78	2	80	84	0	0.1	1.2	148.60
34	154	70	74	0	379.49	3.0	6256.42	171.50	0.41	0.00	1	60	79	0	0.1	1.2	137.20
35	155	70	73	0	372.65	2.0	6166.51	170.60	0.42	4.57	2	60	71	0	0.1	1.1	135.10
36	156	65	65	0	375.79	3.0	6176.47	168.70	0.43	0.00	2	60	65	0	0.1	1.0	134.90
37	157	75	79	5	377.60	1.9	6178.23	168.50	0.44	3.56	1	60	61	0	0.1	0.9	133.50
38	158	80	70	0	329.03	3.9	5597.57	167.40	0.45	0.00	2	40	56	0	0.1	0.8	119.30
39	159	60	63	0	334.62	2.7	5662.42	167.20	0.46	0.25	1	40	53	0	0.1	0.7	121.00
40	160	70	68	6	442.92	3.1	6836.42	166.50	0.47	0.51	2	80	77	14	0.1	0.4	142.60
41	161	60	64	0	408.05	2.7	6462.90	166.70	0.48	0.51	2	60	71	0	0.0	0.3	136.20
42	162	70	65	6	416.27	5.3	6537.32	166.50	0.49	0.00	2	60	65	0	0.0	0.2	136.40
43	163	65	63	6	482.99	5.7	7346.69	167.50	0.51	0.00	3	100	96	20	0.0	0.1	157.70
44	164	60	61	5	484.43	6.2	7329.72	167.50	0.53	0.00	4	100	95	5	0.0	0.1	154.30
45	165	60	59	6	475.69	6.3	7188.42	169.50	0.54	0.00	3	80	86	0	0.0	0.1	145.50
46	166	60	60	8	487.29	6.5	7311.34	170.30	0.56	0.00	4	80	76	0	0.0	0.1	146.60
47	167	60	60	7	443.12	6.7	6826.40	170.50	0.59	0.00	6	60	63	0	0.0	0.0	137.30
48	168	60	63	8	439.48	5.1	6791.11	172.00	0.62	0.00	4	60	53	0	0.0	0.0	135.60
49	169	60	61	4	444.61	5.6	6835.37	171.20	0.66	0.00	5	60	55	8	0.0	0.0	136.10
50	170	65	63	9	386.24	6.5	6198.94	172.80	0.69	0.00	6	40	44	0	0.0	0.0	122.80
51	171	70	69	11	393.08	6.6	6284.03	175.20	0.71	0.00	7	40	32	0	0.0	0.0	123.00
52	172	75	73	11	401.30	7.0	6366.13	174.70	0.74	0.00	8	40	38	13	0.0	0.1	124.30
53	173	75	74	9	473.32	6.8	7105.80	175.20	0.77	0.00	9	60	56	24	0.0	0.3	133.10
54	174	70	68	4	414.76	7.0	6492.05	175.00	0.80	0.00	10	40	41	0	0.0	0.3	124.40
55	175	70	69	9	449.72	7.4	6789.25	172.00	0.84	0.00	12	40	36	9	0.0	0.1	125.10
56	176	65	68	4	480.31	5.0	7080.38	170.90	0.87	0.00	9	40	43	16	0.0	0.0	127.70
57	177	75	77	11	117.29	1.8	3163.36	174.50	0.89	0.00	3	20	38	0	0.0	0.0	56.10
58	178	80	75	5	549.14	6.0	7822.63	171.60	0.91	0.00	10	60	48	20	0.0	0.4	139.70
59	179	65	69	0	174.30	5.8	3699.62	169.00	0.94	0.76	11	20	35	0	0.0	0.5	63.60
60	180	75	74	11	639.01	6.3	8689.99	170.90	0.95	0.00	11	80	69	44	0.0	0.2	146.00
61	181	75	75	9	579.80	6.9	8003.07	170.90	0.96	0.00	10	40	58	0	0.0	0.5	129.60
62	182	70	69	0	604.88	5.8	8239.47	169.20	0.98	0.00	11	40	46	0	0.0	0.1	132.30
63	183	60	63	0	613.49	6.5	8313.81	168.20	0.99	0.00	6	40	39	0	0.0	0.1	132.80
64	184	55	56	0	652.31	6.2	8652.23	165.40	1.00	0.00	3	40	36	0	0.0	0.0	134.00
65	185	60	62	11	666.57	4.8	8755.53	164.50	1.00	0.00	12	40	31	7	0.0	0.0	132.00
66	186	55	58	0	416.92	3.7	6028.72	163.60	1.00	0.00	3	20	28	0	0.0	0.0	82.60
67	187	60	60	6	690.95	4.2	8985.10	162.60	1.00	0.00	11	40	32	15	0.0	0.0	134.80
68	188	60	58	5	701.07	6.8	9085.04	162.80	1.00	0.00	10	40	41	19	0.0	0.0	135.50
69	189	55	56	4	566.91	6.3	7503.30	163.10	1.00	0.00	7	20	34	0	0.0	0.0	95.30
70	190	60	59	11	701.61	7.7	9090.07	163.30	1.00	0.00	12	40	35	13	0.0	0.0	135.00
71	191	60	61	10	711.05	8.1	9191.76	162.90	1.00	0.00	12	40	40	17	0.0	0.0	137.10
72	192	60	61	8	736.09	7.5	9377.74	161.20	1.00	0.00	8	40	44	12	0.0	0.0	134.20
73	193	65	66	11	726.27	5.8	9074.93	160.90	1.00	0.00	8	20	36	0	0.0	0.0	111.10
74	194	60	64	0	678.11	2.3	8603.36	157.20	1.00	0.00	3	20	33	0	0.0	0.0	111.10
75	195	65	64	4	635.75	3.7	8215.51	156.90	1.00	0.00	5	20	28	0	0.0	0.0	111.10
76	196	70	68	11	618.63	6.6	8066.98	157.70	1.00	0.25	0	20	29	0	0.0	0.0	111.10
77	197	70	71	10	634.42	7.2	8205.02	157.10	1.00	0.00	0	20	29	0	0.0	0.0	111.10
78	198	70	71	7	661.38	7.2	8444.31	156.40	1.00	0.00	3	20	26	0	0.0	0.0	111.10
79	199	65	65	0	684.95	6.6	8659.54	156.50	1.00	0.00	2	20	24	0	0.0	0.0	111.10
80	200	70	68	11	711.81	7.5	8906.33	156.80	1.00	0.00	0	20	24	0	0.0	0.0	111.10
81	201	70	71	11	751.23	8.1	9263.80	156.70	1.00	0.00	1	20	23	0	0.0	0.0	111.10
82	202	75	73	11	802.89	9.2	9724.46	155.70	1.00	0.00	0	20	23	0	0.0	0.0	111.10
83	203	75	75	11	824.31	9.3	9917.05	155.50	1.00	0.00	0	20	23	0	0.0	0.0	111.10
