This is to certify that the

thesis entitled

LINKING GEOGRAPHIC INFORMATION SYSTEMS
WITH SIMULATION MODELING FOR RISK-BENEFIT
ANALYSIS IN POTATO PRODUCTION

presented by

Mark Sadler Swartz

has been accepted towards fulfillment
of the requirements for

M.S. degree in Resource Development

Joe T. Ritchie
Major professor

Date 12/05/88

LINKING GEOGRAPHIC INFORMATION SYSTEMS WITH SIMULATION MODELING FOR RISK-BENEFIT ANALYSIS IN POTATO PRODUCTION

By

Mark Sadler Swartz

A THESIS

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

MASTER OF SCIENCE

Department of Resource Development

1988

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LINKING GEOGRAPHIC INFORMATION SYSTEMS WITH SIMULATION MODELING FOR RISK-BENEFIT ANALYSIS IN POTATO PRODUCTION

by

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ABSTRACT

Development of an integrated modeling system capable of estimating risks and benefits associated with nitrogen fertilizers and aldicarb in regional potato (*Solanum tuberosum*) production was the goal of this project. Risk was measured as aldicarb and nitrate mass leached below the root zone. Benefit was measured as on-farm agricultural profitability. An analytical model (SUBSTOR) which describes plant growth, nitrogen movement, and aldicarb movement was used to estimate profitability and potential groundwater contamination under alternative management scenarios. The ERDAS geographic information system (GIS) was used to spatially correlate weather, soils, and land use information for model parameterization in heterogeneous environments. Potato production information from Sections 8,9,16,17 of Douglass Township in Montcalm County, Michigan was used for prototype analysis.

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ACKNOWLEDGMENTS

I would like to thank Dr. Joe Ritchie, Dr. George Bird, and Dr. Tom Edens for serving on my guidance committee. Thanks to Brian Baer, Farsad Fotouhi, Dr. Brad Johnson, Dr. Russel Jones, and Dr. Joe Hudson for there help in completion of this project. I would also like to thank the Movement Arts community for their energy and comradery. Special thanks to Fred, Rose Ann, and Matt Swartz for their love, unending support, personal, and professional abilities, John Davenport, Becky Mather, Fred Warner, and the rest of the nematology crew for work and good times we have shared. Thanks to Richard Kemp and Jim Smania. I always knew you were there. Thanks to Laura Abraczinkas,"because she makes me laugh".

Title: Lin
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Title: Linking geographic information systems with simulation modeling for risk-benefit analysis in potato production

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CHAPTER I

INTRODUCTION

Agricultural non-point source pollution is a difficult problem to analyze because of spatial variation in soil type, farming practices, precipitation and other factors which affect pollution occurrence and severity. System complexities develop from the relationships between irrigation, chemical movement, and crop development under relatively uniform environmental conditions and from the impact of regional variation in soil types and land use. Analytical tools are needed to study the trade-offs between production input values and the non-point source risks. Such a tool may be used to meet the dual challenge of crop yield optimization and mitigation of agricultural ground water contamination.

Goal and Objectives.

The goal of this project was to develop a system capable of estimating ground water contamination risks and economic benefits associated with the use of nitrogen fertilizers and aldicarb in regional potato production. The system was intended to be sensitive to agricultural management practices, and spatial variation in environmental parameters.

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To meet the goal, five thesis objectives were defined:

1. Quantify spatially variable factors important to potato production (i.e. weather, land-use, soils) in a prototype study area.

2. Identify alternate management strategies which would reduce risk of aldicarb and nitrate ground water contamination while sustaining profitability.

3. Expand SUBSTOR's capabilities to include degradation and movement of aldicarb and its oxidative metabolites in the soil environment

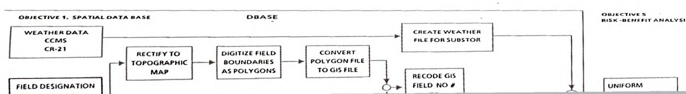
4. Expand SUBSTOR's capabilities to include estimation of the impact of aldicarb and *Pratylenchus penetrans* (Root-lesion nematode) on potato tuber yield

5. Integrate simulation modeling with geographic information systems to facilitate model parameterization for regional potato production risk-benefit analysis.

Project Overview

Project Organization

This thesis was divided into five distinct but interrelated categories; 1) spatial data base development, 2) alternate management practice identification, 3) aldicarb movement and degradation model development, 4) yield impact model development, and 5) simulation modeling for risk benefit analysis (Figure 1). Given the comprehensive nature of the study goal, a diverse array of research procedures and system development parameters were needed. Objectives were accomplished using a variety of procedures including: spatial data gathering, literature reviews, literature integration techniques, computer programming, and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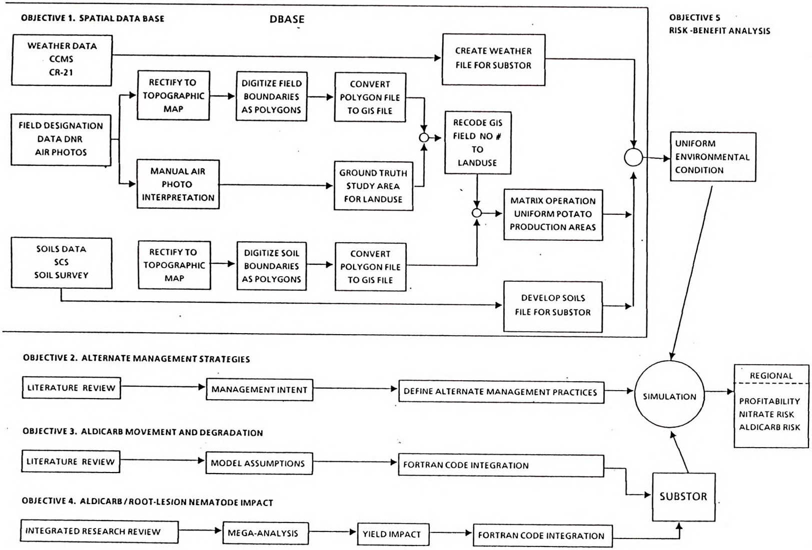

Figure 1. System diagram for project development

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multivariate statistical analysis. An overview of the activity related to each thesis objective is presented.

Thesis Objective 1 - Spatial data base

Information pertaining to spatial variability in non-grower controlled variables such as rainfall, soil type, and land use was collected and analyzed. Spatial data analysis was performed using ERDAS Earth Resource Data Analysis System. ERDAS is a geographic information system (GIS). GIS is an integrated software package designed for the entry, manipulation, analysis, and display of single or multiple layers of spatial referenced information. Information on weather, land use, and soils can be electronically overlaid to produce new maps based on the relationship between map features (Figure 2). ERDAS was used to electronically overlay and relate multiple map features in order to show geographic relationships important to regional potato production.

Land use and soil type maps were developed for a prototype study area which included sections 8,9,16, and 17 of Douglass township in Montcalm County, Michigan (Figure 3). A four-section area was used so that it would be large enough to show the impact of spatial variation, but yet small enough so that data handling would be sufficiently manageable in a comprehensive modeling system.

The completion of Thesis Objective 1 provided information on soil types in the study area on which potatoes were produced in 1986-1988. Files representing

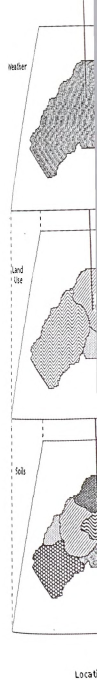

Figure 2. GIS

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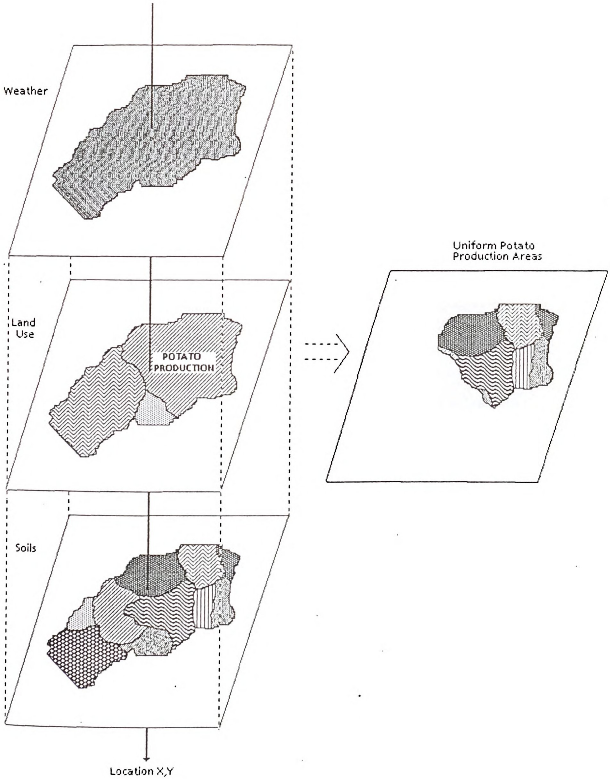
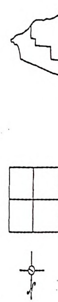


Figure 2. GIS analysis for uniform potato production regions.



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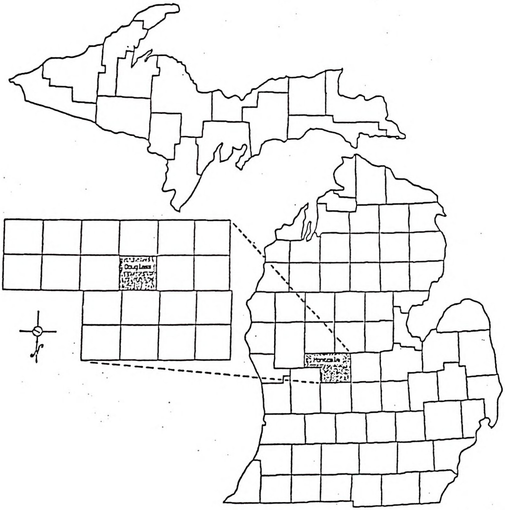

Figure 3. Location of Douglass Twn, Montcalm Co., Michigan

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soil physical characteristics and weather for each of these years were used as SUBSTOR input parameters.

Thesis Objective 2 - Alternate management strategies

A review of the scientific literature and sensitivity to grower field practices were used to identify alternate potato management strategies. This information was used to create input files for simulation models representing standard grower practices and a hypothesized improved management practice. The intent of the improved system was to optimize the relationship between agricultural profitability and risk to ground waters.

Thesis Objective 3 - Aldicarb movement and degradation

A model of aldicarb movement and degradation was developed and integrated with SUBSTOR, an existing potato plant growth and development model. Findings reported in the scientific literature were used for model development.

SUBSTOR, Simulation of Underground Bulking STorage ORgans was developed at Michigan State University by Dr. Joe Ritchie and Mr. Dale Magnusson. SUBSTOR is a S.tuberosum growth and development model. SUBSTOR was designed to serve as: an aid to within-year crop management decisions, for multi-year risk analysis and strategic planning, large area yield forecasting, and to assist in the definition of research needs.

SUBSTOR operates on a daily time step and uses readily available weather, soil, and genetic data inputs. The model simulates phenological development, soil water balance, and nitrogen transf

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Eight subroutines were developed and integrated with SUBSTOR. The addition of new subroutines upgraded the programs capability to include an estimation of aldicarb movement and degradation. SUBSTOR modifications allowed for estimation of risks associated with alternate aldicarb and irrigation management.

Thesis Objective 4 - Aldicarb/Root-lesion nematode impact

The impact of aldicarb and P.penetrans on potato yield was determined using integrated research review techniques and meta-analysis. Meta-analysis included a variety of statistical analysis methods such as, analysis of variance, multivariate general linear regression, and stepwise regression procedures. Information obtained from the meta-analysis was used in SUBSTOR for estimation of the impact of aldicarb and P.penetrans on tuber yield. The new version of SUBSTOR could then estimate of the value of aldicarb to growers.

Thesis Objective 5 - Risk/benefit analysis

The appended version of SUBSTOR (Thesis Objectives 3 and 4) was used to estimate impacts of selected management factors identified in Thesis Objective 2, on potato yield, nitrate leaching and aldicarb leaching under each set of environmental conditions of soil type and land use determined through Thesis Objective 1.

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Risk-benefit analysis system

Upon completion of simulation modeling upgrades performed under Thesis Objectives 3 and 4, the procedures under Thesis Objectives 1, 2, and 5 formed a risk-benefit analysis system. Data flow in this system consisted of transferring information on soil type, land-use, and weather into computer readable formats followed by matrix analysis to determine uniform potato production subregions. For each subregion, data necessary for simulation model operation was collected and used for simulation of management scenarios. Simulation output was used to show regional variation in profitability, nitrate leaching and aldicarb leaching potential associated with alternate production management schemes (Figure 4).

Project Justification

The potential expense required for field research to test the impacts of alternate management strategies on all soil types in a region limits the amount and quality of information available to agricultural decision makers. The impacts of these multiple factors (i.e. soil type, rainfall, irrigation, and pesticide application timing) on production and environmental concerns can best be analyzed through an integrated modeling approach (Wagenet and Hudson, 1986). The risk benefit analysis system developed in this study was designed to provide information for agricultural decision makers through integration of the best available technology for dealing with potato production system complexities.


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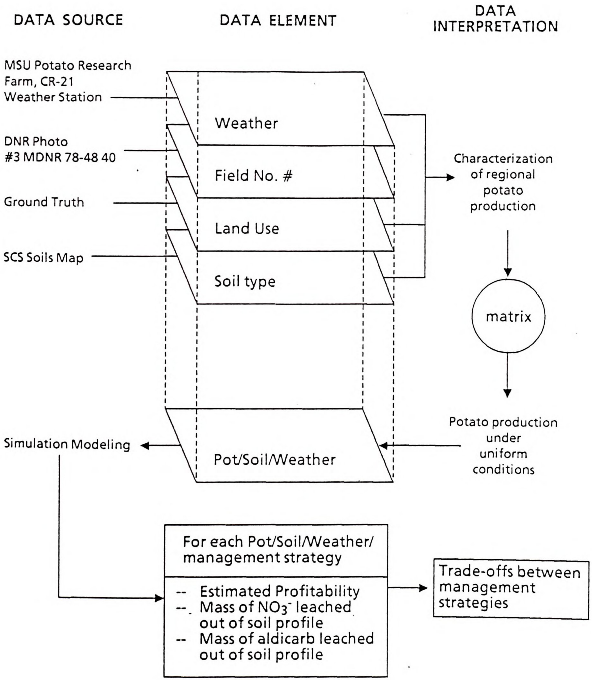

Figure 4. Risk-benefit analysis information flow.

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If a chemical moving into ground water supplies is non-toxic then it may be of little concern to an agricultural manager. However, if the compound is toxic or persistent then management of material leaching is of major importance. The two sources of risk considered in this system were nitrate nitrogen and aldicarb metabolites.

Nitrogen

In soil, non-nitrate forms of fertilizer are converted to nitrates by soil microorganisms. Nitrates are water soluble are not absorbed by soil and thus subject to leaching. The movement of nitrate in soil is impacted by plant uptake. Plants both remove nitrate from soil and converted it to an immobile organic form. Nitrate mass movement is also impacted by the denitrification processes. Under saturated soil conditions some anaerobic microorganisms use nitrate as an oxygen source resulting in a conversion to nitrogen gas.

Nitrate Risk. The Michigan Department of Public Health abides by the EPA standard that public drinking water supplies may not contain more then 10 ppm of nitrate nitrogen (McWilliams, 1984). Ingestion of water containing nitrate concentrations greater than 10 ppm may cause methemoglobinemia in infants under the age of six months. Methemoglobinemia occurs when nitrates enter the infant's blood stream decreasing the blood's ability to carry oxygen. This may result in slightly retarded body growth, reflexes or death (Dorsch et al., 1984). Methemoglobinemia known as the '

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known as the 'blue baby syndrome' does not affect adults because of shifts which occur in blood pH during childhood.

Cows and other cud-chewing animals that drink well water are also at risk from nitrates in ground waters. Nitrate can be reduced to nitrite in the rumen increasing risk of chronic disease. High nitrate in ground waters has also been correlated with spontaneous abortion of litters in swine (McWilliams, 1984).

Regional Nitrate Concern. Public health records in Montcalm County, Michigan revealed groundwater nitrate concentrations above the 10 ppm health standard (Erving, 1986). An analysis of public well water quality records indicated background levels of nitrate in ground waters to be 1-2 ppm (Kruska, 1986; Hallberg, 1986). Concentrations above this level may come from agriculture, septic tank seepage, municipal waste sites, or feed lot operations (McWilliams, 1984; Singh and Sekhon, 1979). Potato production is considered to be a probable cause due to its occurrence on sandy and sandy loam soils, use of nitrogen fertilizers, and use of irrigation.

Occurrence of elevated nitrate levels in ground waters may also serve as an indicator of pesticide contamination. In Iowa, 67% of well water samples which contained elevated nitrate levels also contained pesticide residues. (Kelley et al., 1986). Pesticide concentrations were not significantly correlated with nitrate concentrations but co-occurrence was significantly correlated.

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Aldicarb

Aldicarb is a systemic insecticide and contact nematicide. It is highly water soluble and does not appreciably bind to the soil matrix (Bromilow and Leistra, 1980). This makes aldicarb susceptible to leaching into ground water supplies.

Aldicarb was first discovered in ground water in 1979 when it was found in shallow test wells in eastern Long Island, New York potato fields (Zaki et al., 1982). Aldicarb's registration as a nematicide has been restricted in Long Island, New York due to its presence in ground water.

Aldicarb residues were detected in irrigation well water in Wisconsin's Central Sands potato production region (Rothschild et al., 1982). The state of Florida has also been concerned with the possibility of aldicarb moving into ground water as a result of that state's citrus production (Jones and Back, 1984). Aldicarb has also been found in Maine ground waters in regions associated with potato production (McWilliams, 1984).