84	204	65	67	0	838.63	8.1	10051.68	156.00	1.00	0.00	0	20	23	0	0.0	0.0	111.10
85	205	70	71	11	831.67	7.0	10110.72	155.00	1.00	0.00	13	40	27	17	0.0	0.0	125.50
86	206	70	70	7	889.73	8.2	10579.54	154.30	1.00	0.00	8	20	25	6	0.0	0.0	119.70
87	207	70	70	9	1021.58	8.9	11763.76	152.70	1.00	0.00	1	20	24	0	0.0	0.0	119.70
88	208	70	72	10	1026.42	7.8	11794.00	151.20	1.00	0.00	0	20	25	0	0.0	0.0	119.70
89	209	65	65	0	1030.42	7.0	11834.44	151.70	1.00	0.00	0	20	25	0	0.0	0.0	119.70
90	210	70	69	11	1035.20	7.0	11896.22	153.70	1.00	0.00	0	20	25	0	0.0	0.0	119.70
91	211	60	62	0	1041.29	7.4	11925.92	150.90	1.00	0.00	0	20	25	0	0.0	0.0	119.70
92	212	60	61	6	1041.14	6.8	11965.97	149.80	1.00	0.00	5	40	35	15	0.0	0.0	125.30
93	213	65	65	11	1036.24	7.2	12077.29	150.60	1.00	0.00	2	80	77	44	0.0	0.0	141.70
94	214	70	69	11	1039.53	6.6	12101.53	148.10	1.00	0.00	3	80	79	5	0.0	0.0	143.60
95	215	70	71	8	1056.74	5.9	12259.54	148.20	1.00	0.00	2	60	77	0	0.0	0.0	143.60
96	216	65	66	0	1065.81	5.5	12337.14	147.70	1.00	0.00	2	60	75	0	0.0	0.0	143.60
97	217	70	70	11	1073.79	7.1	12442.15	148.60	1.00	0.00	2	80	80	7	0.0	0.0	146.20
98	218	70	73	8	1066.46	5.2	12367.09	147.70	1.00	0.00	2	60	78	0	0.0	0.0	146.20
99	219	75	75	8	1073.44	6.4	12409.18	145.30	1.00	0.00	3	60	75	0	0.0	0.0	146.20
100	220	80	80	11	1097.70	6.4	12625.85	144.90	1.00	0.00	2	60	73	0	0.0	0.0	146.20
101	221	80	80	7	1097.85	7.4	12635.00	145.80	1.00	0.00	2	60	71	0	0.0	0.3	146.20
102	222	85	82	11	1108.80	9.2	12731.77	145.50	1.00	0.00	3	60	68	0	0.1	1.1	146.20
103	223	70	76	0	1096.67	5.8	12638.92	147.40	1.00	0.00	2	60	66	0	0.1	1.1	146.20
104	224	70	69	0	1102.50	7.5	12669.32	144.90	1.00	0.00	5	60	61	0	0.1	0.9	146.20
105	225	70	71	9	1113.71	6.6	12785.05	146.40	1.00	0.00	5	40	56	0	0.0	0.4	146.20
106	226	70	73	6	1111.65	3.5	12758.52	145.60	1.00	0.00	3	40	53	0	0.0	0.2	146.20
107	227	80	77	11	1116.51	7.3	12777.29	142.80	1.00	0.00	5	40	48	0	0.0	0.3	146.20
108	228	80	82	11	1121.47	6.1	12815.93	142.10	1.00	0.00	4	40	44	0	0.0	0.7	146.20
109	229	80	80	5	1134.60	6.7	12935.75	142.10	1.00	0.00	4	20	40	0	0.1	0.9	146.20
110	230	70	74	0	1141.82	5.6	13017.60	143.90	1.00	0.00	4	20	36	0	0.1	0.8	146.20
111	231	65	69	0	1156.12	4.8	13109.35	139.70	1.00	0.00	4	20	32	0	0.0	0.6	146.20
112	232	60	64	0	1162.90	5.0	13169.52	139.60	1.00	0.00	4	20	28	0	0.0	0.1	146.20
113	233	65	66	7	1167.54	4.6	13205.72	138.90	1.00	0.00	3	20	25	0	0.0	0.1	146.20
114	234	70	70	10	1171.32	5.9	13263.80	141.50	1.00	0.00	3	20	22	0	0.0	0.0	146.20
115	235	65	65	0	1191.78	4.9	13430.52	139.30	1.00	0.00	2	20	20	0	0.0	0.0	146.20
116	236	70	69	11	1192.42	7.4	13455.41	141.40	1.00	0.00	0	20	21	0	0.0	0.0	146.20
117	237	60	64	0	1194.26	5.4	13453.63	139.40	1.00	0.00	0	20	21	0	0.0	0.0	146.20

118	238	55	59	0	1193.84	5.4	13445.22	138.90	1.00	0.00	0	20	21	0	0.0	0.0	146.20
119	239	50	54	0	1187.43	4.7	13394.73	139.80	1.00	0.00	0	20	21	0	0.0	0.0	146.20
120	240	45	49	0	1198.63	4.8	13474.19	137.30	1.00	0.00	0	20	21	0	0.0	0.0	146.20
121	241	40	44	0	1189.91	5.2	13394.51	137.30	1.00	0.00	0	20	21	0	0.0	0.0	146.20
122	242	35	39	0	1185.89	4.5	13286.55	129.40	1.00	0.00	0	20	21	0	0.0	0.0	146.20
123	243	30	35	0	1176.02	4.2	13235.76	133.70	1.00	0.00	0	20	21	0	0.0	0.0	146.20
124	244	30	31	0	1182.64	4.2	13305.87	134.80	1.00	0.00	0	20	21	0	0.0	0.0	146.20
125	245	25	27	0	1180.51	4.2	13294.02	135.60	1.00	0.00	0	20	21	0	0.0	0.0	146.20
126	246	25	23	0	1184.54	4.4	13344.25	137.10	1.00	0.00	0	20	21	0	0.0	0.0	146.20
127	247	25	26	7	1167.87	4.0	13155.60	133.00	1.00	0.00	0	20	21	0	0.0	0.0	146.20
128	248	25	22	0	1144.77	3.7	12891.20	127.00	1.00	0.00	0	20	21	0	0.0	0.0	146.20
129	249	20	18	0	1131.46	4.4	12712.08	120.60	1.00	0.00	0	20	21	0	0.0	0.0	146.20
130	250	20	21	7	1101.84	3.6	12401.84	116.10	1.00	0.00	0	20	21	0	0.0	0.0	146.20
131	251	25	26	8	1096.31	3.5	12329.51	113.70	1.00	0.00	0	20	21	0	0.0	0.0	146.20
132	252	25	22	0	1102.42	4.4	12350.15	109.90	1.00	0.00	0	20	21	0	0.0	0.0	146.20