Aldicarb Risk. Aldicarb is a cholinesterase inhibitor. As such, it is highly toxic. In New York a concentration 7 ppb is the health advisory level, while the EPA sets 10 ppb as its maximum recommended limit in ground waters (Zaki et al., 1982). Once under the anaerobic conditions found in most ground waters, aldicarb degrades very slowly (Lemley and Zhong, 1984; Bank and Tyrell, 1984).

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Regional Aldicarb Concern. The aquifers in Montcalm County, Michigan also appear to be at risk to aldicarb contamination. This area has received a 5.2 rating using Back, Romine, and Hansen's aldicarb appearance in potable water numerical index. This can be compared to a rating of 9.1 for the Central Sands region of Wisconsin and a 5.1 rating in Central Florida (Back et al., 1984). Both of these regions have experienced problems with aldicarb in ground water. The aldicarb appearance in potable water numeric index was developed based on relationships between thirteen environmental factors which fell under the general categories of application, degradation, transport, depth to ground water.

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CHAPTER II

REGIONAL DATA BASE DEVELOPMENT

Development of a regional data base was necessary to quantify spatially variable factors important to potato production (Thesis Objective 1). Soil, land use, and weather factors were included. Soil and land use data was quantified for use in ERDAS for determination of uniform potato production areas.

The region used for the prototype study area included Sections 8,9,16, and 17 of Douglass Township, Montcalm County, Michigan. This region was chosen because of its long history of potato production, proximity to the Michigan State University Potato Research Farm, and regional concern for ground water quality.

Thirty-five different soil types in this four section area overlay unknown depositional materials of glacial origins (United States Department of Agriculture, 1960). Optimal potato production strategies may differ for each of these soil types (Awad, 1984; Pionke and Urban, 1985).

Materials and Methods

Materials refer to the spatial data sources and software used to meet Thesis Objective 1. Methods refer to how the maps were handled to produce a matrix output showing the soils on which potatoes were produced in each year of the study.

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Spatial Data Base

The first step in data base development was to quantify the soil types, field boundaries, land uses, and weather characteristics in the study area. The second step in data base development involved using ERDAS to create uniform potato production area maps (Figure 2). Spatial data used in this study was obtained from several different sources.

Data Source

Information used in the development of the regional potato production data base came from many different sources.

Soils. Soils maps were obtained from the United States Department of Agriculture Soil Conservation Service Soil Survey of Montcalm County Series 1949, No.11. The study area was covered by Map Sheets number 23 and number 24. The map scale was 1:20,000. Soils maps were georeferenced using section corner coordinates.

Field Boundaries. Aerial photography of the region was obtained from the Michigan Department of Natural Resources. Black and white imagery was obtained from a September 4th flight during 1978, print number 3MDNR 78-48 40. Color slide imagery from 1986 was also available from the Montcalm County Office of the Soil Conservation Service but was not used because of oblique projection.

Land use. Land use information was obtained through ground truthing. The field boundary map was used as a base for these operations.

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<u>Weather</u>. Weather information was available for the period 1974 to 1986 from the Cooperative Crop Monitoring Service for a weather station located in Entrican, Michigan. Weather information was also available from 1985 to 1988 from the Montcalm County Potato Research Farm. Because of its greater accuracy in solar radiation data, the Potato Research Farm data was used for all analysis.

<u>Data processing</u>

Data processing consisted of air photo interpretation, map and photo spatial rectification, followed by image translation into computer readable formats (geocoding).

Air photo interpretation

Land use information was obtained through manual air photo interpretation of DNR image 3MDNR 78-48 40. Major field and land use boundaries were delineated by fence rows, roads, tree lines, water bodies, and textural changes.

Rectification

The spatial consistency of the soils map, and the aerial photograph was checked by projection onto a 7.5 min USGS topographic base map (Six Lakes and Edmore quadrangle) using a Bausch & Lomb Zoom Transfer Scope. Both the soils map and the aerial photograph were spatially consistent with the topographic base map. Map rectification procedures were unnecessary.

Geocoding

Soils and land use boundaries were then geocoded for input into ERDAS. The geocoding process consisted of three stages: digiti

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Digitization. The digitation process was completed using an electronic digitizing board and Mapdig2 software. State plane coordinates were used for geo-referencing. Soil and field boundaries were represented by a series of line segments which formed complete polygons on each boundary. The region inside of each polygon was assigned an attribute value which represented the soil type or field number inside the polygon.

Rasterization. The spatial information contained in the soil and field number polygon files was translated into 8-bit raster files. The raster grid was 355 columns by 355 rows. Each pixil in the grid represented a 10-yard by 10-yard square corresponding to the minimum mapping size in Soil Conservation Service soil maps.

CRIES (POL2DIG, CREATE, and POLYFILL) Software was used for the polygon-to-raster conversion process. POL2DIG converted the overlapping polygons of a digitizer file into dimensioned strings of attribute data. CREATE initialized an empty raster structure of appropriate dimensions. POLYFILL mapped dimensioned strings of attribute data into the appropriate location within the raster structure. ERDAS was used to convert rasterized attribute data to a GIS file.

GIS Creation. The output file from the POLYFILL operation was input to the ERDAS strip application program which removed CRIES header information. The pixil index

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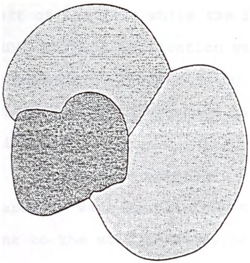
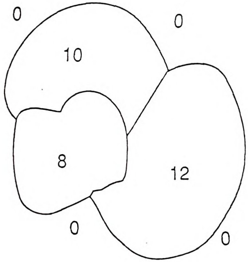
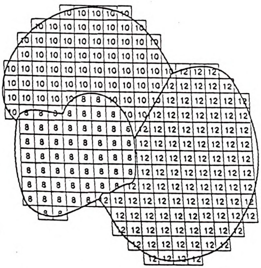


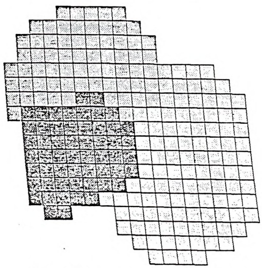
A. Uncoded base map.



B. Areas with assigned numerical codes. Non-features keyed as zero.



C. Approximation of base map by cells.



D. Reconstruction of base map.

Figure 5. The geocoding process - Map feature boundaries of uncoded base map **A**, are represented by a series of line segments linked to numeric attribute codes **B**. Boundary and attribute information is converted into a grid based raster file **C**, which is subsequentially converted into a GIS reconstruction of the base map **D**.

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origin for the CRIES GIS system was located at the bottom left of the file while the ERDAS origin is on the top left. ERDAS REVERSE application was used to renumber pixil coordinates. The geocoding process was then completed using ERDAS FIXHEAD to create a new GIS header file.

Soils GIS

Soil series attribute values coded during digitization (Table 1) were used to identify soil series, and provide a link to the soil chemical/physical properties table of the County Soil Survey as well as Soil Conservation Service 232 forms.

Land use GIS

Field number values created during digitization were unique but nominal. Ground truthing observations were made on July 28, 1986; August 23, 1987; and August 17, 1988 in order to determine land use in each year. During ground truthing, field numbers obtained from air photo interpretation were linked with land-use attribute codes (Table 2). The field number map was then re-coded using ERDAS to indicate regional land-use in each year of the analysis.

Table 1. Soil
geocoding.

ATT No#	SCS SYMBOL
1	AQ
2	Aa
3	Ca
4	Eb
5	Ec
6	Ga
7	Gc
8	Gd
9	Ge
10	Gg
11	Gk
12	Kc
13	Mb
14	Mc
15	Md
16	Mh
17	Mt
18	Mw
19	Mx
20	Ra

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ATT NO#
1
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Table 1. Soil series names and attribute numbers used in geocoding.

ATT No#	SCS SYMBOL	SOIL SERIES NAME	% SLOPE
1	AQ	Water	
2	Aa	Alluvial land	
3	Ca	Carlisle Muck	0 - 2
4	Eb	Ensley loam and Edmore loamy fine sand	0 - 2
5	Ec	Epoufette loamy sand and Ronald sandy loam	0 - 2
6	Ga	Gladwin loamy and sand and Palo sandy loam	0 - 2
7	Gc	Grayling sand	0 - 2
8	Gd	Grayling sand	2 - 6
9	Ge	Grayling sand	6 -10
10	Gg	Grayling sand	10 -18
11	Gk	Greenwood and Dawson peats	0 - 2
12	Kc	Kerston muck	0 - 2
13	Mb	Mancelona loamy sand	0 - 2
14	Mc	Mancelona loamy sand	2 - 6
15	Md	Mancelona loamy sand	6 -10
16	Mh	McBride and Isabella sandy loams	0 - 2
17	Mt	Montcalm loamy sand and sandy loam	6 -10
18	Mw	Montcalm and McBride loamy sands and sandy loams	0 - 2
19	Mx	Montcalm and McBride loamy sands and sandy loams	2 - 6
20	Ra	Rifle and Tawas peats	0 - 2

Table 2. Land-use attribute codes used in geocoding.

ATT NO#	LAND USE
1	Potatoes
2	Corn
3	Soybeans
4	Forage Crops
5	Small Grains
6	Grass and Open
7	Apple Orchard
8	Christmas Trees
9	Forest Covered
10	Farmstead
11	Urban Residential
12	Cemetery
13	Marsh
14	Water
15	Unknown
16	Cucumbers

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Weather data

Weather data was already in digital format and needed only to be converted to the proper format for SUBSTOR simulation modeling. This conversion was accomplished using the file import and export functions of a LOTUS 123 data manager. The spatial distribution of available weather data forced the assumption that weather characteristics would be uniform across the study area.

Potato production analysis

The next step was to determine the soil types on which potato production occurred during the land use year. This was accomplished using the ERDAS MATRIX operation. Land use was re-coded dichotomously as (potato=1, non-potato=2). Soil type was used as the row variable and land-use was the column variable. The MATRIX operation was performed for each year of the study resulting in new GIS files showing soil types under potato production and relative acreage.

Results

The geocoding process conducted under Thesis Objective 1 produced a GIS file representing soil types (Figure 6). A map representing field identification numbers was also produced (Figure 7). Using information gained from ground truthing (Table 3), maps of study area land use were developed for 1986, 1987, and 1988 (Appendix A, Figures 1,2,3 respectively).

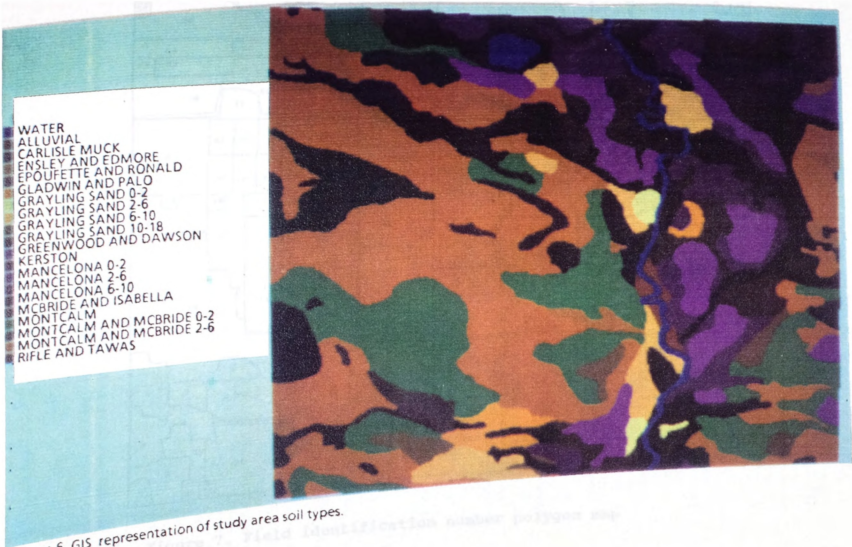

Figure 6. GIS representation of study area soil types.

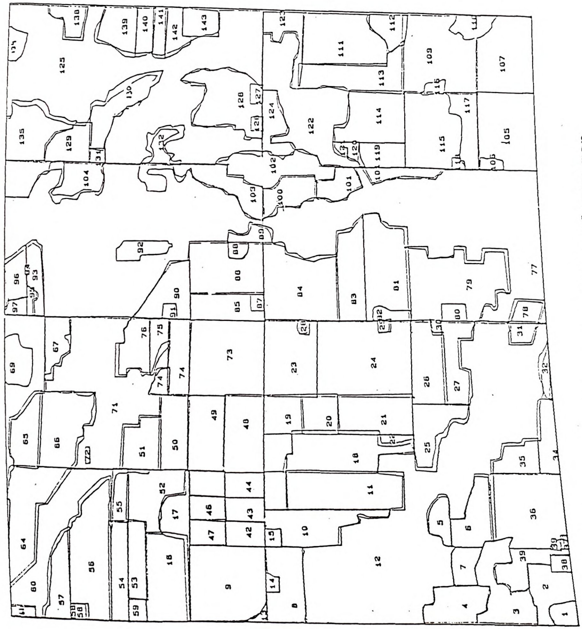

Figure 7. Field identification number polygon map

Table 3. Field identi

ID No.	1986	1987
1	Forest	Forest
2	C-tree	C-tree
3	Forest	Forest
4	C-tree	C-tree
5	Corn	Open
6	Corn	Open
7	C-tree	C-tree
8	Corn	Open
9	Potato	Forage
10	Forage	Open
11	Sm-grain	Open
12	Forest	Forest
13	Open	Open
14	Farmsted	Farmste
15	Farmsted	Farmste
16	Corn	Potato
17	Open	Open
18	Corn	Open
19	Corn	Corn
20	Corn	Corn
21	Corn	Corn
22	Forest	Forest
23	Forage	Forage
24	Forage	Forage
25	Unknown	Unknow
26	Soybean	C-tree
27	Soybean	C-tree
28	Farmsted	Farmst
29	Farmsted	Farmst
30	Farmsted	Farmst
31	Forage	Forage
32	C-tree	Forage
33	Forage	Forage
34	Corn	Forage
35	Forage	Forage
36	Forest	Forest
37	Farmsted	Farmst
38	Farmsted	Farmst
39	Forest	Forest
40	Farmsted	Farmst
41	Farmsted	Farmst
42	Soybean	Forage
43	Forage	Forage
44	Potato	Potat
45	Potato	Potat
46	Forage	Potat
47	Forage	Potat
48	Corn	Open

Table 3. Field identification numbers and ground-truthed land use for 1986, 1987, and 1988

ID No.	1986	1987	1988	ID No.	1986	1987	1988	ID No.	1986	1987	1988
1	Forest	Forest	Forest	49	Corn	Open	Corn	97	Farmsted	Farmsted	Farmsted
2	C-tree	C-tree	C-tree	50	Forage	Corn	Corn	98	Corn	Corn	Open
3	Forest	Forest	Forest	51	Forage	Forage	Forage	99	Farmsted	Farmsted	Farmsted
4	C-tree	C-tree	C-tree	52	Corn	Corn	Potato	100	Potato	Corn	Corn
5	Corn	Open	Open	53	Sm-grain	Forage	Corn	101	Open	Open	Open
6	Corn	Open	Open	54	Forage	Forage	Forage	102	Urban	Urban	Urban
7	C-tree	C-tree	C-tree	55	Sm-grain	Corn	Open	103	Open	Open	Open
8	Corn	Open	Open	56	Sm-grain	Forage	Open	104	Open	Open	Open
9	Potato	Forage	Open	57	Sm-grain	Forage	Open	105	Corn	Potato	Corn
10	Forage	Open	Open	58	Farmsted	Farmsted	Farmsted	106	Farmsted	Farmsted	Farmsted
11	Sm-grain	Open	Open	59	Farmsted	Farmsted	Farmsted	107	Corn	Open	Open
12	Forest	Forest	Forest	60	Forest	Forest	Forest	108	Forage	Forage	Open
13	Open	Open	Open	61	Corn	Corn	Open	109	Corn	Open	Open
14	Farmsted	Farmsted	Farmsted	62	Corn	Corn	Open	110	Marsh	Marsh	Marsh
15	Farmsted	Farmsted	Farmsted	63	Open	Open	Open	111	Apple	Apple	Apple
16	Corn	Potato	Corn	64	Corn	Corn	Open	112	Marsh	Marsh	Marsh
17	Open	Open	Potato	65	Corn	Corn	Forage	113	Corn	Open	Open
18	Corn	Open	Forage	66	Forage	Forage	Forage	114	Potato	Forage	Forage
19	Corn	Corn	Forage	67	Open	Open	Open	115	Corn	Open	Open
20	Corn	Corn	Forage	68	Forest	Forest	Forest	116	Forest	Forest	Forest
21	Corn	Corn	Corn	69	Water	Water	Water	117	Forest	Forest	Forest
22	Forest	Forest	Forest	70	Farmsted	Farmsted	Farmsted	118	Farmsted	Farmsted	Farmsted
23	Forage	Forage	Forage	71	Open	Open	Open	119	Corn	Forage	Forage
24	Forage	Forage	Forage	72	Water	Water	Water	120	Farmsted	Farmsted	Farmsted
25	Unknown	Unknown	Unknown	73	Potato	Cucumber	Potato	121	Forage	Forage	Forage
26	Soybean	C-tree	C-tree	74	Corn	Open	Open	122	Forest	Forest	Forest
27	Soybean	C-tree	C-tree	75	Forage	Forage	Forage	123	Open	Open	Open
28	Farmsted	Farmsted	Farmsted	76	Corn	Forage	Forage	124	Open	Open	Open
29	Farmsted	Farmsted	Farmsted	77	Forest	Forest	Forest	125	Forest	Forest	Forest
30	Farmsted	Farmsted	Farmsted	78	Forage	Forage	Forage	126	Alfalfa	Open	Open
31	Forage	Forage	Corn	79	Corn	Corn	Corn	127	Farmsted	Farmsted	Farmsted
32	C-tree	Forage	Forage	80	Farmsted	Farmsted	Farmsted	128	Farmsted	Farmsted	Farmsted
33	Forage	Forage	Forage	81	Corn	Open	Open	129	Potato	Open	Open
34	Corn	Forage	Corn	82	Farmsted	Farmsted	Farmsted	130	Open	Open	Open
35	Forage	Forage	Forage	83	Soybean	Open	Open	131	Farmsted	Farmsted	Farmsted
36	Forest	Forest	Forest	84	Soybean	Open	Open	132	Open	Open	Open
37	Farmsted	Farmsted	Farmsted	85	Potato	Corn	Open	133	Forage	Forage	Forage
38	Farmsted	Farmsted	Farmsted	86	Corn	Potato	Open	134	Corn	Corn	Open
39	Forest	Forest	Forest	87	Farmsted	Farmsted	Farmsted	135	Open	Open	Open
40	Farmsted	Farmsted	Farmsted	88	Forest	Forest	Forest	136	Open	Open	Open
41	Farmsted	Farmsted	Farmsted	89	Open	Open	Open	137	Open	Open	Open
42	Soybean	Forage	Potato	90	Corn	Corn	Corn	138	Open	Open	Open
43	Forage	Forage	Potato	91	Farmsted	Farmsted	Farmsted	139	Open	Open	Open
44	Potato	Potato	Potato	92	Unknown	Unknown	Unknown	140	Corn	Open	Open
45	Potato	Potato	Potato	93	Sm-grain	Open	Open	141	Farmsted	Farmsted	Farmsted
46	Forage	Potato	Corn	94	Forest	Forest	Forest	142	Corn	Open	Open
47	Forage	Potato	Open	95	Forest	Forest	Forest	143	Cemetary	Cemetary	Cemetary
48	Corn	Open	Corn	96	Corn	Alfalfa	Open				

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Table 4. Soil
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ERDAS MATRIX analysis provided information on soil types for which potato production occurred for each year of the study (Table 4).

Table 4. Soils on which potatoes were produced in 1986, 1987, and 1988.

	Acres in production		
Soil type	1986	1987	1988
Epoufette	3	.	.
Grayling	9	2	.
Mancelona	24	8	.
McBride	100	57	91
Montcalm	8	30	.
Total	144	97	91

Summary

The data on potato production by soil type provided in Table 4 was used to determine what simulations were necessary to estimate the impact of alternate management practices on associated risks and benefits in the prototype study area. For example, potato production on Grayling soil needed to be simulated for 1986 and 1987, but not for 1988. Twenty simulations were needed, ten sets of environmental factors each with two alternate management scenarios.

Declining acreage over three years is evident, perhaps because a major potato packing company moved out of the study area in 1986. If the study area had been large enough to include multiple weather data sets, then a three-way table showing potato production by soil type, and weather region would be required. ERDAS has the capability to handle that condition.

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CHAPTER III

ALTERNATE MANAGEMENT STRATEGY DETERMINATION

Alternative management strategies were identified with the desire to meet the dual challenge of optimizing economic benefits to the grower, while protecting ground waters from agricultural non-point source contamination. These alternate management strategies were to fall within the scope of standard chemical intensive practices and were intended to be modifications on existing management schemes. The alternate management strategy was one which could be implemented by growers with little change in cropping or machinery requirements. A literature review provided the background necessary for understanding potato production system interactions. Alternate management practices were developed based on this information. These strategies were quantified for input into SUBSTOR which was used to estimate associated risks and benefits.

Literature Review

The literature review is divided into three sections. Information pertaining to potato production scope is intended to place the project study area within a larger regional environment. Information pertaining to selected production management components describes the use and value of irrigation, nitrogen, and aldicarb application. The risk assessment section provides ideas on how risk to ground waters can be minimized while profitability maintained with out radical c

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Potato Production Scope

Michigan is the tenth largest producer of potatoes in the United States (Michigan Agricultural Statistics Service, 1987). Between 1985 and 1987 an average of 53,000 acres of potatoes were planted with an average yield of 261 cwt/acre (Michigan Agricultural Statistics Service, 1988). In Michigan, potato production occurs in both upper and lower peninsulas providing for great variation in potato production environments (Michigan Agricultural Statistics Service, 1988).

Montcalm County is ranked first in the state of Michigan for potato production (Michigan Department of Agriculture, 1986). An average of 12,950 acres of potatoes were planted between 1985 and 1986 in Montcalm County. The average yield of marketable tubers was 332 cwt/acre (Michigan Agricultural Statistics Service, 1988).

Selected Management Components

Three potato management factors were considered by this study. They are irrigation application amount and timing, nitrogen fertilizer amount and timing, and aldicarb application timing.

Irrigation

As a standard practice in Michigan potato production one inch of irrigation water is usually applied every three to five days when natural rainfall is not sufficient of meet crop needs (Vitosh, 1987).

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Irrigation Value. The potato plant is susceptible to water stress. Irrigation is used in Michigan to reduce crop water stress when natural precipitation is not great enough to meet crop needs. Research in Wisconsin's Central Sands region indicates that in some years irrigation may increase yields from 100-200 cwt/acre to 500 cwt/acre (Butler, 1978). Comparison of two experimental plots at the Michigan State University Montcalm Potato Research Farm indicates that in 1988 (a very dry year) irrigation may have increased total tuber yields as much as 331 cwt/acre. As such, the value of irrigation to potato production is considerable.

Irrigation Concern. Two conditions are necessary for the movement of chemicals out of the root zone. They are: presence of the compound in the soil, and downward movement of water. Downward movement of water is a function of natural rainfall, irrigation, soil type, evaporation, and plant uptake (McWilliams, 1984). Of these factors, irrigation is the most easily controlled. Irrigation increases the amount of water available for the plant and also the amount of water available for movement of aldicarb or nitrates.

As would be expected, there appears to be a relationship between application of irrigation to crops and contamination of ground waters. In Holt County, Nebraska, nitrate concentration in ground water was significantly correlated (r^2 0.66) with the age of irrigation wells. The analysis revealed nitrate levels increasing in shallow ground waters

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ground waters on an average of 4.92 ppm for each year irrigation was applied to nitrogen fertilized corn (Exner and Spalding, 1979).

Using conventional irrigation practices 17% to 53% of applied fertilizer is expected to leach below the rooting zone (Hubbard, 1984; Hallberg, 1986) depending on natural rainfall distribution and irrigation management scheme.

When irrigation application is analyzed in conjunction with the uncertain nature of precipitation events, then application of smaller amounts of irrigation water on a more frequent basis will reduce compound leaching more than the application of fewer, heavier irrigations (Singh and Sekhon, 1976).

Nitrogen

Nitrogen is applied to commercial potato production acreage to increase yield and quality of tubers.

Nitrogen Use. Nitrogen fertilizer is applied to virtually all of Michigan's commercial potato production acreage. A standard application would consist of 200 lbs/acre split between planting and two side-dress applications. Nitrogen may be applied as animal manure, urea, potassium nitrate, sodium nitrate, or anhydrous ammonia.

Nitrogen Value. Nitrogen fertilizers are used in potato production to increase the yield and quality of tubers. In research conducted on Superior potatoes the application of nitrogen fertilizer at 300 and 150 lbs/acre increased tu

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increased tuber yields by 39 and 27 cwt/acre respectively over an application of 75 lbs/acre nitrogen (Vitosh et al., 1980). Increased levels of nitrogen fertilization also decreases the percentage mass of B grade potatoes to total yield.

Nitrate Concern. Nitrate movement is affected by amount, timing, and formulation of applied fertilizer, as well as the frequency and magnitude of precipitation or irrigation events, and the growth status of the potato plant (McWilliams, 1984). As with irrigation, frequent applications of small amounts of nitrogen should reduce the mass of nitrogen leaching out of the root zone when compared with less frequent and large fertilizer applications.

Aldicarb

Aldicarb is a water soluble systemic and contact insecticide and nematicide used in Michigan as Temik 15G, primarily for the control of *P.penetrans* and *Leptinotarsa decemlineata* (Colorado Potato Beetle).

Aldicarb Use. Aldicarb is usually applied at planting at a rate of 3.0 lbs.a.i./acre and is distributed throughout the soil profile via water movement (Rhone Poulenc, 1988). Since 1975, approximately 25,000 acres have been treated annually with aldicarb in Michigan (Bird, 1987). Although crop rotation is a common control practice, some sites have been treated continuously for as many as eight years.

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Aldicarb Value. Typical P.penetrans infestations cause a yield reduction of approximately 16 percent. L. decemlineata at high population densities can cause yield reductions of up to 66% but losses of 5% are more common with current control practices (Noling et al., 1984). The impact of L.decemlineata on potato production was not considered as a part of this project. The value of aldicarb in potato production may be underestimated.

Aldicarb Concern. Factors affecting aldicarb movement are similar to those affecting nitrogen movement. However, only a single application of aldicarb occurs during the growing season. The risk of aldicarb movement out of the root zone may be lessened with application of aldicarb at plant emergence (Jones et al., 1986) to increase plant uptake of the compound.

Risk Management

The use of nitrogen fertilizers, aldicarb and irrigation can have a significant impact on the profitability of potato production (Vitosh et al., 1980). These potato production inputs can also pose significant threats to ground water quality (Zaki et al., 1982; Bunyan et al., 1981; Back, et al., 1984). Method of irrigation water application may have an impact on the potential for ground water contamination by impact soil water relations (McWilliams, 1984). Frequency of nitrogen applications also impacts contamination risk to ground waters. Timing of aldicarb application may also be important in the mitigation of risk to g

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The purpose of this literature review was to provide background information regarding potato production methods necessary for determination of standard grower practices and potential practices which may reduce risk to ground waters while maintaining tuber yields. Quantification of these practices is required for a comprehensive modeling system. The impacts of these alternate management systems are estimated through the use of simulation modeling.

Materials and Methods

Two alternate potato production strategies were identified. They based on information provided by the literature for the management of irrigation, nitrogen, and aldicarb. One management strategy was developed to represent standard grower practices in the Montcalm County potato production region. The second management strategy was designed to improve nitrogen, aldicarb, and irrigation application efficiency through timing of applications to directly meet plant needs.

Irrigation applications were based on weather data obtained under Thesis Objective 1. Nitrogen application methods were subjectively determined. Aldicarb application timing was also studied.

Results

The chapter objective was to determine management practices for comparison of associated risks and benefits. Results provided in this section show the treatments used for risk-ben

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for risk-benefit analysis simulation. The impact of these treatments is provided in Chapter VI.

<u>Irrigation</u>. Irrigation application amounts were decreased from one inch per application in the standard grower practice to one-half inch per application in the conservation practice. This results in a greater frequency of irrigation application in the conservation treatment but a lower total volume (Table 5).

<u>Nitrogen</u>. Application of smaller amounts of nitrogen (particularly at planting) and making more frequent applications is what distinguished the conservation from the standard grower practice. The intent of the conservation practice was to directly meet plant needs without providing excess materials which would be available for leaching.

The standard treatment was 75 lbs./acre at planting followed by 70 lbs./acre 50 days after planting, and 55 lbs./acre 70 days after planting. The conservation treatment involved application of 25 lbs./acre at planting, 25 lbs./acre 25 days after planting followed 50 lbs./acre 50 days after planting, and 25 lbs./acre 80 days after planting (Table 6). This treatment was intended to provide nitrogen to the potato plant just ahead of the growth demand for nitrogen.

<u>Aldicarb</u>. The standard aldicarb application was 3 lbs. a.i./acre applied at-planting. Aldicarb application may also be delayed until plant emergence. The intent of delayed application was to make aldicarb unavailable for

Table 5. Ir
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Standard	C
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Table 5. Irrigation dates and total number of applications for alternate management strategies.

1986		1987		1988	
Standard	Conser[1]	Standard	Conser	Standard	Conser
06/13	06/10	06/12	06/08	06/10	06/10
06/17	06/14	06/16	06/13	06/15	06/13
06/23	06/20	06/20	06/16	06/20	06/16
06/30	06/23	06/24	06/19	06/25	06/19
07/05	06/29	06/29	06/22	06/30	06/22
07/10	07/02	07/03	06/25	07/05	06/25
07/19	07/05	07/07	06/28	07/12	06/28
07/23	07/08	07/13	07/01	07/22	07/01
07/29	07/19	07/17	07/04	07/27	07/04
08/03	07/22	07/22	07/07	08/01	07/07
08/08	07/27	07/26	07/13	08/06	07/11
08/13	07/30	07/30	07/16	08/12	07/14
08/18	08/02	08/30	07/19	08/22	07/20
	08/05	09/04	07/22	08/27	07/23
	08/09	09/09	07/25	08/31	07/26
	08/12	09/14	07/28	09/09	07/29
	08/15		08/29	09/16	08/01
			09/01		08/04
			09/04		08/07
			09/07		08/11
			09/10		08/14
			09/13		08/25
					08/28
					08/31
					09/07
					09/10
					09/16
No. 13	17	16	22	16	27

1 - Conservation managment strategy

Table 6. Nitrogen management strategies for standard and conservation treatments.

Standard		Conservation	
Days after Planting	N applied	Days after Planting	N applied
0	75	0	25
.	.	25	25
50	70	50	50
70	55	80	50
Total	200		150

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leaching by increasing plant uptake. Risk associated with both at-plant and at-emergence applications of aldicarb was estimated.

Summary

The impact of the two alternate management strategies was tested using SUBSTOR simulation modeling. The procedures and formats used are provided in Chapter VII.

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CHAPTER IV

ALDICARB MOVEMENT AND DEGRADATION MODEL

As part of Thesis Objective 3, computer routines simulating aldicarb movement and degradation to oxidative metabolites in the soil environment were developed and integrated with SUBSTOR water movement routines. Factors considered in model development were: binding to soils, volatilization from the soil surface, systemic uptake, aldicarb and oxidation products degradation rates.

Literature Review

The literature review was developed to provide the base of information necessary for the development of an aldicarb and metabolite movement and degradation model. Information is categorized based on modeling concerns of soil binding, volatilization, systemic uptake, degradation.

Soil Binding. Compound binding with soil organic matter or soil clays may retard movement with soil water. Aldicarb and degradation products only weakly partition into soil organic matter as demonstrated by Bromilow and Leistra, (1980) p.372 (Table 7).

Table 7. Aldicarb and metabolite soil adsorption coefficients.

		Adsorption Coefficients ($\times 10^6$) $k_{s/l}$ (m^3kg^{-1})		
Soil	OM%	Aldicarb	A-sulfoxide	A-sulfone
Sandy Loam	1.35	64	0	8
Sandy Loam	5.92	550	160	185

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Smelt et al., (1983), summarized materials pertaining to aldicarb and metabolite binding to soil in soil columns, lysimeters, and arable fields. They concluded that in the presence of water flux aldicarb and its degradation products are available for movement between soil layers.

Aldicarb and degradation products do not significantly bind with clay minerals in the soil. In montmorillonite clays aldicarb is excluded from the first layers of water adsorbed on external surfaces (Supak et al., 1978).

Volatilization. Aldicarb and its metabolites are also translocated upward by capillary action. Significant mass losses can be expected through volatilization from the soil surface (Maitlen and Powell, 1982). In-furrow application of aldicarb reduces volatilization.

Systemic Uptake. In the soil aldicarb exhibits both systemic and contact pesticidal activity. No articles were retrieved which dealt with aldicarb exclusion or active uptake by plant roots.

Degradation Rate. The degradation of aldicarb begins with its oxidation to aldicarb-sulfoxide. Aldicarb sulfoxide is then oxidized to aldicarb sulfone and hydrolysis products. Aldicarb sulfone is then degraded to other hydrolysis products. Aldicarb and its oxidation products are active pesticides whereas the hydrolysis products are relatively non-toxic (Leistra et al., 1984).

Degradation rates follow first-order conditions (Li-Tse Ou et al., 1985) and are highly variable (Table 8).

Table 8. Deg
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3 - ALDICAR
4 - CITATIO

Table 8. Degradation constants for aldicarb, aldicarb-sulfoxide, and aldicarb-sulfone.

Soil Texture	Temp C°	pH	OM	Deg. Const. k 1/days Aldic[1]	A-sox[2]	A-son[3]	Cit.[4]
SAND	20	6.4	3.7	0.300	0.010	0.230	a
LOAMY SAND	20	6.9	3.8	0.460	0.010	0.230	a
LOAM	20	7.1	9.7	0.240	0.007	0.100	a
SANDY LOAM	5	7.0	1.4	0.300	0.015	0.012	b
SANDY LOAM	10	7.0	1.4	0.440	0.033	0.020	b
SANDY LOAM	15	7.0	1.4	0.210	0.034	0.013	b
SANDY LOAM	15	7.0	1.4	0.800	0.035	0.021	b
SANDY LOAM	15	7.0	1.4	0.800	0.025	0.016	b
PEATY SANDY LOAM	5	6.3	5.9	0.200	0.011	0.005	b
PEATY SANDY LOAM	10	6.3	5.9	0.270	0.030	0.010	b
PEATY SANDY LOAM	15	6.3	5.9	0.140	0.013	0.005	b
PEATY SANDY LOAM	15	6.3	5.9	0.460	0.031	0.012	b
PEATY SANDY LOAM	15	6.3	5.9	0.550	0.031	0.015	b
SAND	23	7.2	0.2	.	.	0.020	c
SAND	23	7.2	0.2	.	.	0.017	c
SAND	23	6.7	1.0	.	.	0.011	c
SAND	23	6.7	1.0	.	.	0.013	c
SAND	23	6.7	1.0	.	.	0.016	c
SAND	10	7.9	0.8	.	0.008	0.008	d
LOAMY FINE SAND	10	8.0	1.2	.	0.004	0.006	d
FINE SAND	10	5.0	0.4	.	0.002	0.001	d
MEAN				0.419	0.019	0.037	

1 - ALDICARB (KP)
2 - ALDICARB SULFOXIDE (KA)
3 - ALDICARB SULFONE (KB)
4 - CITATION CODE

a = Leistra et al., 1984
b = Bromilow et al.,1980
c = Li-Tse Ou et al.,1985b
d = Smelt et al.,1983

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7.0 - 7.9
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3.0 - 5.9
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Aldicarb degradation rate is not significantly affected by typical soil pH ranges (Chapman and Cole, 1982). There does not seem to be any clearly discernable relationship between degradation rates and soil type, pH, organic matter content or soil temperature (Table 9).