133	253	20	18	0	1066.90	4.4	11992.39	106.00	1.00	0.00	0	20	21	0	0.0	0.0	146.20
AVERAGE:			58mm	9mm		5.0mm					2.9kg		45kg	16kg			
TOTAL:				605mm		661.6mm				35.30mm	384kg			391kg	2.0kg@	41mm@	

* Rainfall plus snow pack melt
@ Total for full growing season

Solution File for the Base Potato (Alfalfa) Optimization Analysis

THIS IS RUN NUMBER: 1

RUN TIME REPORT:
THE PROFIT MAXIMIZING FINAL Sa IS 20 mm & N IS 20 kg/ha YIELDING $4224.27 IN NET REVENUE
THE AVARAGE TIME IN CERES WAS 0.68 SECONDS IN 240434 CALLS OF CERES

PERIOD	JULIAN DATE	POINTER STATE mm/m	TRUE STATE mm/m	IRRI-GATION mm	CURRENT SUM $	ETa mm	MARGINAL YIELD kg/ha	WATER COSTS $	ROOT DEPTH m	MOIS-TURE* mm	N USED kg	POINTER N kg/ha/m	TRUE N kg/ha/m	FERTIL-IZER kg/ha	N LEACH kg/ha	WATER LEACH mm	NITR. COSTS $
1	91	30	33	0	161.15	1.7	2542.97	27.00	0.30	0.51	0	260	257	0	0.0	0.0	0.00
2	92	25	30	0	540.38	1.0	7753.87	33.40	0.30	0.00	0	240	257	0	0.0	0.0	0.00
3	93	55	60	9	546.48	1.7	7835.37	33.30	0.30	2.54	0	260	257	0	0.0	0.0	0.00
4	94	50	50	0	547.29	3.0	7833.02	32.40	0.30	0.51	0	240	257	0	0.0	0.0	0.00
5	95	35	40	0	546.39	2.7	7829.34	33.00	0.30	0.00	0	240	257	0	0.0	0.0	0.00
6	96	30	37	0	546.52	1.5	7817.34	32.00	0.30	0.00	1	240	253	0	0.0	0.0	0.00
7	97	45	43	4	547.08	2.0	7832.59	32.50	0.30	0.51	0	240	253	0	0.0	0.0	0.00
8	98	35	37	0	546.83	1.7	7828.78	32.50	0.30	0.00	0	240	253	0	0.0	0.0	0.00
9	99	50	47	6	547.37	2.5	7826.04	31.80	0.30	0.00	1	260	250	0	0.0	0.0	0.00
10	100	55	53	6	550.08	4.5	7863.33	31.80	0.30	0.00	1	260	247	0	0.0	0.0	0.00
11	101	35	47	0	552.85	2.6	7892.70	31.20	0.30	0.00	0	240	247	0	0.0	0.0	0.00
12	102	55	50	6	553.35	4.8	7886.86	30.30	0.30	0.00	1	260	243	0	0.0	0.0	0.00
13	103	55	60	7	559.09	4.4	8004.80	31.00	0.30	0.00	2	260	257	6	0.0	0.0	2.30
14	104	65	70	7	558.88	3.8	8025.74	32.70	0.30	0.00	3	260	247	0	0.0	0.0	2.30
15	105	55	63	0	566.20	1.7	8111.34	31.80	0.30	0.00	3	240	237	0	0.0	0.0	2.30
16	106	75	73	6	567.84	3.1	8146.75	32.70	0.30	0.00	3	240	227	0	0.0	0.0	2.30
17	107	90	70	9	568.74	10.0	8179.69	34.30	0.30	0.00	4	220	213	0	0.0	0.2	2.30
18	108	40	77	0	570.98	0.7	8211.44	34.40	0.30	3.05	3	180	203	0	0.0	0.3	2.30
19	109	100	70	9	576.83	11.1	8298.28	35.00	0.30	0.00	4	200	190	0	0.1	0.4	2.30
20	110	65	80	11	588.65	7.7	8487.66	37.10	0.30	0.00	3	160	180	0	0.1	0.6	2.30
21	111	80	83	0	589.24	0.8	8495.90	37.20	0.30	11.68	3	160	170	0	0.1	0.8	2.30
22	112	105	83	0	581.49	0.8	8392.17	37.20	0.30	11.43	2	140	163	0	0.2	0.9	2.30
23	113	110	79	4	576.13	5.4	8332.23	38.20	0.30	7.11	3	140	152	0	0.2	1.0	2.30
24	114	60	68	0	611.34	2.5	8806.41	38.00	0.31	0.00	3	140	140	0	0.2	0.9	2.30
25	115	60	60	0	603.77	2.8	8703.60	38.00	0.31	0.00	1	120	133	0	0.1	0.7	2.30
26	116	75	71	8	610.10	4.1	8803.44	39.10	0.32	0.00	3	120	120	0	0.1	0.6	2.30
27	117	55	60	0	618.31	3.7	8927.58	40.00	0.33	0.00	3	100	108	0	0.1	0.4	2.30
28	118	75	73	10	612.31	4.9	8848.17	40.20	0.34	0.00	3	80	97	0	0.1	0.4	2.30
29	119	85	74	10	683.85	8.8	9816.45	40.30	0.35	0.25	4	80	83	0	0.1	0.5	2.30
30	120	80	67	9	824.56	11.0	11746.79	42.40	0.36	4.06	3	60	72	0	0.1	0.5	2.30
31	121	50	70	6	875.38	4.1	12478.30	43.40	0.37	0.00	5	80	73	6	0.1	0.5	4.60
32	122	75	71	7	872.64	5.9	12435.58	43.00	0.38	0.00	3	40	63	0	0.1	0.6	4.60
33	123	80	75	10	1012.53	7.9	14493.68	43.50	0.39	0.00	5	140	132	32	0.1	0.5	16.50
34	124	80	71	11	1033.86	11.8	14939.54	46.60	0.39	0.00	10	180	163	23	0.1	0.5	25.10
35	125	40	62	0	1018.08	3.2	14727.69	46.70	0.40	0.00	3	120	152	0	0.0	0.1	25.10
36	126	50	54	0	1051.65	4.5	15185.16	47.00	0.41	0.00	4	140	139	0	0.0	0.1	25.10
37	127	40	43	0	1190.50	4.4	17093.95	49.40	0.42	0.00	1	120	133	0	0.0	0.1	25.10
38	128	30	35	0	1152.81	5.2	16603.92	50.80	0.43	0.00	1	120	127	0	0.0	0.0	25.10
39	129	20	29	0	1234.82	3.7	17724.41	51.70	0.44	0.25	0	120	124	0	0.0	0.0	25.10
40	130	45	42	11	1357.36	4.9	19581.67	54.40	0.45	0.00	10	200	173	33	0.0	0.0	37.30
41	131	30	35	0	1441.99	4.9	20733.08	54.90	0.46	0.00	2	140	165	0	0.0	0.0	37.30