Table 9. Mean degradation rate for aldicarb, aldicarb-sulfoxide and aldicarb-sulfone by soil physical and chemical parameters.

	Degradation Constant k 1/days		
Parameter	Aldicarb	A-sulfoxide	A-sulfone
Texture			
Sand	0.300	0.007	0.040
Loamy Sand	0.460	0.007	0.118
Sandy Loam	0.442	0.026	0.013
Loam	0.240	0.007	0.100
pH			
5.0 - 5.9	.	0.002	0.001
6.0 - 6.9	0.320	0.021	0.035
7.0 - 7.9	0.460	0.022	0.025
8.0 - 8.9	.	0.004	0.006
% Om			
0.0 - 2.9	0.510	0.019	0.013
3.0 - 5.9	0.340	0.019	0.072
6.0 - 9.0	0.240	0.007	0.100
Temp C°			
5	0.250	0.013	0.008
10	0.350	0.015	0.009
15	0.490	0.028	0.013
20	0.330	0.009	0.186
23	.	.	0.015

Implications of the Literature

The degree of aldicarb and metabolite binding to soil organic matter and clay minerals is small. Pesticide mass can be expected to be lost through volatilization. There is a great deal of variability associated with reported values of aldicarb and metabolite degradation rates. Variability in degradat

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in degradation rates reported is not easily explained by soil texture, pH, organic matter, or temperature.

The expected impact on movement and degradation of aldicarb binding to soil organic matter or clay minerals is small in comparison to the uncertainty associated with degradation rates.

Materials and Methods

Aldicarb degradation and movement routines were developed using Microsoft FORTRAN v.4.0. A structured approach was used to maintain program readability. INCLUDE files were used in place of subroutine common blocks for data transfer between subroutines. Each INCLUDE file contains a data dictionary, variable initialization, and common blocks.

Assumptions. Several operational assumptions were made based on the information provided in the scientific literature. The attenuation of aldicarb movement due to its interaction with the soil organic matter or clay materials was considered to be negligible. Pesticide movement was assumed to be a function of soil water movement. A mixing coefficient was used to represent differential mass flow due to active and non-active soil pores. Quantitative information on the loss of aldicarb and metabolites through volatilization was not available. The volatilization of aldicarb mass was assumed to be zero. Plant uptake of aldicarb is assumed to be proportional to root water uptake with no active uptake and no exclusion. Aldicarb degradation

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degradation follows first-order kinetics. The mass of aldicarb, aldicarb-sulfoxide, and aldicarb-sulfone are the variables of concern with all other degradation products assumed non-toxic. Aldicarb and metabolite degradation rates are not affected by soil organic matter, pH, organic matter content, or temperature.

Computer Code Development

SUBSTOR operates on a daily time step and uses readily available weather, soil, and potato variety inputs. Nine subroutines simulating aldicarb movement and degradation were developed and linked with SUBSTOR.

Existing Routines

The majority of SUBSTOR routines were adapted from the CERES corn model. A brief statement regarding each routine's function is provided (Table 10). Additional information on routines not developed as part of this research is available in CERES - Maize: A simulation model of maize growth and development (Jones and Kiniry, 1986) or SUBSTOR Model Documentation (Swartz, 1987).

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```
MAIN
     -IPEXP
     -IPPEN#
  -IPALD*
  -IPTRT
       -IPSOIL
       -IPVAR
       -IPNIT
       -IDWTH
       -OPECO
  -IPWTH
  -PROGRI
       -OPSEAS
  -SOILRI
  -SOILNI
       -SOILT
  -CALDAT
  -PTRANS*
  -NTRANS
  -WATBAL
       -NFLUX
       -PFLUX*
       -PFLOW*
       -NFLUX
       -SYSTEMIC*
  -PHENOL
       -CALDAT
       -PHASEI
  -GROSUB
       -NUPTAKE
  -NWRITE
  -XWRITE
  -PSTDAY*
       -TTOUT*
       -SOILPST*
       -OUTPLCH*

  -PPIMPACT#
       -OUTYLD#
       -SUMOUT#
```

* sub-routine developed under Thesis Objective 3
\# sub-routine developed under Thesis Objective 4

Figure 8. Simplified SUBSTOR Flow Diagram.

Table 10. S

Subroutine
IPEXP
IPPEN
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IPTRT
IPSOIL
IPVAR
IPNIT
IDWTH
OPECO
IPWTH
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OPSEAS
SOILNI
SOILT
CALDAT
PTRANS
NTRANS
WATBAL
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PFLUX
PFLOW
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GROSUB
NUPTAKE
NWRITE
XWRITE
PSTDAY
TTOUT
SUMOUT

Table 10. SUBSTOR program routines and primary functions.

Subroutine	Primary Functions
IPEXP	Initialization of experiment to be simulated
IPPEN	Initialize aldicarb/P.penetrans yield impact routines
IPALD	Initialize aldicarb movement and degradation routines
IPTRT	Called if run time option to modify experiment variables is selected
IPSOIL	Modify soils
IPVAR	Modify potato variety
IPNIT	Modify fertilizer applications
IDWTH	Modify weather data used
OPECO	Writes new experimental parameters to screen
IPWTH	Initialize weather data
PROGRI	Starts simulation loop
OPSEAS	Generates output headings and initialize counters
SOILNI	Determine nitrogen contribution of stem and roots
SOILT	Calculates soil temperature
CALDAT	Converts day of the year to calendar date
PTRANS	Applies aldicarb to appropriate soil layer on application date. Calculates aldicarb and metabolite degradation
NTRANS	Distributes fertilizer on appropriate days. Calculates nitrification and denitrification
WATBAL	Determines runoff and infiltration of rainfall Determines movement of water with saturated flow Determines water movement with unsaturated flux Determines evapotranspiration Determines root growth, depth, and water uptake
NFLUX	Move nitrogen with soil water
PFLUX	Move aldicarb and degradation products with unsaturated flux as determined by WATBAL
PFLOW	Move aldicarb and degradation products with saturated flow as determined by WATBAL
SYSTEMIC	Determine plant uptake of aldicarb and degradation products as determined by WATBAL
PHENOL	Calculates thermal time
PHASEI	Determines plant growth stages
GROSUB	Partitions Photosynthates
NUPTAKE	Determines nitrogen available and nitrogen desired
NWRITE	Determines if nitrogen output files are to be written
XWRITE	Calculates cumulative environmental parameters
PSTDAY	Calls nitrate and aldicarb daily output routines Resets aldicarb mass matrix for next days degradation
TTOUT	Writes output files for aldicarb total toxic metabolites
SUMOUT	Writes summary output file for yield and leaching

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APDATE
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CUMLEACH(
CUMPUP(3)
TLEACH
TPUP
PSTDOWN(3
PSTUP(3,1
APLAYR
PSTLCH(4)
PLANTUP(4

Newly Developed Routines

The following routines were developed under Thesis Objective 3. Routines are presented in the order in which they are called by the SUBSTOR program.

Include File

ALDIC.INC contains variables used in aldicarb movement and metabolism routines.

DATA DICTIONARY

Variable	Description
PSTMASS(P,T,L)	IS A THREE DIMENSIONAL ARRAY HOLDING INFORMATION ON PESTICIDE MASS BY SOIL LAYER.
P	RANGES FROM 1 TO 4 STANDING FOR ALDICARB, ALDICARB SULFOXIDE, ALDICARB SULFONE, AND PESTICIDE DEGRADED TO NON-TOXIC METABOLITES MASS RESPECTIVELY (kg/ha).
T	RANGES FROM 0 TO 1 WITH 0 STANDING FOR PRESENT DAY, AND 1 STANDING FOR PREVIOUS DAY.
L	RANGES FROM 1 TO NLAYR AND REPRESENTS INDIVIDUAL SOIL LAYERS.
JDATE	DAY OF THE YEAR
ALDRATE	RATE OF ALDICARB APPLICATION:(kg/ha) ACTIVE INGREDIENT
KP,KA,KB	DEGRADATION CONSTANTS OF ALDICARB, A-SULFOXIDE, A-SULFONE
CTP,CTA,CTB	COEFFICIENT OF TRANSFORMATION FOR OXIDATIVE DEGRADATION 1=COMPLETE 0=NONE
APDEPTH	DEPTH OF ALDICARB APPLICATION IN CENTIMETERS
PSTCOST	COST OF ALDICARB APPLICATION $/AC
APDATE	DATE OF ALDICARB APPLICATION
TRTVAL	PESTICIDE VALUES BASED ON AT PLANTING APPLICATION
CUMLEACH(3)	CUMULATIVE LEACHING OF PESTICIDE
CUMPUP(3)	CUMULATIVE PLANT UPTAKE OF PESTICIDE
TLEACH	TOTAL MASS LEACHED FROM BOTTOM SOIL LAYER
TPUP	TOTAL MASS TAKEN UP BY THE PLANT
PSTDOWN(3,10)	MASS OF PESTICIDE IN GRAMS MOVED TO LOWER SOIL LAYER
PSTUP(3,10)	MASS OF PESTICIDE IN GRAMS WICKED TO UPPER SOIL LAYER
APLAYR	DEPTH INDICATOR USED FOR PLACEMENT OF ALDICARB IN PROPER SOIL LAYER
PSTLCH(4)	DAILY LEACHING OF PESTICIDE OUT OF PROFILE
PLANTUP(4,10)	DAILY PLANT UPTAKE OF PESTICIDE FROM EACH SOIL LAYER

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ALDFILE
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+CUMLEACH(

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```

IPPST

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```
    OPEN
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```

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31	UNIT NUMBER FOR TOTAL TOXIC OUTPUT FILE
32	UNIT NUMBER FOR SOIL PESTICIDE OUTPUT FILE
33	UNIT NUMBER FOR LEACHING OUTPUT FILE
34	UNIT NUMBER FOR ALDICARB PARAMETER FILE
39	UNIT NUMBER FOR SUMMARY OUTPUT FILE
ALDFILE	NAME OF ALDICARB INPUT PARAMETER FILE
SUMOUT	OUTPUT FILE NAME FOR SUMMARY DATA
ALDFLAG	FLAG INDICATING IF ALDICARB DEGRADATION ROUTINES ARE TO BE USED 1 = YES
TOXOUT	OUTPUT FILE NAME FOR TOTAL TOXIC MASS
SPSTOUT	OUTPUT FILE NAME FOR SOIL PESTICIDE RESIDUE
LCHOUT	OUTPUT FILE NAME FOR LEACHATE SUMMARY

```
 REAL ALDRATE,KP,KA,KB,CTP,CTA,CTB,APDEPTH,PSTCOST,
+CPSTLCH(4),CUMPUP(4),PSTDOWN(4,10),
+PSTUP(4,10), APLAYR, PSTMASS(4,2,10), PSTLCH(4),
+CUMLEACH(4), PLANTUP(4,10), TLEACH,TPUP

 INTEGER OUT31,OUT32,OUT33,OUT37,OUT39,INAL34,APDATE

 CHARACTER SUMOUT*11,ALDFLAG*1,TOXOUT*11,SPSTOUT*11,
+LCHOUT*11

 COMMON /ALDIC/ALDRATE,KP,KA,KB,CTP,CTA,CTB,APDEPTH,
+PSTCOST,CPSTLCH,CUMPUP,PSTDOWN,PSTUP,APLAYR,
+PSTMASS,PSTLCH,PLANTUP,TLEACH,TPUP,
+OUT30,OUT31,OUT32,OUT33,OUT37,OUT39,INAL34,APDATE,
+SUMOUT,ALDFLAG,TOXOUT,SPSTOUT,LCHOUT
```

IPPST

IPPST is called from the MAIN program and reads the aldicarb parameter file 34. File 34 "ALDFILE.PAR" is free format. Parameter variable units are provided in the include file, ALDIC.INC. Parameter variables include ALDRATE, APDEPTH, PSTCOST, APDATE, KP, KA, KB, CTP, CTA, CTB.

```
     OPEN(34,FILE='ALDFILE.PAR',STATUS='OLD')
     READ(34,*)ALDRATE,APDEPTH,PSTCOST,APDATE,
     KP,KA,KB,CTA,CTB
```

Next the summary output file is named and opened.

```
       WRITE(*,320)
 320   FORMAT(5X,'ENTER NAME OF SUMMARY OUTPUT FILE')
       READ(*,'(A)')SUMOUT
       OPEN(OUT39,FILE=SUMOUT,STATUS='NEW')
```

Program execution returns to MAIN.

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PTRANS

Subroutine PTRANS is used to simulate application and degradation of aldicarb and metabolites. If the simulation date is previous to the pesticide application date APDATE, then the subroutine returns to MAIN. If the simulation date equals APDATE, then aldicarb is applied to the appropriate soil layer as defined by APDEPTH and soil layer depths from SUBSTOR. If the simulation date is after the aldicarb application date then the program executes aldicarb degradation routines.

```
IF (JDATE.LT.APDATE) THEN
   RETURN
ELSEIF (JDATE .EQ.APDATE) THEN
   GOTO 100
ELSE
   GOTO 200
ENDIF
```

The amount of water required to dissolve a standard application of aldicarb is 227.27 Kg corresponding to 0.0056 cm of soil water. The assumption was made that a greater amount exists in the application layer.

```
100   DO 110 L=1,NLAYR
      APLAYR = APLAYR + DLAYR(L)
      IF (APDEPTH .GT. APLAYR) GOTO 110
      PSTMASS (1,1,L) = ALDRATE
      RETURN
110   CONTINUE
```

Aldicarb and metabolite masses are held in a three dimensional array called PSTMASS(P,T,L). The index P ranges from 1 to 4 representing aldicarb mass aldicarb sulfoxide, aldicarb sulfone and mass degraded to non-toxic metabolites. The index T ranges from 1 to 2 with 1 representing today's mass and 2 representing yesterday's mass. Values of L range from 1 to

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from 1 to 10 representing up to 10 soil layers. Array units are in kilograms per hectare. Daily mass changes are tracked using the following algorithm based on first-order kinetics.

```
PSTMASS(1,1,L) = PSTMASS(1,2,L)*EXP(-KP)[1]
PSTMASS(2,1,L) = PSTMASS(1,2,L)*(1-EXP(-KP))[2]
           +PSTMASS(2,2,L)*EXP(-KA)[3]
PSTMASS(3,1,L) = CTA*PSTMASS(2,2,L)*(1.0-EXP(-KA))[4]
           +PSTMASS(3,2,L)*EXP(-KB)[5]
PSTMASS(4,1,L) = PSTMASS(4,2,L)[6]
          +(1.0-CTA)*PSTMASS(2,2,L)*(1.0-EXP(-KA))[7]
          +PSTMASS(3,2,L)*(1.0-EXP(-KB))[8]
```

1 First-order degradation of aldicarb mass
2 Add mass of aldicarb degraded to A-sulfoxide mass
3 First-order degradation of A-sulfoxide mass
4 Add mass of A-sulfoxide degraded by oxidation to A-sulfone
5 First-order degradation of A-sulfone mass
6 Yesterdays' cumulative mass degraded to non-toxic products
7 Add mass of A-sulfoxide degraded by hydrolysis to non-toxic products
8 Add mass of A-sulfone degraded by hydrolysis to non-toxic products

These calculations are performed for each layer in the soil being simulated. The one-day time lag is used so that aldicarb mass degraded to aldicarb sulfoxide on a given day is not available for metabolism to aldicarb sulfone until the next day etc.. The values of KP, KA, and KB are the first-order degradation coefficients for the parent compound (aldicarb), the first metabolite (aldicarb sulfoxide) and the second metabolite (aldicarb sulfone) respectively. A coefficient of transformation (CTA) is used to separate the mass of aldicarb sulfoxide degraded by oxidation from mass degraded by hydrolysis. The mean values for degradation rate constants reported in Table 9 were used.

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PFLUX is called from WATBAL and is used to simulate the movement of aldicarb and metabolites between soil layers with saturated flux. The value of DRAIN is converted from millimeters to centimeters. DRAIN indicates the volume of water flowing out of the lowest layer of the soil profile. Pesticide mass moved to a lower layer is assumed to be proportional to the water flow out of that layer divided by the total water content of that layer. A proportionality constant of 0.65 was used to represent differential mass movement due to in-layer water mixing. This in-layer mixing is due to soil pore size variability.

```
DO 40 P=1,4 (for each pesticide mass)
 DO 30 L=1,NLAYR (for each layer)
  IF (L.LT.NLAYR) THEN
     PSTDOWN(P,L)[1]=0.65*PSTMASS(P,1,L)[2]*FLUX(L)[3]/
          (SW(L)*DLAYR(L)+FLUX(L)[4])
     PSTMASS(P,1,L)=PSTMASS(P,1,L)-PSTDOWN(P,L)[5]
     PSTMASS(P,1,L+1)=PSTMASS(P,1,L+1)
          +PSTDOWN(P,L)[6]
  ELSE (bottom layer)
     PSTDOWN(P,L)= 0.65*PSTMASS(P,1,L)*DRAIN[7]
      /(SW(L)*DLAYR(L)+DRAIN)
     PSTMASS(P,1,L)=PSTMASS(P,1,L)-PSTDOWN(P,L)
     CPSTLCH(P)[8]=CPSTLCH(P)+PSTDOWN(P,L)
  ENDIF
30 CONTINUE
40 CONTINUE
```

1 Pesticide mass moving out of soil layer L
2 Pesticide mass in soil layer L before movement
3 Soil water moving out of soil layer L
4 Total water previously in soil layer
5 Subtract mass moved out of layer L from layer L
6 Add mass moved out of layer L to layer below
7 Soil water leaching out of profile
8 Update cumulative pesticide leaching

After execution of this routine the program returns to WATBAL where movement with unsaturated flow is determined.

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PFLOW

PFLOW is called from WATBAL after the evaporation of water from the surface soil layer and redistribution of water between unsaturated soil layers has been determined. The value of FLOW represents the direction of water movement between layers. If flow is positive then flow by capillary action from a lower level to the next higher levels occurs. If FLOW is negative then water moves from the higher level to the lower level.