42	132	35	36	6	1529.85	4.9	22053.59	55.80	0.47	0.00	2	220	209	24	0.0	0.0	46.30
43	133	35	36	5	1578.06	5.1	22750.09	56.50	0.47	0.51	12	220	196	7	0.0	0.0	48.90
44	134	25	29	0	1557.44	3.7	22484.46	57.50	0.48	0.00	3	180	187	0	0.0	0.0	48.90
45	135	20	22	0	1625.37	4.0	23423.16	59.00	0.49	0.00	0	180	183	0	0.0	0.0	48.90
46	136	30	30	9	1711.23	5.1	24593.46	59.80	0.50	0.00	8	180	163	0	0.0	0.0	48.90
47	137	30	37	6	1717.38	2.2	24684.84	60.40	0.51	0.51	21	140	120	0	0.0	0.0	48.90
48	138	30	27	0	1713.97	4.7	24640.52	60.50	0.52	0.00	0	80	117	0	0.0	0.0	48.90
49	139	35	38	10	1824.71	4.8	26108.52	58.40	0.53	0.51	5	120	106	0	0.0	0.0	48.90
50	140	40	39	7	1980.74	6.1	28256.77	61.30	0.54	0.00	5	100	94	0	0.0	0.0	48.90
51	141	45	45	11	2046.79	7.4	29106.09	58.10	0.55	0.00	16	80	63	0	0.0	0.0	48.90
52	142	30	34	0	2055.97	6.7	29293.31	62.80	0.56	0.00	0	40	63	0	0.0	0.0	48.90
53	143	35	35	8	2075.66	7.0	29577.86	64.20	0.57	0.00	4	60	55	0	0.0	0.0	48.90
54	144	35	42	8	2086.62	3.9	29724.54	64.10	0.57	0.00	0	40	54	0	0.0	0.0	48.90
55	145	50	46	10	2095.53	7.2	29849.99	64.40	0.58	0.00	6	60	43	0	0.0	0.0	48.90
56	146	50	51	10	2097.12	6.9	29860.65	63.60	0.59	0.00	1	40	41	0	0.0	0.0	48.90
57	147	55	50	10	2118.98	10.5	30171.17	64.80	0.60	0.00	2	20	37	0	0.0	0.0	48.90
58	148	30	42	0	2125.35	5.3	30286.95	67.00	0.60	0.00	1	20	35	0	0.0	0.0	48.90
59	149	75	85	11	2139.65	1.5	30477.98	66.80	0.60	19.81	2	40	32	0	0.0	0.2	48.90
60	150	100	82	11	2146.11	0.3	30513.62	63.00	0.60	0.00	3	20	27	0	0.1	0.6	48.90
61	151	100	78	11	2114.78	0.2	30172.82	64.90	0.60	0.00	4	40	38	11	0.0	0.7	53.10
62	152	95	78	11	2119.12	11.0	30283.73	66.90	0.60	1.52	6	40	37	5	0.0	0.6	55.00
63	153	70	77	7	2117.16	8.2	30317.35	68.30	0.60	1.78	7	40	38	8	0.0	0.6	58.00
64	154	80	75	11	2102.29	12.1	30179.10	69.90	0.60	0.00	7	40	40	8	0.0	0.3	61.00
65	155	75	75	10	2107.84	10.0	30309.59	71.40	0.60	4.57	5	40	43	7	0.0	0.2	63.70
66	156	65	73	4	2136.63	5.1	30707.66	72.10	0.60	0.00	4	40	37	0	0.0	0.3	63.70
67	157	85	73	10	2098.69	9.9	30368.29	73.70	0.60	3.56	14	80	63	30	0.0	0.0	74.80
68	158	55	68	0	2556.11	3.9	36557.00	74.30	0.60	0.00	13	20	42	0	0.0	0.0	74.80
69	159	60	63	0	2537.60	2.7	36311.88	74.60	0.60	0.25	6	20	32	0	0.0	0.0	74.80
70	160	55	58	0	2570.73	3.1	36760.88	74.70	0.60	0.51	0	20	32	0	0.0	0.0	74.80
71	161	60	63	5	2594.61	2.8	37102.01	76.10	0.60	0.51	0	20	32	0	0.0	0.0	74.80
72	162	55	53	0	2624.57	6.4	37537.66	78.40	0.60	0.00	2	20	28	0	0.0	0.0	74.80
73	163	40	43	0	2658.73	5.8	38026.46	80.40	0.60	0.00	0	20	28	0	0.0	0.0	74.80
74	164	35	33	0	2677.57	6.2	38312.81	82.70	0.60	0.00	0	20	28	0	0.0	0.0	74.80
75	165	30	30	5	2374.01	7.4	34330.68	89.00	0.60	0.00	2	40	37	7	0.0	0.0	77.50
76	166	30	32	8	2786.72	6.6	39916.16	89.60	0.60	0.00	3	20	32	0	0.0	0.0	77.50
77	167	30	28	6	2594.26	7.7	37442.09	95.90	0.60	0.00	4	40	38	8	0.0	0.0	80.50
78	168	25	28	6	3008.19	6.1	43108.17	101.30	0.60	0.00	3	20	33	0	0.0	0.0	80.50
79	169	30	32	8	2673.51	5.7	38707.57	98.80	0.60	0.00	16	80	58	31	0.0	0.0	92.10
80	170	30	27	5	3157.87	7.5	45306.09	102.70	0.60	0.00	6	20	48	0	0.0	0.0	92.10
81	171	25	27	7	3202.32	6.6	45926.61	104.20	0.60	0.00	4	20	42	0	0.0	0.0	92.10
82	172	25	25	6	3260.54	7.0	46758.91	107.60	0.60	0.00	1	20	40	0	0.0	0.0	92.10
83	173	30	30	11	3203.36	7.8	45915.95	102.40	0.60	0.00	3	20	35	0	0.0	0.0	92.10
84	174	35	33	11	2747.30	9.0	39781.67	97.80	0.60	0.00	15	60	40	18	0.0	0.0	98.80
85	175	35	38	11	3149.84	8.4	45225.68	98.10	0.60	0.00	6	20	30	0	0.0	0.0	98.80
86	176	40	43	10	3158.07	7.0	45334.65	97.90	0.60	0.00	1	20	28	0	0.0	0.0	98.80
87	177	30	40	0	3284.02	1.8	47123.75	104.40	0.60	0.00	0	20	30	0	0.0	0.0	98.80
88	178	45	38	5	2937.28	6.0	42439.90	102.20	0.60	0.00	6	40	30	6	0.0	0.0	101.10
89	179	30	30	0	3359.38	5.8	48229.00	108.50	0.60	0.76	1	20	28	0	0.0	0.0	101.10
90	180	30	30	6	3006.36	6.3	43492.64	108.00	0.60	0.00	5	40	33	8	0.0	0.0	104.10
91	181	35	35	10	3326.96	6.9	47738.17	101.60	0.60	0.00	3	20	28	0	0.0	0.0	104.10
92	182	35	37	8	2921.10	6.8	42346.66	100.30	0.60	0.00	15	60	40	22	0.0	0.0	112.30
93	183	30	27	0	3518.86	6.5	50592.05	112.70	0.60	0.00	3	20	35	0	0.0	0.0	112.30
94	184	25	25	6	3547.99	7.2	51027.71	115.80	0.60	0.00	2	20	32	0	0.0	0.0	112.30
95	185	20	25	5	3602.48	4.8	51849.61	122.10	0.60	0.00	1	20	30	0	0.0	0.0	112.30
96	186	25	27	5	3619.01	3.7	52075.65	122.30	0.60	0.00	1	20	28	0	0.0	0.0	112.30
97	187	30	28	6	3626.72	5.2	52118.25	117.70	0.60	0.00	0	20	30	0	0.0	0.0	112.30
98	188	35	35	10	3244.04	5.8	46839.10	107.50	0.60	0.00	6	40	30	6	0.0	0.0	114.60
99	189	25	23	0	3687.62	7.3	53022.58	121.50	0.60	0.00	1	20	28	0	0.0	0.0	114.60
100	190	25	27	9	3664.21	6.7	52525.89	108.10	0.60	0.00	0	20	30	0	0.0	0.0	114.60
101	191	30	30	10	3666.83	8.1	52742.63	121.50	0.60	0.00	1	20	28	0	0.0	0.0	114.60
102	192	25	27	6	3393.30	7.5	49076.54	120.70	0.60	0.00	5	40	33	8	0.0	0.0	117.60
103	193	25	30	7	3669.03	4.8	52809.35	121.20	0.60	0.00	3	20	28	0	0.0	0.0	117.60
104	194	20	25	0	3715.82	3.3	53541.23	128.60	0.60	0.00	0	20	30	0	0.0	0.0	117.60
105	195	25	25	4	3734.93	3.7	53786.40	127.70	0.60	0.00	1	20	28	0	0.0	0.0	117.60
106	196	30	27	7	3751.27	5.6	53984.52	126.00	0.60	0.25	0	20	28	0	0.0	0.0	117.60
107	197	30	28	8	3398.92	7.2	49242.46	115.90	0.60	0.00	18	80	50	31	0.0	0.0	129.10
108	198	35	35	11	3799.10	7.2	54834.89	129.50	0.60	0.00	10	20	33	0	0.0	0.0	129.10
109	199	30	32	5	3759.90	6.6	54185.64	120.70	0.60	0.00	2	20	30	0	0.0	0.0	129.10
110	200	30	30	6	3818.95	6.5	55032.26	124.30	0.60	0.00	0	20	30	0	0.0	0.0	129.10
111	201	35	35	11	3465.94	8.1	50397.82	118.70	0.60	0.00	26	100	57	42	0.0	0.0	144.80
112	202	40	37	11	3856.89	10.2	55807.62	128.10	0.60	0.00	13	20	35	0	0.0	0.0	144.80
113	203	30	33	7	3921.15	9.3	56668.31	127.60	0.60	0.00	4	20	28	0	0.0	0.0	144.80
114	204	30	33	8	3895.94	8.2	56265.60	123.00	0.60	0.00	0	20	28	0	0.0	0.0	144.80
115	205	30	33	7	3912.81	7.0	56530.18	125.70	0.60	0.00	0	20	30	0	0.0	0.0	144.80
116	206	35	35	9	3956.73	8.2	57128.14	126.00	0.60	0.00	0	20	30	0	0.0	0.0	144.80
117	207	35	35	9	3894.83	9.0	56383.63	130.50	0.60	0.00	6	40	30	6	0.0	0.0	147.00
118	208	35	37	10	4056.20	8.9	58470.47	123.60	0.60	0.00	2	20	27	0	0.0	0.0	147.00
119	209	40	40	11	4117.23	9.2	59414.59	132.40	0.60	0.00	0	20	28	0	0.0	0.0	147.00

120	210	40	42	10	4142.12	9.1	59751.50	132.50	0.60	0.00	0	20	30	0	0.0	0.0	147.00
121	211	40	42	9	4155.96	8.6	59953.61	133.60	0.60	0.00	0	20	30	0	0.0	0.0	147.00
122	212	35	37	5	4137.18	8.0	59663.76	130.90	0.60	0.00	0	20	30	0	0.0	0.0	147.00
123	213	35	38	8	4137.08	7.3	59696.21	133.40	0.60	0.00	1	20	28	0	0.0	0.0	147.00
124	214	40	42	9	4157.58	6.7	59995.66	135.10	0.60	0.00	0	20	28	0	0.0	0.0	147.00
125	215	40	42	6	4175.89	6.0	60234.11	134.40	0.60	0.00	0	20	28	0	0.0	0.0	147.00
126	216	45	43	9	4180.48	7.7	60292.14	134.10	0.60	0.00	0	20	28	0	0.0	0.0	147.00
127	217	35	32	0	4185.82	7.3	60369.31	134.50	0.60	0.00	0	20	28	0	0.0	0.0	147.00
128	218	35	42	10	4183.73	4.3	60368.46	136.50	0.60	0.00	0	20	28	0	0.0	0.0	147.00
129	219	50	40	10	4177.43	10.5	60297.46	137.50	0.60	0.00	0	20	28	0	0.0	0.0	147.00
130	220	40	45	11	4179.78	8.5	60300.68	135.40	0.60	0.00	0	20	28	0	0.0	0.0	147.00
131	221	35	37	0	4188.94	5.5	60454.52	137.70	0.60	0.00	0	20	28	0	0.0	0.0	147.00
132	222	40	38	8	4112.16	7.3	59448.03	137.30	0.60	0.00	6	40	30	7	0.0	0.0	149.70
133	223	45	45	11	4172.51	6.9	60265.05	137.40	0.60	0.00	2	20	27	0	0.0	0.0	149.70
134	224	50	43	11	4168.97	11.6	60258.74	140.50	0.60	0.00	0	20	28	0	0.0	0.0	149.70
135	225	20	33	0	4161.36	5.7	60164.81	141.10	0.60	0.00	0	20	28	0	0.0	0.0	149.70
136	226	20	27	0	4140.86	3.6	59920.52	143.60	0.60	0.00	0	20	28	0	0.0	0.0	149.70
137	227	20	18	0	4163.69	5.2	60198.03	141.30	0.60	0.00	0	20	30	0	0.0	0.0	149.70
138	228	20	20	7	4187.21	6.2	60489.65	139.30	0.60	0.00	1	20	28	0	0.0	0.0	149.70
139	229	20	22	7	4224.27	5.8	61007.36	140.60	0.60	0.00	0	20	30	0	0.0	0.0	149.70