```
DO 60 P=1,4 (for each pesticide mass)
DO 50 L=1,K (for soil layers 1 - (nlayr-1))
IF (FLOW(L).GT.0.0) THEN (upward movement)
    PSTUP(P,L)=0.65*PSTMASS(P,1,L+1)¹*FLOW(L)/
     (SW(L+1)*DLAYR(L+1)+FLOW(L)²)
     PSTMASS(P,1,L)=PSTMASS(P,1,L)+PSTUP(P,L)³
     PSTMASS(P,1,L+1)=PSTMASS(P,1,L+1)-PSTUP(P,L)⁴
ELSE (downward movement)
    PSTDOWN(P,L)=-0.65*PSTMASS(P,1,L)⁵*(FLOW(L)/
          (SW(L)*DLAYR(L)+FLOW(L)⁶)
     PSTMASS(P,1,L)=PSTMASS(P,1,L)-PSTDOWN(P,L)⁷
     PSTMASS(P,1,L+1)=PSTMASS(P,1,L+1)+ PSTDOWN(P,L)⁸
ENDIF
50   CONTINUE
60   CONTINUE
```

1 Pesticide mass in lower layer (movement up)
2 Proportion of water movement out of layer to higher layer modified by 0.65 assumed mixing factor
3 Add pesticide mass moved from lower layer to higher layer
4 Subtract pesticide mass moved from lower layer from the mass in the lower layer
5 Pesticide mass in layer (movement down)
6 Proportion of water moved out of layer to lower layer
7 Subtract pesticide mass from upper layer
8 Add pesticide mass to lower layer

The value for FLOW in layer one is always 0.0. This subroutine returns to WATBAL where plant uptake of soil water is determined.

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SYSTEMIC

Subroutine SYSTEMIC is called from WATBAL after root uptake of water has been estimated. Movement of pesticide mass is assumed to be proportional to water taken in by the roots.

```
DO 80 P=1,4 (for each pesticide mass)
DO 70 L=1,NLAYR (for each soil layer)
   PLANTUP(P,L)1=PSTMASS(P,1,L)*(RWU(L)
   /DLAYR(L))2/(SW(L)*DLAYR(L))3
   CUMPUP(P)=CUMPUP(P)+PLANTUP(P,L)4
   PSTMASS(P,1,L)=PSTMASS(P,1,L)-PLANTUP(P,L)5
70 CONTINUE
80 CONTINUE
```

1 Plant pesticide uptake from layer
2 Root water uptake from layer
3 Total soil water in layer
4 Update cumulative plant uptake
5 Subtract pesticide mass taken up by roots from soil layer

Program execution returns to WATBAL.

PSTDAY

PSTDAY is called by the MAIN program at the end of the simulation day. PSTDAY calls daily pesticide output files (TTOUT, SOILPST, and OUTPLCH) prior to updating the pesticide mass matrix. Today's mass value T = 1 is shifted to the T = 2 position.

```
DO 100, T=2,1,-1 (for time index 2 to 1)
  DO 75, P=1,4  (for each pesticide)
    DO 50, L=1,NLAYR (for each soil layer)
      C=T
    IF(C.GT.1)THEN
      PSTMASS(P,T,L)=PSTMASS(P,T-1,L)1
    ELSE
      PSTMASS(P,T,L)=-99.92
    ENDIF
 50    CONTINUE
 75   CONTINUE
 100 CONTINUE
```

1 Set the matrix value at T=2 equal to the matrix value at T=1

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DO 3
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```

2 Set the matrix value at T=1 equal to -99.9 to facilitate error checking

Execution returns to the MAIN program.

TTOUT

TTOUT is called from PSTDAY and is used to write information on total toxic residues remaining in the soil, taken up by the plant plant, and leached out of the lowest layer of the soil profile to output file 31. Total toxic mass is calculated as the mass sum of aldicarb, A-sulfoxide, and A-sulfone. It is calculated using:

```
DO 20 P=1,3 (for aldicarb, A-sulfoxide, A-sulfone)
DO 10 L=1,NLAYR (for each soil layer)
   TTSOIL(L)=TTSOIL(L)+PSTMASS(P,1,L)
10 CONTINUE
20 CONTINUE
```

Total pesticide mass degraded in the soil is determined:

```
DO 25 L=1,NLAYR (for each soil layer)
   DEGSOIL=DEGSOIL+PSTMASS(4,1,L)
25 CONTINUE
```

Total toxic mass taken up by the plant, and leached is calculated using:

```
DO 30 P=1,3 (Sum mass for total toxic residue)
   TTPUP=TTPUP+CUMPUP(P)
   TTLCH=TTLCH+CPSTLCH(P)
30 CONTINUE
```

Calculate total degraded mass in plant, leached, and remaining in soil:

```
TDEGMASS=CUMPUP(4)+CPSTLCH(4)+DEGSOIL
```

Check for mass balance:

```
DO 40 L=1,NLAYR
    CHECK=CHECK+TTSOIL(L)[1]
40  CONTINUE
```

1 Sum total toxic mass in each soil layer

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CHECK=CHECK+TTPUP+TTLCH+TDEGMASS

Add mass in other pools. CHECK equals the application rate.

If simulation date equals application date then the total toxic output file is opened and header information is written. If simulation date is greater than application date then date, cumulative (rainfall, irrigation, precipitation, total toxic leached, nitrate leached), total toxic in up to five soil layers, and cumulative (plant uptake, degraded mass) are written to the output file. The routine returns to PSTDAY.

SOILPST

SOILPST is called from PSTDAY and writes daily soil pesticide mass information for aldicarb and metabolites. If simulation date equals application date then output file 32 is opened and header information is written to that file. If the simulation date is greater than the application date then the pesticide mass in each soil layer is written along with the soil water content in that layer. Program operation returns to PSTDAY.

OUTPLCH

OUTPLCH is called from PSTDAY and writes cumulative pesticide parameters to output file 33. If simulation date equals application date then output file 33 is opened and header information is written to that file. If the simulation date is greater than the application date then date, cumulative precipitation and water drainage variables are written to file 33 as well as cumulative nitrate, aldicarb,

non-toxic.

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aldicarb, A-sulfoxide, A-sulfone, and total mass degraded to non-toxic. Return to PSTDAY.

Summary

New FORTRAN routines were developed and linked with existing SUBSTOR routines. If variables obtained from pre-existing SUBSTOR routines were modified within these routines, they were reinitialized before exiting the routine. This insured that the execution of the original code was unchanged.

The modifications described here resulted in a expansion of SUBSTOR's capabilities to include estimation of aldicarb and metabolite movement and degradation. This allowed for the estimation of how irrigation scheduling and aldicarb application timing affect the movement of aldicarb and metabolites through the soil profile.

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CHAPTER V

ALDICARB / ROOT-LESION NEMATODE YIELD IMPACT MODEL

The impact of aldicarb and Pratylenchus penetrans (Root-lesion nematode) on Solanum tuberosum (potato) tuber yield was studied from the perspective of an integrative research review and meta-analysis (Thesis Objective 4).

During the past 15 years, the Michigan State University (MSU) Nematology Program has conducted research at the MSU Montcalm Potato Research Station. The research results have been published in graduate student theses, MSU research reports and professional journals. The current research contribution uses previously and un-published published research findings as a base for extended analysis.

Use of previous research findings is frequently constrained by the isolation of each study to its particular research objectives. Most agricultural research results are restricted in that they provide information only for one or a limited number of crop growing seasons with specific pest pressures and distributions of temperature and rainfall. This may result in limited generalizability of research results. Integrated research review and meta-analysis procedures, however, can be used to generalize research results.

Integrated Research Review

A distinct difference exists between classic research reviews and integrated research reviews. In a classic research

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research review, the reviewer makes cognitive inferences from available literature. In an integrative research review, the researcher uses the rigor and power of quantitative methodologies to describe the available literature. This alternate approach resembles changes which have occurred in primary information collection since the time of Galileo (Drake, 1981). Researchers have progressed from writing about observable phenomenon (cognitive inference) to using replicated experimental units for statistical testing of hypothesis (quantitative methodology). Integrative reviews use similar methodologies to those of today's primary researchers.

The following are the five stages of an integrative research review: 1) objective definition, 2) data collection, 3) data evaluation, 4) meta-analysis, and 5) presentation of results (Cooper, 1984).

Objective Definition

The objective definition stage determines the scope of the project by defining research boundaries. Methodologies for reviewing and analyzing data are objective dependant; therefore, it is imperative for objectives to be precise.

Data Collection

The data collection stage describes the methods used for information retrieval from the scientific literature or specific data bases. It also serves as an indicator of research bias and describes where data how were obtained. An integrated research review summarizing information from one speci

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one specific scientific journal has a value different from an integrated research review which summarizes many sources of scientific information.

Data Evaluation

Each specific study used in an integrated research review may not contain all the information required to meet research objectives and is a potential source of research bias. The data evaluation section identifies biases in collected variables and potential problems with using study results in meta-analysis It also describes procedures used to handle missing values.

Presentation

Presentation of research results is the final stage of an integrated research review. The value of an integrated research review can be measured in the amount of past work it summarizes and the degree to which the study clarifies future research needs (Cooper, 1984).

The five stages of an integrated research review were used for the analysis of thirty-four studies, and provided a framework for synthesis of results. Data collected in the integrated research review provide a measure of variability in available published research results.

Meta-analysis

Meta-analysis is defined as research on research. This requires an integrative research review and subjects research results to further quantitative analysis. Meta-analysis uses information from the integrative research

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review to meet specific research objectives. Meta-analysis, because it integrates findings across studies, can provide a global picture of research results.

The prefix "meta" is defined as a change in position or form, altered, transposed; or going beyond, higher, transcending (Webster, 1979). The term "meta-analysis" means a change in research position to a level above primary data collection; or research on research. Going beyond or higher does not indicate better, it indicates a change of position, a stepping out of a discipline's plane of reference in order to objectively analyze the goals, current position and objectives of the subject.

Meta-analysis may or may not be part of an integrated research review. If the objectives of the integrated research review can be met with in the scope of the original studies then this stage is more appropriately termed analysis. If the integrated research review has objectives which go beyond the original research objectives, then the term meta-analysis can be used to describe the analysis procedure. The term meta-analysis is also used to indicate that published study results are being analyzed, not the phenomenon for which the original studies were designed.

Objective Definition

Five, meta-analysis objectives were developed because of the need to define the current state of the scientific literature, and where possible, develop a hierarchial series of models which could be used to simulate the impact of

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aldicarb and P.penetrans on potato production. The scope of this integrative research review (IRR) and meta-analysis covers research pertaining to potato production with aldicarb used to control P.penetrans. The following five objectives were used to describe the information base and categorize 14 meta-analysis methods.

Objective I) Describe the variability in research results showing the impact of aldicarb application and P.penetrans on potato production
- Analysis 1) Descriptive Statistics
- Analysis 2) ANOVA

Objective II) Determine the impact of aldicarb on potato yield
- Analysis 3) Average Yield loss [1]
- Analysis 4) Cumulative Probability Distribution
- Analysis 5) Preseason Model
- Analysis 6) Postseason Model

Objective III) Determine the impact of aldicarb on P.penetrans population dynamics
- Analysis 7) Regression Model
- Analysis 8) Distributed Delay Model

Objective IV) Determine the impact P.penetrans population dynamics on potato variety tuber yield
- Analysis 9) Class Correlation
- Analysis 10) Class Regression Model

Objective V) Determine the impact of aldicarb on potato plant development
- Analysis 11) Correlation
- Analysis 12) Regression Delta Plant Growth
- Analysis 13) Regression Percentage Plant Growth
- Analysis 14) Regression Plant Partitioning

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[1] Aldicarb application is the current normal practice the Michigan potato production. In this thesis,"Yield Loss" is defined as potential tuber yield loss associated with not applying aldicarb

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Model Hierarchy

The hierarchy of models used in the research contains five levels: average yield loss, cumulative probability distribution, regression prediction, population linked with yield loss, and population linked with plant development parameters. Each level represents an increase in complexity and the degree to which the dynamics of the system are evaluated. The quality of data needed to support each model also increases.

Materials and Methods

The Materials and Methods section is divided into two parts. The first describes procedures used in the integrated research review. The second describes general procedures used in the meta-analysis. Methods for specific analyses are organized by meta-analysis objective and provided with analysis results.

Integrated Research Review

Seven procedures were used for the integrated research review, literature search procedure, selection criteria, variable description, research bias, data bias, data availability, missing value, and estimator test.Data

Literature Search Procedure

The Michigan State University (MSU) Montcalm Potato Research Farm Annual Report provided the majority of the information presented in this study. To augment this information source, a computer-aided search of information published in scientific journals was conducted. CAIN, CAB, BIOZ, and

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BIOZ, and CABA data bases where searched using off-line facilities at the MSU Library. The key word search conditions were: (Pratylenchus penetrans, or root-lesion nematode, and Solanum tuberosum, or Potato). Citations and abstracts were retrieved and searched for studies in which aldicarb was used as a control measure for P.penetrans in potato production. Theses and dissertations at the MSU library were also searched. These papers were then located and copied for potential inclusion in the P.penetrans data base (PPDB) developed as a part of the research review.

Literature Selection Criteria

The criteria for inclusion of a paper in the PPDB, were that a paper had to be a field study, use aldicarb in conjunction with a non-treated control, report tuber yield measurements, and have information on P.penetrans populations. A minimum of three studies were needed for inclusion of a specific potato variety. Papers not meeting these criteria were not included in the integrated review. Twenty-three out of fifty-seven papers retrieved were excluded from the analysis (Table 11).

Variable Description

The information contained in studies which met the inclusion criteria was coded into the PPDB using LOTUS 123 as a spreadsheet. The spreadsheet was divided into the following four: sections pre-plant measures, yield measures, agronomic measures, and growing season measures.

Table 11

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Table 11. Research not included in the literature review.

REFERENCE	Reason for Non-Inclusion			
	MICRO TILE	GREEN HOUSE	NO ALD	OTHER
Bernard and laughlin,1976	.	.	.	NO NEMA DATA
Biehn et al., 1971	.	.	X	.
Bird,1986	.	.	.	NO CHECK
Brown et al., 1980	X	.	.	.
Burpee and Bloom,1978	.	X	.	.
Dickerson et al., 1964	.	.		SURVEY
Dunn, 1972	.	.	X	.
Francel et al.,1987	.	X	.	.
Hawkins and Miller,1971a	.	.		SINGLE STUDY
Hawkins and Miller,1971b	.	.	X	.
Kable and Mai, 1968	.	X	.	.
Kimpinski,1979	.	.	.	NO YIELD
Kimpinski,1982	.	.	.	AVERAGED
Kotcon et al.,1985	X	.	.	.
Kotcon and Loria, 1986	.	X	.	.
Martin et al.,1982	X	.	.	.
Olthof,1983	X	.	.	.
Olthof,1985	X	.	.	.
Olthof,1986	X	.	.	.
Oostenbrink,1958	.		X	.
Patterson and Bergeson, 1967	.	X	.	.
Riedel et al., 1985	X	.	.	.
Rowe et al., 1985	X	.	.	.
Wong and Ferris,1968	.	X	.	.

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Pre-plant Measures. The pre-plant measures section included four variables: 1) the year the study was conducted, 2) date of pre-plant sampling, 3) degree days (base 10) accumulated by planting date, and 4) initial nematode population density /100 cm^3 soil for aldicarb treated and non-treated plots (Appendix B, Table 1).

Yield Measures. The yield section included eleven variables: 1) harvest date, and 2-9) tuber yield by size category (B, A, J, total yield) for both check and aldicarb treatment, 10-11) knobby yield is reported for Russet Burbank[2]. Yields are reported in hundred-weight per acre (Appendix B,Table 2).

Agronomic Measures. The agronomic section included information on N,P,K fertilizer use, rotation crops, potato cultivar, study location, and a code for citations (Appendix B,Table 3).

Growing Season Measures. The growing season section included five variables: 1) date of nematode samples, 2) the degree days (base 10) accumulated at the day of sampling, 3) the number of nematodes in 100 cm^3 soil, 4) the nematode population in 1.0 gram of root tissue, and 5) total nematode population in soil plus roots. For ease of presentation growing season measures are arranged by cultivar, (Appendix B, Tables 4,5,6 for Superior, Russet

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[2] B size class tubers, less then 5 cm in diameter
A size class tubers, 5-8 cm in diameter
J size class tubers, greater then 8 cm in diameter
Knobby class tubers, are mis-shaped russet burbank

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Data Evaluation

Data evaluation is divided into five sections: research bias, data bias, data availability, missing values, and estimator test.

Research Bias

All of the studies selected were conducted at the MSU Montcalm Potato Research Farm on a McBride sandy loam. This created a spatial bias and limitation for generalization across soil types and climate. The studies, however, were conducted over a ten-year period from 1977 to 1987; providing for ample weather variability. Many different researchers, working both independently and in teams contributed the selected studies. This variation should minimize researcher bias.

Data Bias

Information on aldicarb impact in potato production may be bias in that experiments were conducted by removing aldicarb from a production system which has developed around its use. Aldicarbs value to potato production with in a production system not dominated by pesticide use may be substantially different.

Growing season nematode population density measures of the database created unique problems. Relatively few nematode population samples were reported. Variation in the frequency of sampling (multiple measures) and unevenly spaced sampling complicated the statistical analysis. Data bias in

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bias in this situation relates more to the results of this study than the data reported in the original field research. The bias developed when an attempt was made to use the data in a meta-analysis format.

Data Availability

Pre-plant measures study year and nematode population density data were complete. Information on degree day accumulation, if not reported in the original study, was estimated using historic weather information. No estimates were made for missing in-season nematode population densities.

Data reported for Atlantic potatoes was complete in regard to yield information. However, for Superior tuber yield measures, 13 studies had complete data reported. One study lacked a measure for the B size category. One study reported only the yield of A size category potatoes. Three studies reported only total yield.

For Russet Burbank, five studies had complete yield data and three studies reported only total yield. Russet Burbank potatoes were a special case in that in addition to B, A, and J size classes, data regarding deformed or knobby tubers was reported. The decision was made to ignore the knobby class in the size categories, but to include the knobs in the total weight category. B, A, and J classifications represent economic differences, whereas total tuber weight represents biomass production.

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Missing Values

Since the original data were not collected with thought given to potential for meta-analysis, some desired data points were unavailable. Of the optimal 132 points in the potato yield section, 22 were missing.

Missing values create a dilemma (Tabachnik and Fidell, 1984). Many statistical procedures do not accommodate missing values and disregard all data associated with cases having missing values. It is necessary to weigh the relative worth of the existing measures for an observation against the uncertainty added by estimating missing values. The proportion of missing values to existing values and the accuracy of the estimation procedure are important considerations.

The decision was made to estimate missing yield values using mean proportions of the existing data. Where complete yield data existed, the ratio of each size class to the A size class and total yield was determined. This ratio was then used to estimate missing size class values based on the partial information available (Table 12). In study number 17 the reported total yield of Superior tubers was 196 cwt/acre. The A tuber yield was estimated to be 173 cwt/acre (196 X 0.887). Twenty-two missing data points were estimated using this procedure.

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Table 12. Mean proportion of tuber size classes to Total and A size classes.

Estimator		Superior B	Superior A	Superior J	Russet Burbank B	Russet Burbank A	Russet Burbank J	Russet Burbank N	Atlantic B	Atlantic A	Atlantic J
Aldicarb	T	4.3	88.7	7.0	17.5	69.7	5.5	7.3	7.1	81.3	11.6
Check	T	4.8	90.8	4.4	23.9	66.1	4.5	5.4	7.0	86.7	6.3
Aldicarb	A	5.8		7.5							
Check	A	5.2		4.6							

T - Based on reported total tuber yields
A - Based on reported A tuber yields

Estimator Test

The mean proportions of available B, A, J, and Knobby yield measurements to A and Total yield measurements were evaluated as an estimator for missing yield measurements. A paired t-test was performed. The probability of the difference between an estimated value and a measured value being not different from zero was calculated (Table 13).

Table 13. Paired t-test probabilities associated with estimation of missing size class measures using mean proportion.

Tested Estimator		Superior B	Superior A	Superior J	Russet Burbank B	Russet Burbank A	Russet Burbank J	Russet Burbank K
Aldicarb	T	0.85	0.98	0.93	0.86	0.91	0.86	0.04
Check	T	0.82	0.99	0.89	0.92	0.79	0.95	0.00
Aldicarb	A	0.06		0.92				
Check	A	0.93		0.83				

T - Based on reported total tuber yields
A - Based on reported A tuber yields

The t-test results indicated that the mean proportion of each size class to available total yield data was adequate for estimation of all size classes except Russet Burbank knobby. Because of the low significance (PR=0.06) of the estimate, the mean proportion of A yield to total yield was not used as an estimator. Mean proportions for each tub

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each tuber size class to Total yield were used for all yield estimations.

Meta-analysis

General meta-analysis methodologies are divided into two categories. The first is a discussion to the hierarchy used to organize the research. The second is a description of analytical methodologies used in meta-analysis

Model Hierarchy

A mean yield loss model provides a measure of central tendency and is the simplest method of estimating the value of aldicarb to potato production. Its weakness is that it fails to account for variation in study results and uses only presence or absence of aldicarb application as the information source.

A cumulative probability distribution model, in addition to providing central tendency information, shows the degree of uncertainty associated with average yield loss. This type of model improves decision making ability but still is based only on presence or absence of aldicarb application.

Multivariate regression models increase the degree of predictability by using additional information such as initial nematode population and/or planting date to determine aldicarb application value. Variables in regression models can be chosen based on the information available during different portions of the growing season. This type of model may improve grower pesticide use decision making al

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making ability, but does little to explain the biology of the system.

A biologically based model of the system links in-season nematode population dynamics with functions that estimate yield loss. This type of model shows an implied correlation between nematode populations and yield loss but does not show how the nematode causes tuber yield loss.

A fifth type of model would relate nematode population dynamics to plant growth parameters such as root growth, stolon initiation, root uptake of soil water, or plant partitioning of photosynthates. This type of model represents implied causation and should be the most accurate because of its potential sensitivity to potato management factors such as nitrogen application or irrigation.

The choice of which type of model to be implemented for decision making should be based on decision objectives and the degree to which available data supports the chosen model. The advantage of using a hierarchical modeling structure is that it can be used to organize available information into a usable formats, while clearly indicating the limitations of the information base. The integrated research review and meta-analysis design of this study was used to make optimal use of information available for aldicarb use decision making, and to document the limitations in currently available information.