AVERAGE:			45mm	8mm		5.8mm					3.4kg		86kg	15kg			
TOTAL:				799mm		810.2mm				76.95mm	469kg			400kg	0.0kg@	14mm@	

Solution File for the Base Potato (Grain) Optimization Analysis

THIS IS RUN NUMBER: 1

RUN TIME REPORT:
THE PROFIT MAXIMIZING FINAL Sa IS 20 mm & N IS 20 kg/ha YIELDING $4438.48 IN NET REVENUE
THE AVARAGE TIME IN CERES WAS 0.79 SECONDS IN 193451 CALLS OF CERES

PERIOD	JULIAN DATE	POINTER STATE mm/m	TRUE STATE mm/m	IRRI-GATION mm	CURRENT SUM $	ETa mm	MARGINAL YIELD kg/ha	WATER COSTS $	ROOT DEPTH m	MOSI-TURE* mm	N USED kg	POINTER N kg/ha/m	TRUE N kg/ha/m	FERTIL-IZER kg/ha	N LEACH kg/ha	WATER LEACH mm	NITR. COSTS $
1	91	30	33	0	149.75	1.7	2393.42	27.40	0.30	0.51	0	40	37	0	0.0	0.0	0.00
2	92	50	43	7	442.60	3.5	6510.99	32.10	0.30	0.00	0	100	100	19	0.0	0.0	7.10
3	93	45	60	4	483.17	1.7	7060.46	32.20	0.30	2.54	0	80	100	0	0.0	0.0	7.10
4	94	50	50	0	485.35	3.2	7083.59	31.70	0.30	0.51	0	80	100	0	0.0	0.0	7.10
5	95	35	43	0	485.01	2.7	7086.45	32.30	0.30	0.00	1	80	97	0	0.0	0.0	7.10
6	96	30	37	0	386.43	1.6	5759.53	32.70	0.30	0.00	0	80	97	0	0.0	0.0	7.10
7	97	30	33	0	474.42	1.7	6954.25	33.10	0.30	0.51	0	100	97	0	0.0	0.0	7.10
8	98	40	37	4	535.00	2.9	7848.94	32.70	0.30	0.00	0	160	150	16	0.0	0.0	13.10
9	99	40	37	4	536.06	3.9	7871.92	33.40	0.30	0.00	0	160	150	0	0.0	0.0	13.10
10	100	35	40	4	535.51	2.9	7856.37	32.80	0.30	0.00	0	160	150	0	0.0	0.0	13.10
11	101	50	50	7	543.93	4.4	7956.15	31.70	0.30	0.00	0	160	150	0	0.0	0.0	13.10
12	102	50	53	5	548.25	3.9	8030.69	32.90	0.30	0.00	1	160	147	0	0.0	0.0	13.10
13	103	65	63	8	550.68	5.4	8094.01	33.30	0.30	0.00	1	160	160	5	0.0	0.0	15.00
14	104	60	67	5	555.34	3.8	8161.86	33.60	0.30	0.00	2	160	153	0	0.0	0.0	15.00
15	105	65	70	4	563.88	2.7	8272.91	33.30	0.30	0.00	2	160	147	0	0.0	0.0	15.00
16	106	75	70	5	564.94	5.1	8299.04	34.20	0.30	0.00	2	140	140	0	0.0	0.2	15.00
17	107	65	67	4	565.06	5.0	8346.19	34.50	0.30	0.00	3	160	157	8	0.0	0.2	18.00
18	108	85	90	9	572.65	1.7	8460.33	35.40	0.30	3.05	1	160	153	0	0.0	0.6	18.00
19	109	100	83	5	570.92	7.1	8445.03	36.00	0.30	0.00	3	160	143	0	0.1	0.8	18.00
20	110	95	80	11	580.33	11.7	8591.00	37.40	0.30	0.00	3	120	133	0	0.1	1.0	18.00
21	111	90	83	7	584.42	5.8	8686.36	38.40	0.30	11.68	3	140	140	5	0.1	1.0	19.90
22	112	90	83	0	570.34	0.8	8496.85	38.50	0.30	11.43	0	120	140	0	0.1	1.1	19.90
23	113	95	79	0	569.58	2.4	8486.99	38.50	0.30	7.11	3	140	129	0	0.1	1.1	19.90
24	114	90	74	6	570.13	6.5	8507.91	39.50	0.31	0.00	2	120	120	0	0.1	1.0	19.90
25	115	65	73	4	562.27	3.8	8410.47	40.20	0.32	0.00	3	100	108	0	0.1	1.0	19.90
26	116	75	71	5	586.02	5.1	8735.00	40.40	0.32	0.00	3	80	96	0	0.1	0.9	19.90
27	117	70	70	5	593.74	4.7	8851.04	41.30	0.33	0.00	3	80	85	0	0.1	0.9	19.90
28	118	80	77	9	588.12	5.9	8787.19	42.20	0.34	0.00	4	60	71	0	0.1	0.9	19.90
29	119	90	72	11	672.04	11.8	9947.40	44.10	0.35	0.25	3	40	61	0	0.1	0.9	19.90
30	120	60	70	5	777.67	5.0	11380.36	44.50	0.36	4.06	2	40	53	0	0.1	0.9	19.90
31	121	85	76	11	888.51	8.1	13033.66	46.40	0.37	0.00	9	120	98	26	0.1	0.9	29.60
32	122	50	64	0	885.23	3.9	13001.33	47.30	0.38	0.00	0	60	96	0	0.1	0.6	29.60
33	123	50	57	0	896.11	1.9	13157.43	47.90	0.38	0.00	4	80	84	0	0.1	0.4	29.60
34	124	50	49	0	950.50	3.6	13896.95	48.30	0.39	0.00	2	60	77	0	0.0	0.3	29.60
35	125	35	43	0	938.89	3.2	13745.79	48.70	0.40	0.00	0	60	75	0	0.0	0.1	29.60
36	126	50	49	7	1020.13	4.5	14972.32	48.50	0.41	0.00	6	140	123	26	0.0	0.1	39.30
37	127	50	50	5	1172.57	4.4	17139.58	49.00	0.42	0.00	2	160	162	20	0.0	0.0	46.80
38	128	50	49	5	1181.10	5.2	17265.55	49.80	0.43	0.00	11	140	133	0	0.0	0.0	46.80
39	129	50	55	6	1236.31	3.7	18135.87	50.40	0.44	0.25	21	160	134	23	0.0	0.0	55.30
40	130	60	58	7	1311.67	4.9	19271.42	53.50	0.45	0.00	0	120	165	15	0.0	0.0	61.00
41	131	45	48	0	1419.22	5.0	20740.08	54.60	0.46	0.00	0	160	162	0	0.0	0.0	61.00
42	132	35	39	0	1470.97	4.5	21459.05	56.00	0.47	0.00	0	160	159	0	0.0	0.0	61.00
43	133	25	32	0	1490.44	4.6	21721.35	56.00	0.47	0.51	1	140	155	0	0.0	0.0	61.00