Research methods which were used for all analyses are described in the general analytical methods section of this

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chapter. Because of the number of methods used, methods and results for each analysis are organized based on the five primary research objectives.

General Analytical Methods

Through out the study treated refers to plots where aldicarb was applied to control P.penetrans, check refers to non-treated controls. In both treated and check plots pesticides may have been applied to control non-nematode pests. The singular difference between treated and check plots was the application of aldicarb.

All statistical analyses were performed using SAS software on a VAX 1170 in the MSU Entomology Department. Since this is a descriptive study, 0.15 was used as the significance level for discussion and for the minimum significant difference calculations of ANOVA. The associated probability of each mean is provided where appropriate.

SAS General Linear Methods (GLM) procedures accommodates unbalanced data design and was used for analysis of variance and yield impact work for researcher determined models.

SAS STEPWISE procedures were also used. In stepwise regression, variables are entered one at a time into the regression equation and then retained or set aside depending on variable statistical significance criteria. A significance level of 0.40 was used for variable entry into the model. A significance level of 0.20 was required for

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variable retention. The advantage of stepwise procedures is that the variables in regression equations are based on the statistical significance of those variables. The disadvantage in using this procedure is that it does not accommodate unbalanced design. Each variety must be analyzed separately, effectively lowering the sample size available for regression analysis. This procedure was used for descriptive purposes and when sample sizes were too small to accommodate a researcher designed GLM model.

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Meta-Analysis Objective 1
Study Variability

Methods used under Meta-Analysis Objective 1 are described. Associated results are provided.

Specific Methodology

Description of original study variability has two parts. The first uses simple descriptive statistics to show the range of results reported in scientific literature which met literature selection criteria. The second is an analysis of variance conducted on selected parameters to determine if results reported in the individual studies were supported across studies.

Variability in Potato Production Measures

For each variable in the PPDB the number of observations, number of missing observations, mean value, standard deviation, minimum value, and maximum value was calculated. Results reported for this section are for original data. No estimated values were used.

Impact of Selected Management Practices on Tuber Yield

The hypothesis that potato cultivar, P.penetrans and aldicarb impact potato yield was statistically tested (PR=0.15) to see if results reported in single studies were globally supported. A three way analysis of variance was performed using SAS GLM for unbalanced ANOVA. Unbalanced ANOVA accommodates unequal n-counts for main effects. Yields of B, A, J, and the Total were analyzed separately.

Presence or absence of aldicarb, potato cultivar and pre-plant nematode count were independent variables.

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Aldicarb or no aldicarb (1 or 0, respectively) is a nominal dichotomous variable. P.penetrans population at planting is a continuous variable converted to dichotomous ordinal variable with 0 indicating less than 23 nematodes / 100cm^3 soil and 1 indicating greater than or equal to 23 nematodes /100cm^3 soil. 23 nematodes / 100cm^3 soil was the midpoint of initial nematode count distribution. It was used to represent high vs. low initial nematode count. An attempt to divide initial nematode count into three categories (high,medium,low) resulted in empty analysis cells. Cultivar was a three level nominal variable with 1 = Superior, 2 = Russet Burbank, and 3 = Atlantic.

Meta-Analysis Objective 1 Results

Variability in Potato Production Measures

Superior. The typical planting date was May 15 with dates ranging from May 1 to May 29. Pre-plant nematode population density ranged from 0 to 54/100 cm^3 soil with an average of 22.3/100 cm^3 soil. The typical growing season length was 114 days with values ranging from 95 to 161 days.

Soil nematode population density during the growing season ranged from 0.0 to 54.0/100 cm^3 for aldicarb treated soil and from 1.2 to 120.8/100cm^3 for non-treated soils. Nematodes in the roots of aldicarb treated plots ranged from 0 to 48/1.0 gram fresh root. Nematodes in the roots of non-treated plots ranged from 14.8 to 213.8/1.0 gram fresh root. The number of days between nematode samples ranged from 2 to 58 with an mean of 24 days.

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The mean yields of B size category tubers were 12.40 and 11.35 cwt/acre for aldicarb treated and non-treated, respectively. The mean yields of A size category tubers were 280.89 and 236.20 for aldicarb treated and non-treated, respectively. The mean yields of J size category tubers were 21.39 and 11.33 cwt/acre for aldicarb treated and non-treated, respectively. Mean total yields of tubers were 281.65 and 224.54 cwt/acre for aldicarb treated and non-treated, respectively.

Sample size, number of missing points, means, standard deviations, minimum, and maximum values for all variables are provided (Appendix C, Table 1).

Russet Burbank. The typical planting date was May 7 but dates ranged from May 2 to May 21. Pre-plant nematode counts ranged from 3.2 to 67/100cm^3 soil with an mean of 33.5. The typical growing season length was 145 days with values ranging from 136 to 161 days.

Soil nematode population density during the growing season ranged from 0 to 31/100 cm^3 soil for aldicarb treated soil and from 2.5 to 286/100cm^3 soil for non-treated soils. Nematode density in the roots of aldicarb treated plots ranged from 0 to 5.8/1.0 gram fresh root. Nematodes in the roots of non-treated plots ranged from 9.7 to 269/1.0 gram fresh root. The number of days between nematode samples ranged from 6 to 77 with a mean of 28 days.

The mean yields of B size category tubers were 54.27 and 62.53 cwt/acre for aldicarb treated and non-treated, respec

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respectively. The mean yields of A size category tubers were 277.55 and 211.67 cwt/acre for aldicarb treated and non-treated, respectively. The mean yields of Jumbo size category tubers were 25.45 and 13.58 cwt/acre for aldicarb treated and non-treated, respectively. Mean total yields of tubers were 346.69 and 274.04 cwt/acre for aldicarb treated and non-treated, respectively.

Sample size, number of missing points, means, standard deviations, minimum, and maximum values for all variables are provided (Appendix C, Table 2).

Atlantic. The typical planting date was May 7 but dates ranged from April 26 to May 16. Pre-plant nematode population density ranged from 2.5 to 57/100cm^3 soil with a mean of 22.17. The typical growing season length was 136 days with values ranging from 118 to 140 days.

Soil nematode population density during the growing season ranged from 0 to 25.3/100 cm^3 soil for aldicarb treated soil and from 5 to 237/100cm^3 soil for non-treated soils. Nematodes in the roots of aldicarb treated plots ranged from 0 to 19.4/1.0 gram fresh root. Nematodes in the roots of non-treated plots ranged from 0.1 to 37.0/1.0 gram fresh root. The number of days between nematode samples ranged from 2 to 58 with a mean of 24 days.

The mean yields of B size category tubers were 29.3 and 27.3 cwt/acre for aldicarb treated and non-treated, respectively. The mean yields of A size category tubers were 328.73 and 235.75 cwt/acre for aldicarb treated and non-tre

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non-treated, respectively. The mean yields of J size category tubers were 47.17 and 24.03 cwt/acre for aldicarb treated and non-treated, respectively. Mean total yield of tubers were 404.93 and 386.63 cwt/acre for aldicarb treated and non-treated, respectively.

Sample size, number of missing points, means, standard deviations, minimum, and maximum values for all variables are provided (Appendix C, Table 3).

Impact of Selected Management Practices on Tuber Yield

B Tuber Yield. A significant result was obtained (PR>F=0.0001) for B yield. The variables in the analysis accounted for 66 percent of the variance.

Initial nematode count significantly (PR>F=0.15) impacted B category potato yield (Appendix D, Table 1). with a minimum significant difference (MSD) of 6.56. Treatment (+/-) aldicarb was not significant (PR>F=0.73). Cultivar was significant (PR>F=0.0001). The MSD for comparison of Superior and Russet Burbank was 10.91, for Russet Burbank and Atlantic was 12.44, for Superior and Atlantic was 10.35 (Table 14).

Table 14. Influence of cultivar, initial nematode population density and aldicarb on B tuber yield.

	Superior		Russet Burbank		Atlantic	
P.p > 23	mean	n	mean	n	mean	n
CHECK	12.34	9	52.30	4	25.64	5
ALDICARB	13.39	9	40.87	3	25.80	4
P.p >=23						
CHECK	12.34	5	83.00	2	30.50	2
ALDICARB	13.36	5	67.67	3	33.33	3

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A Tuber Yield. A significant result was obtained for A yield (PR>F=0.0042). The variables in the analysis explained 36 percent of the variance (Appendix D, Table 2).

For the yield of A category potatoes initial nematode count and treatment were significant with a MSD of 26.47. There was no significant mean separation between Superior and Russet Burbank. The MSD between Superior and Atlantic was 42.76. The MSD between Russet Burbank and Atlantic was 46.66 (Table 15).

Table 15. Influence of cultivar, initial nematode population density and aldicarb on A tuber yield.

	Superior		Russet Burbank		Atlantic	
P.p < 23	mean	n	mean	n	mean	n
CHECK	230.73	9	205.75	4	335.00	5
ALDICARB	272.88	9	281.10	3	313.78	4
P.p >=23						
CHECK	194.21	9	169.64	5	337.00	2
ALDICARB	248.68	9	226.57	6	348.67	3

Jumbo Tuber Yield. Significant results were obtained for Jumbo yield (PR>F=0.0005). The variables in the analysis explained 42 percent of the variance (Appendix D,Table 3).

For the yield of Jumbo category potatoes initial nematode count and treatment were significant. The MSD for PPCODE and TRE was 4.94. There was not a significant mean separation between Superior and Russet Burbank. There was significant difference between Russet Burbank and Atlantic with MSD of 46.6. The MSD between Superior and Atlantic was 42.76 (Table 16).

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Table 16. Influence of cultivar, initial nematode population density and aldicarb on Jumbo tuber yield.

	Superior		Russet Burbank		Atlantic	
P.p < 23	mean	n	mean	n	mean	n
CHECK	12.38	9	17.13	4	24.44	5
ALDICARB	22.08	9	29.57	3	50.55	4
P.p >=23						
CHECK	9.04	9	8.06	5	23.00	2
ALDICARB	19.50	9	17.75	6	42.67	3

Total Tuber Yield. Total tuber yield analysis also provided significant results (PR>F=0.0016). The variables in the analysis accounted for 39 percent of the variance (Appendix D, Table 4).

For Total potato yield, initial nematode count and treatment were significant with a MSD of 30.40. There was no significant mean separation between Superior and Russet Burbank. The MSD for Superior and Atlantic was 53.59. The MSD for Russet Burbank and Atlantic was 60.64 (Table 17).

Table 17. Influence of cultivar, initial nematode population density and aldicarb on Total tuber yield.

	Superior		Russet Burbank		Atlantic	
P.p < 23	mean	n	mean	n	mean	n
CHECK	255.46	9	304.85	4	385.08	5
ALDICARB	308.34	9	399.40	3	390.13	4
P.p >=23						
CHECK	212.44	9	249.40	5	390.50	2
ALDICARB	279.58	9	320.33	6	424.67	3

In this analysis of variance with the exception of PPCODE*CUL for B size category, all interaction terms were insignificant with (PR>T=>0.3). The results of this study indicat

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indicate that aldicarb and initial nematode count do have significant impacts on potato tuber yield. Superior and Russet Burbank yield differences are insignificant for all but B size category tubers.

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Meta-Analysis Objective 2
Impact of Aldicarb on Tuber Yield

Specific methods used under Meta-Analysis Objective 2 are provided as well as meta-analysis objective results.

Specific Methodology

Potential yield loss associated without the application of aldicarb was calculated for each pair of tuber yield observations in the PPDB, and categorized based on tuber size class and potato cultivar. Potential yield loss was calculated by dividing the difference between aldicarb treated and non-treated yields by the aldicarb treated yield ((treated - non-treated) / treated). This yield loss estimate may be bias. It is an estimate of aldicarb value to an agricultural managment practice dependant on pesticide use.

Mean Yield Loss

Mean potential percentage yield loss was determined by averaging yield loss values for each cultivar and tuber size category.

Cumulative Probability

Cumulative probability distributions were developed by calculating the relative frequency of yield reduction measurements by size category and cultivar. The relationship between yield reduction and associated relative frequency was then plotted. The abscissa of the cumulative probability distribution, gives the probability of experiencing equal to, or less than the yield loss indicated on the ordinate.

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Regression Analysis

Three regression analysis procedures for percentage yield reduction were developed. The sign of regression coefficient (Beta estimate) is included in an attempt to determine if regression coefficients are a function of that variable's impact on percent yield loss or a function of the type of regression analysis. Positive Beta estimate signs indicate an increase in yield loss with increasing values of the variable. Negative Beta estimate signs indicate decreasing yield loss with increasing values of the variable.

Preseason Model. Change in yield based on information a grower has at time of planting was analyzed using GLM. GLM was used because it accommodates the unbalanced number of observations available for each variety.

For the GLM procedure, DV1 and DV2 are dummy variables used to indicate variety. DV1 indicates Superior (1), or not Superior (0). DV2 indicates at Atlantic (1), or not Atlantic (0). Russet Burbank was chosen as 0,0 because it had the least complete original data.

Postseason Model. A sub-objective was to use post season information available in a retroactive mode to improve predictive ability. Growing season length (GSL), and total tuber yield in aldicarb treated plots (TWT) were included along with the variable in the preseason model. TWT was used as an indicator of the general quality of the growing season.

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Stepwise variable selection. The third sub-objective under regression analysis involves using stepwise procedures. The postseason variables were available for selection by the stepwise procedure. Results are provided for average yield loss, cumulative probability distribution, and regression analysis sub-objectives.

Meta-Analysis Objective 2 Results

Mean Yield Loss

Mean yield loss results varied from a 17% increase in tuber yield for Russet Burbank to a 52% tuber yield decrease for Russet Burbank Jumbo yield (Table 18).

Table 18. Mean percentage yield loss without aldicarb application by variety and tuber size class.

Variety	n	B	A	Jumbo	Total
Superior	18	10	16	47	22
Russet Burbank	8	-17	23	52	20
Atlantic	7	5	-2	50	4

Cumulative Probability Distribution

In Superior B grade potatoes (Figure 9), results ranged from an increase of 6% to a decrease of 27% with 50% of the yield losses being less than 8%. A grade yield loss ranged from 8 to 45% with 50% of the losses being less than 13%. The impact on Jumbo tubers ranged from a 5% increase to an 80% decrease with 50% of the losses being less than 48%. Total yield loss ranged from 10 to 51% with 50% of losses being less than 20%.

For Russet Burbank (Figure 10), B grade potato yield increase ranged from 33 to 5% with 50% of the increases being less than 20%. A grade yield loss ranged from 8 to

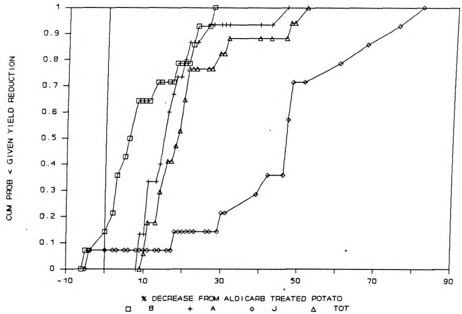

Figure 9. Cumulative probability distribution for the impact of aldicarb on Superior tuber yield by tuber size category.

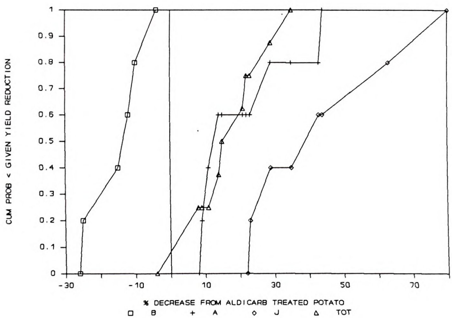

Figure 10. Cumulative probability distribution for the impact of aldicarb on Russet Burbank tuber yield by tuber size category.

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43% with 50% of the results indicating a yield loss of less than 13%. The impact on Jumbo tubers ranged from a 5% increase to an 80% decrease with 50% of the losses being less than 48%. Total yield loss ranged from 10% to 51% with 50% of losses being less than 20%.

For Atlantic potatoes (Figure 11), impact on B grade tuber yield ranged from an increase of 7% to a decrease of 26% with 50% of the results showing less than a 2% increase. The impact on A grade tuber yield ranged from an increase of 11% to a decrease of 8% with 50% of the results showing less than a 4% increase. Jumbo tuber yield decreases ranged from 42 to 57% with 50% of the results indicating a yield loss of less than 48%. The impact on total tuber yield ranged from an increase of 4% to a decrease of 13% with 50% of the results indicating a less than 1% decrease.

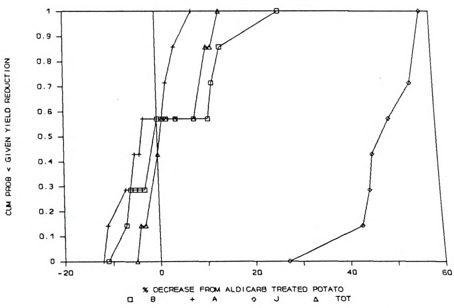

Figure 11. Cumulative probability distribution for the impact of aldicarb on Atlantic tuber yield by tuber size category.

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Regression Analysis

Preseason. Significant regression results were obtained for percentage B, A, and total tuber yield loss (Appendix E, Tables 1,2, and 3 respectively). No significant regression was obtained for Jumbo yield. Regression r-square values ranged from 0.49 to 0.58 (Table 19).

Table 19. Summary of preseason regression analysis results for percentage yield loss by tuber size class.

Dependant Variable	Model PR>F	Model R^ 2	Beta coefficient sign DV1	DV2	APO	PJD
Delta B wt.	0.0007	0.58	+	+	+	-
Delta A wt.	0.0030	0.49	-	-	-	-
Delta J wt.	.	.	.	.	.	.
Delta T wt.	0.0008	0.49	+	-	-	-

Postseason Model. Significant regression results were obtained for percentage B, A,and Total tuber yield reduction (Appendix F, Tables 1,2,and 3 respectively), but not for percentage Jumbo yield reduction. Model r-square values ranged from 0.61 to 0.66 (Table 20).

Table 20. Summary of postseason regression results for percentage yield loss by tuber size class.

Tuber Size Class	Model PR>F	Model R^ 2	Beta coefficient sign DV1	DV2	APO	PJD	GSL	TTW
B	0.0035	0.61	+	+	+	-	+	+
A	0.0018	0.64	+	-	-	+	+	+
Jumbo	.	.	.	.	.	.	.	.
Total	0.0001	0.66	+	-	+	+	+	+

Stepwise Variable Selection. For Superior percentage B tuber yield reduction, PJD was the only variable that met variable selection criteria (Appendix G, Table 1). For

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Superior A yield, PJD was the only variable which met the model criterion (Appendix G, Table 2). No variables met the significance criterion for predicting Jumbo yield. Total yield was estimated using APO GSL and TTW (Appendix G, Table 3). Model r-square values ranged from 0.39 to 0.86 (Table 21).

Table 21. Summary of stepwise regression results for percentage tuber yield loss on Superior.

Tuber Size	Model		Beta coefficient sign			
Class	R^ 2	PR > F	APO	PJD	GSL	TTW
B	0.39	0.0840	.	-	-	.
A	0.70	0.0003	.	-	.	.
Jumbo	.	.	.	.	.	.
Total	0.86	0.0001	+	.	+	+

For Russet Burbank B yield no variables met the entry criterion. Percentage A tuber yield reduction was predicted using PJD (Appendix G, Table 4). No significant regression was obtained for Jumbo yield. Percentage total tuber yield reduction was predicted using PJD (Appendix G, Table 5). Model r-square values ranged from 0.74 to 0.76 (Table 22).

Table 22. Summary of stepwise regression results for percentage tuber yield loss on Russet Burbank.

Tuber Size	Model		Beta coefficient sign			
Class	R^ 2	PR > F	APO	PJD	GSL	TTW
B	.	.	.	.	.	.
A	0.74	0.0266	.	+	.	.
Jumbo	.	.	.	.	.	.
Total	0.76	0.0133	.	+	.	.

For Atlantic percentage B tuber yield reduction, APO was the only significant variable (Appendix G, Table 6). For percentage A tuber yield reduction PJD and GSL were selec

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selected (Appendix G, Table 7). Percentage Jumbo tuber yield reduction was predicted using PJD and TTW (Appendix G, Table 8). Total tuber percentage yield reduction was predicted using APO PJD and GSL (Appendix G, Table 9). Regression r-square values ranged from 0.37 to 0.97 (Table 23).

Table 23. Summary of stepwise regression results for percentage tuber yield loss on Atlantic.

Tuber Size	Model		Beta coefficient sign			
Class	R^ 2	PR > F	APO	PJD	GSL	TTW
B	0.38	0.1412	+	.	.	.
A	0.82	0.0307	.	-	-	.
Jumbo	0.73	0.0715	.	-	.	-
Total	0.97	0.0088	+	-	-	.

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Meta-Analysis Objective 3
Impact of Aldicarb on P.penetrans Populations

Specific methods and results for Meta-Analysis Objective 3 are provided.

Specific Methodology

The determination of the impact of aldicarb on P.penetrans population dynamics has two sections. The first involves using researcher selected regression models to describe population changes. Nematode population density in soils, root, and Total (soil+root) were analyzed for aldicarb treatments and non-treated checks. Threats to model validity such as autoregression and heterogeneous variance structures are discussed. The second involves an attempt to use distributive delay modeling to identify the impact of aldicarb on P.penetrans population dynamics.

Regression Analysis

Regression analysis methods include those for model development and threats to model validity such as autocorrelation and heterogeneity of variance.

Model Development

Regression procedures were developed using degree day accumulation and time measured as day of the year as independent variables. Stepwise procedures indicated that the model equation was third order with respect to either of these variables. Degree day accumulation can be used to explain 48 and 64 percent of the variation of nematode population dynamics in non-treated soils on Superior and

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Russet Burbank respectively. Day of the year can be used to explain 47 and 60 of population variation in non-treated soils on Superior and Russet Burbank respectively. There were insufficient measures to model P.penetrans population dynamics on Atlantic potatoes. Day of the year and degree day are correlated. Their combined explanatory ability is limited.

Day of the year was chosen as the predominant independent variable. Error associated with day of the year is less than that for calculating degree day accumulation. The gain in explanatory power experienced by using degree day for Russet Burbank is small.