44	134	20	27	0	1502.61	3.5	21906.65	57.50	0.48	0.00	0	140	152	0	0.0	0.0	61.00
45	135	20	20	0	1472.39	3.4	21492.09	57.10	0.49	0.00	0	140	149	0	0.0	0.0	61.00
46	136	20	22	4	1539.61	4.1	22430.42	57.40	0.50	0.00	1	160	155	5	0.0	0.0	62.90
47	137	20	18	0	1551.43	2.1	22607.26	58.60	0.50	0.51	0	140	153	0	0.0	0.0	62.90
48	138	20	19	4	1529.60	3.5	22312.21	58.60	0.52	0.00	0	160	149	0	0.0	0.0	62.90
49	139	30	29	10	1746.17	4.8	25269.32	58.60	0.53	0.51	8	160	143	6	0.0	0.0	65.20
50	140	30	30	6	2148.02	5.1	30748.56	59.60	0.54	0.00	11	140	132	7	0.0	0.0	67.80
51	141	30	29	6	2167.72	6.4	31012.31	59.40	0.55	0.00	7	100	117	0	0.0	0.0	67.80
52	142	30	29	8	1914.10	7.7	27610.09	61.20	0.55	0.00	2	100	112	0	0.0	0.0	67.80
53	143	25	29	6	1995.44	6.0	28725.37	62.40	0.56	0.00	5	100	102	0	0.0	0.0	67.80
54	144	25	28	4	2046.93	3.9	29441.06	63.90	0.57	0.00	5	80	92	0	0.0	0.0	67.80
55	145	30	26	5	2083.85	6.1	29931.27	63.20	0.58	0.00	4	80	83	0	0.0	0.0	67.80
56	146	25	26	6	2093.13	5.9	30071.46	64.30	0.58	0.00	4	80	75	0	0.0	0.0	67.80
57	147	25	26	6	2135.12	6.4	30751.38	65.60	0.59	0.00	7	100	95	19	0.0	0.0	74.90
58	148	25	27	7	2105.96	6.3	30545.30	69.10	0.59	0.00	12	140	122	28	0.0	0.0	85.30
59	149	40	57	0	2135.43	1.5	30937.87	68.60	0.59	19.81	6	100	111	0	0.0	0.0	85.30
60	150	50	50	0	2131.01	4.0	30787.00	61.90	0.60	0.00	33	100	55	0	0.0	0.0	85.30
61	151	60	53	11	2532.46	8.9	36297.52	63.70	0.60	0.00	13	20	53	12	0.0	0.0	89.80
62	152	35	52	0	2585.96	2.0	37025.57	64.10	0.60	1.52	12	20	33	0	0.0	0.0	89.80
63	153	45	50	0	2586.95	3.2	37040.27	64.20	0.60	1.78	0	20	33	0	0.0	0.0	89.80
64	154	40	45	0	2609.04	3.1	37343.69	64.60	0.60	0.00	5	20	25	0	0.0	0.0	89.80
65	155	45	48	0	2575.72	2.0	36888.88	64.20	0.60	4.57	0	20	25	0	0.0	0.0	89.80
66	156	40	43	0	2558.33	3.1	36642.09	63.30	0.60	0.00	0	20	25	0	0.0	0.0	89.80
67	157	50	53	5	2227.43	1.9	32222.05	63.80	0.60	3.56	1	40	38	9	0.0	0.0	93.20
68	158	50	47	0	2219.00	3.9	32087.80	62.30	0.60	0.00	2	40	35	0	0.0	0.0	93.20
69	159	40	43	0	2603.79	2.7	37287.35	62.20	0.60	0.25	0	20	35	0	0.0	0.0	93.20
70	160	35	38	0	2662.07	3.1	38087.45	63.20	0.60	0.51	1	20	33	0	0.0	0.0	93.20
71	161	40	43	5	2673.90	2.8	38266.61	64.60	0.60	0.51	1	20	32	0	0.0	0.0	93.20
72	162	35	33	0	2411.59	6.4	34743.60	66.20	0.60	0.00	3	40	27	0	0.0	0.0	93.20
73	163	30	32	5	2451.10	5.8	35358.22	68.00	0.60	0.00	2	40	42	11	0.0	0.0	97.40
74	164	30	28	5	2891.23	7.2	41349.35	71.30	0.60	0.00	3	20	37	0	0.0	0.0	97.40
75	165	25	27	6	2604.48	7.4	37530.77	73.50	0.60	0.00	2	40	42	5	0.0	0.0	99.30
76	166	20	22	4	2641.09	7.0	38022.33	73.30	0.60	0.00	2	40	38	0	0.0	0.0	99.30
77	167	20	22	7	3023.07	6.7	43228.81	76.60	0.60	0.00	1	20	37	0	0.0	0.0	99.30
78	168	20	22	6	3097.02	6.1	44265.63	79.40	0.60	0.00	3	20	32	0	0.0	0.0	99.30
79	169	20	20	6	2808.88	6.7	40419.29	79.80	0.60	0.00	4	40	38	8	0.0	0.0	102.30
80	170	20	20	7	2907.82	6.5	41816.94	82.40	0.60	0.00	4	40	40	5	0.0	0.0	104.20
81	171	20	20	7	2981.92	6.6	42846.71	84.50	0.60	0.00	3	40	35	0	0.0	0.0	104.20
82	172	25	25	11	2990.36	8.0	42942.21	80.90	0.60	0.00	7	40	33	6	0.0	0.0	106.50
83	173	25	27	9	2978.66	7.8	42895.19	80.50	0.60	0.00	12	60	52	23	0.0	0.0	115.10
84	174	25	27	8	3378.23	8.0	48340.28	83.90	0.60	0.00	8	20	38	0	0.0	0.0	115.10
85	175	30	30	11	3344.10	9.4	47844.14	81.30	0.60	0.00	8	20	25	0	0.0	0.0	115.10
86	176	30	37	10	3372.96	6.0	48276.13	82.50	0.60	0.00	9	20	18	5	0.0	0.0	117.00
87	177	45	50	11	3397.63	2.8	48659.90	82.40	0.60	0.00	4	20	28	10	0.0	0.0	120.80
88	178	60	43	10	3428.86	1.3	49104.79	84.10	0.60	0.00	6	20	18	0	0.0	0.0	120.80
89	179	55	45	9	3426.51	7.8	49115.56	84.60	0.60	0.76	7	20	18	7	0.0	0.0	123.40
90	180	50	45	11	3490.71	11.3	50058.81	87.20	0.60	0.00	6	20	22	8	0.0	0.0	126.40
91	181	30	37	0	3511.34	5.9	50349.72	88.10	0.60	0.00	3	20	17	0	0.0	0.0	126.40
92	182	40	40	9	3557.66	6.8	51007.81	88.60	0.60	0.00	4	20	18	5	0.0	0.0	128.40
93	183	40	40	8	3548.63	8.5	50919.93	89.20	0.60	0.00	5	20	18	5	0.0	0.0	130.30
94	184	25	30	0	3575.19	6.2	51302.04	90.90	0.60	0.00	1	20	17	0	0.0	0.0	130.30
95	185	35	38	10	3600.88	4.8	51667.84	92.30	0.60	0.00	1	20	15	0	0.0	0.0	130.30
96	186	45	47	10	3630.24	4.7	52067.02	92.40	0.60	0.00	0	20	15	0	0.0	0.0	130.30
97	187	55	43	11	3676.56	0.5	52692.91	92.40	0.60	0.00	0	20	15	0	0.0	0.0	130.30
98	188	60	43	11	3671.12	10.8	52602.42	91.20	0.60	0.00	0	20	15	0	0.0	0.0	130.30
99	189	40	43	10	3769.81	10.3	53979.61	94.40	0.60	0.00	0	20	15	0	0.0	0.0	130.30
100	190	25	32	0	3833.88	6.7	54864.55	95.80	0.60	0.00	0	20	15	0	0.0	0.0	130.30
101	191	35	35	10	3816.78	8.1	54635.76	96.00	0.60	0.00	0	20	15	0	0.0	0.0	130.30
102	192	30	33	6	3820.81	6.5	54703.70	97.00	0.60	0.00	0	20	15	0	0.0	0.0	130.30
103	193	35	37	8	3796.88	5.8	54403.93	98.70	0.60	0.00	0	20	15	0	0.0	0.0	130.30
104	194	45	50	11	3805.93	3.3	54560.06	101.20	0.60	0.00	0	20	15	0	0.0	0.0	130.30
105	195	45	43	0	3832.41	3.7	54929.05	102.10	0.60	0.00	0	20	15	0	0.0	0.0	130.30
106	196	55	48	11	3843.15	7.6	55060.74	101.10	0.60	0.25	0	20	15	0	0.0	0.0	130.30
107	197	50	42	10	3864.85	1.5	55374.10	102.60	0.60	0.00	0	20	15	0	0.0	0.0	130.30
108	198	55	48	11	3875.63	7.2	55546.75	104.60	0.60	0.00	0	20	15	0	0.0	0.0	130.30
109	199	55	43	11	3686.26	0.9	53224.43	107.60	0.60	0.00	23	80	42	39	0.0	0.0	144.80
110	200	50	40	5	3916.24	7.5	56399.31	108.80	0.60	0.00	15	20	33	10	0.0	0.0	148.50
111	201	35	35	5	3951.66	8.1	56950.89	111.50	0.60	0.00	9	20	30	7	0.0	0.0	151.20
112	202	30	32	6	3995.36	8.2	57544.43	111.70	0.60	0.00	4	20	23	0	0.0	0.0	151.20
113	203	30	28	8	4031.29	10.3	58056.55	113.70	0.60	0.00	2	20	20	0	0.0	0.0	151.20
114	204	30	33	11	4036.14	8.1	58109.44	112.80	0.60	0.00	2	20	17	0	0.0	0.0	151.20
115	205	35	38	10	4083.58	7.0	58823.96	118.20	0.60	0.00	1	20	15	0	0.0	0.0	151.20
116	206	45	43	11	4152.59	8.2	59749.74	117.70	0.60	0.00	0	20	15	0	0.0	0.0	151.20
117	207	40	38	7	4206.14	10.0	60506.54	120.20	0.60	0.00	0	20	15	0	0.0	0.0	151.20
118	208	40	42	11	4231.35	8.9	60819.44	118.10	0.60	0.00	0	20	15	0	0.0	0.0	151.20

119	209	45	45	11	4228.95	9.2	60847.83	122.60	0.60	0.00	0	20	17	0	0.0	0.0	151.20
120	210	45	43	10	4270.86	11.1	61440.02	124.50	0.60	0.00	0	20	17	0	0.0	0.0	151.20
121	211	30	32	0	4298.95	6.6	61843.60	126.30	0.60	0.00	0	20	17	0	0.0	0.0	151.20
122	212	30	30	6	4333.74	7.0	62341.79	128.40	0.60	0.00	0	20	17	0	0.0	0.0	151.20
123	213	25	25	4	4335.20	7.3	62400.48	131.20	0.60	0.00	0	20	17	0	0.0	0.0	151.20
124	214	20	23	5	4341.40	5.7	62532.53	134.80	0.60	0.00	0	20	17	0	0.0	0.0	151.20
125	215	20	20	4	4356.32	6.0	62730.27	134.50	0.60	0.00	1	20	15	0	0.0	0.0	151.20
126	216	25	27	10	4370.96	5.7	62909.79	133.20	0.60	0.00	0	20	17	0	0.0	0.0	151.20
127	217	35	32	11	4370.09	8.3	62880.47	131.90	0.60	0.00	1	20	15	0	0.0	0.0	151.20
128	218	25	33	5	4364.20	4.3	62815.20	132.90	0.60	0.00	0	20	15	0	0.0	0.0	151.20
129	219	40	37	9	4375.96	6.5	62970.08	132.60	0.60	0.00	0	20	15	0	0.0	0.0	151.20
130	220	35	35	6	4380.69	7.5	63045.97	133.50	0.60	0.00	0	20	15	0	0.0	0.0	151.20
131	221	40	43	11	4381.04	5.5	63058.68	134.10	0.60	0.00	0	20	15	0	0.0	0.0	151.20
132	222	50	38	11	4388.36	1.6	63159.53	134.30	0.60	0.00	0	20	15	0	0.0	0.0	151.20
133	223	50	43	10	4369.94	6.9	62927.28	135.50	0.60	0.00	0	20	15	0	0.0	0.0	151.20
134	224	40	40	5	4377.72	6.6	63040.72	136.10	0.60	0.00	0	20	15	0	0.0	0.0	151.20
135	225	35	37	4	4382.30	5.7	63106.87	136.40	0.60	0.00	0	20	15	0	0.0	0.0	151.20
136	226	40	45	9	4374.39	3.6	63012.91	137.40	0.60	0.00	0	20	15	0	0.0	0.0	151.20
137	227	35	35	0	4396.30	6.4	63324.36	138.50	0.60	0.00	0	20	15	0	0.0	0.0	151.20
138	228	20	27	0	4416.58	5.2	63565.92	136.10	0.60	0.00	0	20	17	0	0.0	0.0	151.20
139	229	20	18	0	4438.48	4.8	63861.96	136.10	0.60	0.00	0	20	17	0	0.0	0.0	151.20
AVERAGE:			43mm	7mm		5.4mm					2.9kg		65kg	13kg			
TOTAL:				767mm		749.7mm				76.95mm	407kg			403kg	0.0kg@	15mm@	

* Rainfall plus snow pack melt
@ Total for full growing season