For each population dynamics regression analysis the average residual (AVR) was determined using:
AVR = Summation 1=1,n |predicted-measured|/n. The average residual is used to provide a measure of the predictive accuracy of the model.

Threats to Model Validity

Two threats to model validity which must be analyzed are autocorrelation and heterogeneity of variance.

Autocorrelation. Autocorrelation occurs when measurements within a data set are not independent. The regression analysis assumes that variables are independent. The number of nematodes at one time period for a given study is assumed to be a function of the number of nematodes in previous time periods.

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To test the degree of this association, a new variable was created which represented the nematode population in non-treated soils at the previous sampling within a study Durbin-Watson statistic was not valid due to unequal spacing in time series. Each sample was then a pair of samples, the original and its first-order autoregressor. If a study contained five sampling dates the second sample would be paired with the first, the third with the second, the fourth with the third, and so on.

The average spacing between samples was 23 days. Data pairs (sampling value and autoregressor) were sorted and divided into classes dependent upon the length of time between a sampling and its first order autoregressive sample. Class 1 contained observation pairs which were less then 11.5 days apart, Class 2 contained observation pairs which were less than 23 days apart, and class 3 contained samples which where more than 23 days apart.

To explore higher order degrees of autocorrelation, studies with 4 or more samples per growing season were extracted from the database, and analyzed for first to fourth order autocorrelation.

Heterogeneity of Variance. The second threat to model validity is heterogeneous variance. For regression analysis variance associated with nematode population density is required to be uniform throughout the growing season. For many biological systems population variation increases with time. This potential threat to model validity was studied by gr

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by graphical analysis of regression analysis residuals versus the independent variables in the regression equation.

Distributed Delay

The Meta-Analysis Objective 4 requires the existence of a reliable nematode model. For this reason a second literature search was conducted. The objective of this second literature search was to determine the extent of information available for distributed delay modeling. Distributed delay modeling is based on the impact of temperature on population life stage developmental rates, mortality, and natality.

BIOL and BIOB data bases were searched using the key words (Pratylenchus penetrans or Root lesion nematode, and development or temperature or degree day). The literature search revealed eight studies meeting these criteria.

Meta-Analysis Objective 3 Results

Regression Analysis

For *P.penetrans* population density on Superior potatoes model r-square values ranged from 0.17 to 0.45 (Table 24). Complete regression results for soil, root, and total population densities in aldicarb treatments and non-treated controls are provided (Appendix H, Tables 1,2,3,4,5, and 6 respectively).

Table 24. Summary of regression analysis results for soil, root, and total nematode population densities on Superior.

	SOIL			ROOT			TOTAL		
Treatment	R^ 2	PR > F	*AVR	R^ 2	PR > F	AVR	R^ 2	PR > F	AVR
Check	0.31	0.0153	16.4	0.47	0.0018	33.5	0.45	0.0001	36.9
Aldicarb	0.32	0.0133	7.4	0.17	0.3376	5.1	0.20	0.0478	10.2

* AVR - average residual = Summation i=1,n |measured-predicted|/n

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The results of regression analysis for population densities in the soil root and total on Superior are provided (Figures 12,13,and 14 respectively).

For P.penetrans population density on Russet Burbank potatoes model R-square values ranged from 0.45 to 0.86 (Table 25). Complete regression results for soil, root, and total population densities in treated and non-treated controls are provided (Appendix H, Tables 7,8,9,10,11, and 12 respectively).

Table 25. Summary of regression analysis results for soil, root, and total nematode population densities on Russet Burbank.

	SOIL			ROOT			TOTAL		
Treatment	R^ 2	PR > F	AVR	R^ 2	PR > F	AVR	R^ 2	PR > F	AVR
Check	0.66	0.0002	27.9	0.86	0.0001	20.9	0.53	0.0007	57.4
Aldicarb	0.47	0.0124	4.0	0.45	0.1540	0.8	0.83	0.0004	4.4

AVR - average residual = Summation i=1,n ¦measured-predicted¦/n

The results of regression analysis for population densities in the soil root and total on Russet Burbank are provided (Figures 12,13,and 14 respectively).

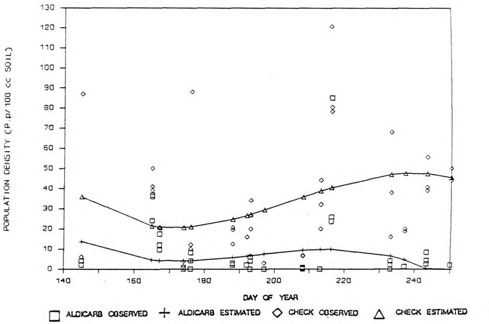

Figure 12. Soil nematode population density on Superior - simulated and observed vs. day of year

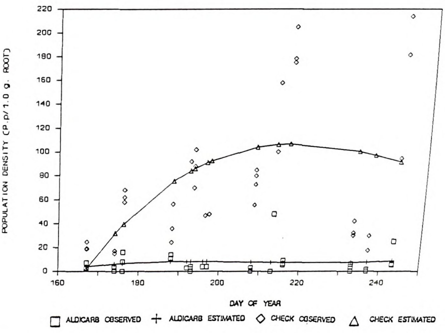

Figure 13. Root nematode population density on Superior - root simulated and observed vs. day of year

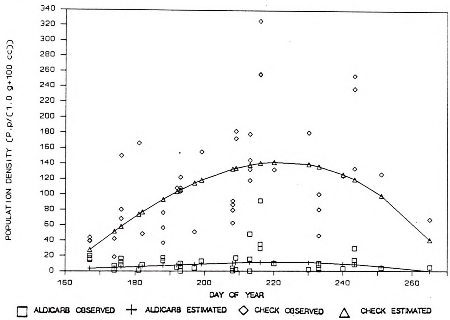

Figure 14. Total nematode population density on Superior - simulated and observed vs. day of year.

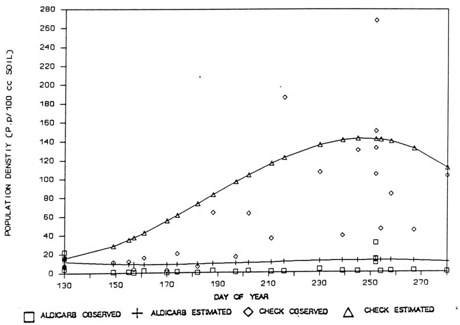

Figure 15. Soil nematode population density on Russet Burbank - simulated and observed vs. day of year.

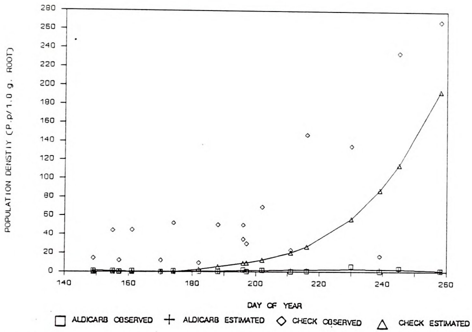

Figure 16. Root nematode population density on Russet Burbank - simulated and observed vs. day of year

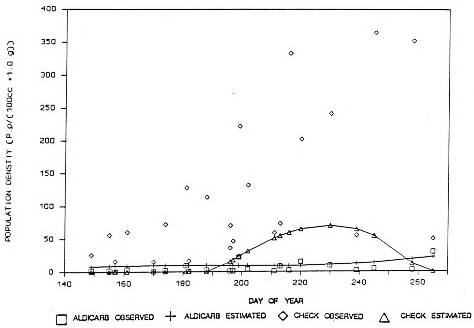

Figure 17. Total nematode population density on Russet Burbank - simulated and observed vs. day of year

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Threats to Model Validity

Threats to model validity included autocorrelation and heterogeneity of variance.

Autocorrelation. For nematode population density in non-treated soil samples the Pearson Correlation Coefficient between values and their autoregressor decreased as time between samples increased. Pearson Correlation Coefficients were 0.61, 0.39, 0.34 for sample spacing categories 1,2, and 3 respectively indicating the degree of first order autocorrelation and its sensitivity to sample spacing. This is important because it shows first order violation of the independence of measures statistical assumption.

Second samples were statistically correlated (Pearson Correlation Coefficient) with first samples, 0.81. Fourth samples where correlated with second samples, 0.73. Fifth samples where correlated with fourth and third samples 0.66 and 0.53 respectively. There were no other significant ($PR>|R|=.15$) correlations. This again supports that there is an independence threat to model validity.

Heterogeneity of Variance. Heterogeneity of variance was most clearly associated with the impact of initial nematode population densities on regression analysis for soil population density in Superior check treatments (Figure 18).

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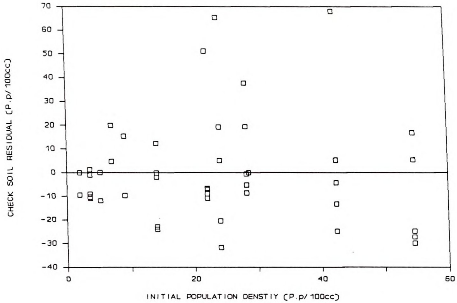

Figure 18. Superior check soil nematode population density regression residual vs. initial nematode population density.

Distributed Delay

Of the eight studies retrieved by the literature search only one contained information regarding P.penetrans development on potatoes. Developmental rates were reported for P.penetrans on alfalfa (Townshend, 1984; Kimpinski, 1981), timothy (Kimpinski, 1981), soybean (Acosta, 1979), Tobacco (Townshend, 1977), and onion (Ferris, 1970). One document was retrieved which reported potato production and temperature (Burpee, 1978). Burpee's analysis concentrated on plant development and not nematode development. Currently, insufficient information exists for distributed delay modeling of P.penetrans population density on potato.

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Meta-Analysis Objective 4
Impact of In-season P.penetrans Populations on Tuber Yield

Specific methodology and results of research performed under Meta-Analysis Objective 4 are provided

Specific Methodology

An attempt was made to determine if there is a window of time in which the nematode populations most affectively impact yield. The impact of in-season P.penetrans population dynamics on yield was analyzed by division of population density measures into time categories. The small number of samples taken during the growing season limits the thoroughness with which this question can be analyzed.

Correlation

The degree of linear relationship between delta nematode population values for two class (early, and late) and percentage tuber yield reduction measures was determined using Pearson product-moment correlation. For each study the growing season was divided into two (early and late season) segments. The difference between treated and non-treated soil, root, and total nematodes was calculated for early and late season time classes. If there was more than one sampling date reported in a study time class, reported values were averaged.

Regression

Two regression analyses were used in an attempt to determine the impact of in-season nematode populations on tuber yield. The analysis for two time classes was used to

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determine which portion of the nematode population (soil, root, or soil+root) was most important to yield impact determination. Four time classes were used to determine the portion of the season in which total nematode population density has the greatest impact on tuber yield.

Two Time Classes. Five regression models were used for prediction of percentage tuber yield loss based on soil, root, and total nematode populations. Impact of *P.penetrans* in soil was determined using pre-plant, early season and late season soil population density measures as independent variables. Impact of *P.penetrans* populations in roots was determined using early and late season root nematode population measures. Impact of total *P.penetrans* populations was determined using early and late season nematode population measures.

Four Time Classes. Yield loss functions were also determined from studies which contained four or more samples. DTN1, DTN2, DTN3, DTN4 represent the difference between check and aldicarb treated total nematode population densities for the first to the fourth sampling respectively. Pre-plant nematode density, planting date, DTN1, DTN2, DTN3, and DTN4 where used to predict percentage tuber yield reduction for each size class. Total nematode density as opposed to soil, or root nematode density was used because it was the only class for which significant regression predictors were available under Meta-Analysis Objective 3. Stepwise procedures were used to determine the model.

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Meta-Analysis Objective 4 Results

Class Correlation

Significant (PR>|R|=.15) Pearson correlation coefficients are reported (Table 26). Positive values represent an increase in yield loss with higher nematode population densities.

Table 26. Pearson correlation coefficients for percentage change in B, A, Jumbo, and Total tuber size classes with soil, root, and total nematode population density for two time categories.

		Soil		Root		Total	
Variety	Size	Early	Late	Early	Late	Early	Late
Superior	B	.	.	.	.	.	.
Superior	A	.	.	.	-0.41	0.44	.
Superior	J	.	.	.	.	.	.
Superior	T	.	.	.	.	.	.
Russet Burbank	B	0.44	0.42	0.72	0.78	0.59	0.33
Russet Burbank	A	0.50		0.72	.	.	.
Russet Burbank	J	-0.52		-0.72	.	-0.47	.
Russet Burbank	T	0.40	-0.58	-0.72	.	.	.
Atlantic	B	.	.	.	.	.	.
Atlantic	A	.	0.82	.	0.90	.	0.72
Atlantic	J	.	.	.	.	.	.
Atlantic	T	.	0.87	.	0.95	.	0.83

. - no significant correlation

Regression

Nematode populations in roots appeared to have the greatest impact on tuber yield for Superior, while total population density had the greatest impact on tuber yield for Russet Burbank.

Two time classes. Four analyses resulted in statistically significant (PR>F .15) regression results (Table 27). Complete regression information is provided (Appendix I, Tables 1,2,3, and 4).

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Table 27. Impact of in-season nematode densities on percentage yield loss by cultivar, B, A, Jumbo, and Total and size categories.

Model	Tuber size category							
	B		A		Jumbo		Total	
Superior	R^ 2	PR > F	R^ 2	PR > F	R^ 2	PR > F	R^ 2	PR > F
Soil	.	.	.	.	.	.	.	.
Root	.	.	0.82	0.0311	.	.	0.63	0.1353
Total	.	.	0.35	0.1420	.	.	.	.
Rus Burb								
Soil	.	.	.	.	.	.	.	.
Root	.	.	.	.	.	.	.	.
Total	.	.	.	.	0.96	0.0375	.	.

. - no significant regression

Four Time Classes. Significant results were obtained for Superior (Table 28) but not for Russet Burbank. Complete regression results for percentage yield loss for B, A, Jumbo, and Total tuber yield are provided (Appendix J, Tables 1,2,3, and 4 respectively).

Table 28. Summary of stepwise regression results for in-season total nematode population density on percentage tuber yield reductions.

Tuber Size Class	PROB > F	R-SQUARE	Beta COEFFICIENT SIGN				
			APO	DTN1	DTN2	DTN3	DTN4
B	0.003	0.73	.	+	.	.	.
A	0.004	0.83	.	.	+	.	+
Jumbo	0.077	0.58	+	.	.	-	.
Total	0.006	0.81	.	+	.	.	+

. - no significant regression

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Meta-Analysis Objective 5
Impact of Aldicarb and P.penetrans on Plant Development

Specific methodologies and results for research performed under Meta-Analysis Objective 5 are provided.

Specific Methodology

The impact of P.penetrans population density on potato growth and development was analyzed using correlation and regression analysis. Absolute and relative changes in plant organ growth were determined. Regression equations for relative partitioning between major sinks were also developed.

Data Base

In order to study the impact of aldicarb and P.penetrans on potato plant development, an additional information source was tapped. During the period (1985-1987) research was conducted at the Montcalm County Potato Research Farm to provide a data base for validation of potato modeling efforts. Data collected in 1986 was confounded by poor germination in the spring and flooding in the fall and was excluded from this study.

The Model Validation Data Base includes weekly or biweekly measurements of nematode populations in soil, stolon, and roots (Appendix B, Table 7) as well as plant growth parameters such as above ground, below ground, root, stem, stolon, and tuber biomass (Appendix B,Table 8).

The difference between nematode population density in non-treated and aldicarb treated plots (delta) is assumed to be the impacting portion of the nematode population.

Changes in plant growth parameters were expressed as delta values (treated mass - non-treated mass) or as relative values (non-treated mass/treated mass). Partitioning was expressed as (mass of sink/total plant mass).

Correlation Analysis

Correlation analysis was performed to quantify the degree of linear relationship between nematode population measurements and growth impact measurements. Days after planting (DAP), Delta soil, root, total, stolon nematodes (DSOIL, DROOT, DTOT, DSTOL respectively), were correlated with delta and relative below ground, above ground, root, stolon, and tuber biomass.

Regression Analysis

Regression analyses were used to determine the impact of aldicarb and P.penetrans on both absolute changes in plant growth parameters and relative partitioning of photosynthates to plant organs.

Plant Growth Parameters. Stepwise regression techniques were employed to determine nonlinear time relationships between nematode populations and change in delta and percentage plant growth parameters. Independent variables available for selection included delta soil, root, and total nematode counts as well as first through third order time (days after planting) measurements.

Plant Partitioning. The affect of aldicarb and P.penetrans on metabolite partitioning between the above ground, below ground, and tuber portions of the plant. The ratio of below ground, above ground, and tuber biomass to total biomass was determined. The difference in relative partitioning between aldicarb and non-treated plots was then determined for graphic explanation of aldicarb / P.penetrans impacts.

Stepwise regression techniques were employed to determine nonlinear time and nematode population impacts on plant partitioning. Variables available for selection included delta soil, root, and total nematode counts as well as first through third order time (days after planting) measurements. For below ground partitioning measures reciprocal first through third order (days after planting) measures were used as time indicators. Because a reliable nematode population model is not currently available, the analysis was repeated using only time variables.

Meta-Analysis Objective 5 Results

Correlation

There were five significant correlations associated with delta plant growth parameters and eight significant correlations associated with percentage plant growth parameters.

Delta Plant Growth. Significant (PR > $|R|$=.15) Pearson Correlation Coefficients are reported (Table 29). Positive values represent less mass in non-treated plots.

Table 29. Pearson correlation coefficients for days after planting, delta (soil, root, total, and stolon) nematode population densities with plant growth parameters expressed as a difference.

Plant Parameters	Nematode parameters DAP	DSOIL	DROOT	DTOT	DSTOL
Below Ground	.	.	.	.	.
Above Ground	.	0.65	.	.	.
Root	.	.	.	.	.
Stolon	.	0.54	.	.	.
Tuber	0.76	0.88	.	0.55	.
U G Stem	.	.	.	.	.

. - no significant correlation

Relative Plant Growth. For plant growth measurements expressed as a ratio significant (PR > $|R|$=.15) Pearson Correlation coefficients are reported (Table 30). Negative values represent less mass in non-treated plots.

Table 30. Pearson correlation coefficients for days after planting, delta (soil, root, total, and stolon) nematode population densities with percentage plant growth parameters.

Plant Parameters	Nematode parameters DAP	DSOIL	DROOT	DTOT	DSTOL
Below Ground	-0.50	.	-0.76	-0.53	.
Above Ground	.	-0.65	.	.	0.77
Root	.	.	-0.69	-0.61	.
Stolon	.	.	.	.	.
Tuber	.	-0.51	.	.	.
UG Stem	.	.	.	.	.

. - no significant correlation

Regression

Two significant regressions were obtained for delta plant growth parameters. Three significant regressions were associated with percentage plant growth parameters.

Delta Plant Growth. Regression results for delta plant growth are provided (Table 31). Complete regression results for delta above ground, and tuber growth parameters are provided (Appendix K, Tables 1 and 2 respectively).

Table 31. Summary of stepwise regression results for the impact of aldicarb and P.penetrans on delta plant growth parameters.

Plant Growth			Beta coefficient sign					
Parameter	Prob>F	r-square	DAP	DAP2	DAP3	DSOIL	DROOT	DTOT
Below Ground	.	.	.	.	.	.	.	.
Above Ground	0.0066	0.58	.	.	.	+	.	.
Root	.	.	.	.	.	.	.	.
Stolon	.	.	.	.	.	.	.	.
Tuber	0.0019	0.68	.	.	.	+	.	.
U G Stem	.	.	.	.	.	.	.	.

. - no significant regression

Relative Plant Growth. Regression results are summarized (Table 32). Complete regression results for percentage below ground, above ground, and stolon growth parameters are provided (Appendix K, Tables 3,4, and 5 respectively).

Table 32. Summary of stepwise regression results for the impact of aldicarb and P.penetrans on percentage plant growth parameters.

Plant Growth			Beta coefficient sign					
Parameter	Prob>F	r-square	DAP	DAP2	DAP3	DSOIL	DROOT	DTOT
Below Ground	0.0063	0.58	.	.	.	.	-	.
Above Ground	0.0411	0.38	.	.	.	-	.	.
Root	.	.	.	.	.	.	.	.
Stolon	0.0177	0.48	.	.	.	.	-	.
Tuber	.	.	.	.	.	.	.	.
U G Stem	.	.	.	.	.	.	.	.

. - no significant regression

Plant Partitioning with Nematode Terms. Significant regression results were obtained for each of the partitioning sinks (Table 33). Days after planting as a cubic term was not selected by any analysis. Complete regression results for partitioning to below ground aldicarb, below ground check, above ground aldicarb, above ground check, tuber aldicarb, and tuber check are provided (Appendix K, Tables 6,7,8,9,10,and 11 respectively).

Table 33. Summary of regression results for the impact of delta nematode population parameters on partitioning ratio.

				Beta coefficient sign				
Sink	Treat	PR > F	R-square	DAP	DAP2	DSOIL	DROOT	DTOT
Below Ground*	Ald	0.0001	0.90	+	+	.	.	.
Below Ground*	Chk	0.0001	0.96	+	+	.	-	.
Above Ground	Ald	0.0003	0.87	.	-	.	+	.
Above Ground	Chk	0.0001	0.85	.	-	.	+	.
Tuber	Ald	0.0001	0.91	+	.	+	.	.
Tuber	Chk	0.0001	0.90	+	.	+	.	.

* For below ground measures time variables (DAP,DAP2) equal (1/DAP, 1/DAP2) respectively

Plant Partitioning w/o Nematode Terms. Significant results were obtained for each partitioning sink (Table 34). Complete regression results for partitioning to above ground aldicarb, above ground check, tuber aldicarb, and tuber check are provided (Appendix K, Tables 12,13,14, and 15 respectively).

Table 34. Summary of regression results for partitioning ratio as a function of days after planting.

				Beta coefficient sign		
Sink	Treat	PR > F	R-square	DAP	DAP2	DAP3
Below Ground*	Ald	0.0001	0.88	.	+	.
Below Ground*	Chk	0.0001	0.91	.	+	.
Above Ground	Ald	0.0001	0.83	.	+	.
Above Ground	Chk	0.0002	0.76	.	+	.
Tuber	Ald	0.0001	0.90	+	.	.
Tuber	Chk	0.0001	0.88	+	.	

* For below ground measures time variables (DAP,DAP2,DAP3) equals (1/DAP, 1/DAP2, 1/DAP3) respectively

These regression results for below ground, above ground, and tuber biomass partitioning ratio were graphically compared with the observed ratios (Figures 19,20, and 21 respectively). The difference in relative partitioning between aldicarb and non-treated plots was then determined and plotted versus days after planting (Figure 22).

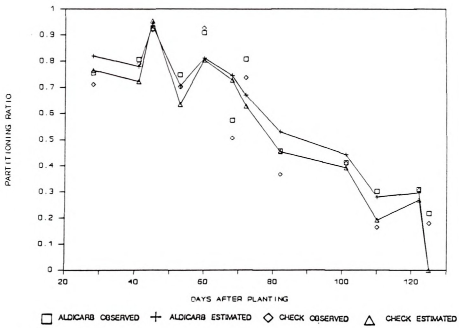

Figure 18. Above ground to total biomass partitioning ratio vs. days after planting

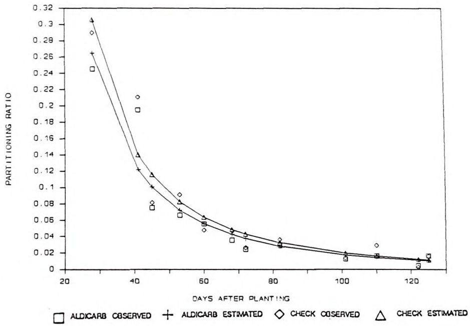

Figure 20. Below ground to total biomass partitioning ratio vs. days after planting

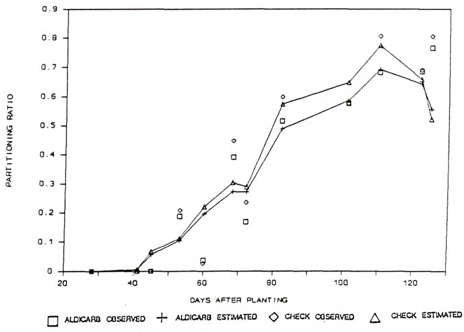

Figure 21. Tuber to total biomass partitioning ratio vs. days after planting

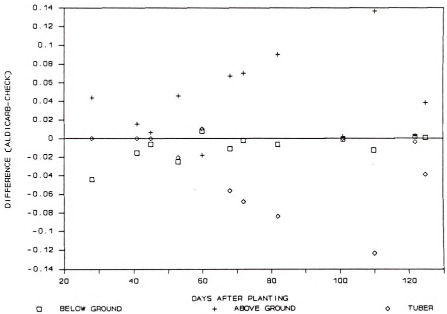

Figure 22. Difference in aldicarb and check treatment partition ratios vs. days after planting.

Discussion

Variability in Study Findings

Superior. Superior B yields were unaffected by either initial nematode population or aldicarb application. Superior A yields were significantly decreased by the higher initial nematode population and increased by aldicarb application. For Jumbo tubers, treatment was significant but initial nematode population was not. Differences in total tuber yield were statistically significant for both treatment and initial nematode population, with treatment increasing yield and initial nematode population decreasing yield.

Russet Burbank. Increase in B tuber yields was significantly associated with high initial nematode populations. This increase in B yield is associated with significant decreases in A and J yields for both high initial nematode population and non-treated control. Total yield is decreased and tuber size class distribution shifts toward smaller sizes.

Atlantic. For B, A, and Total yield, the only significant differences occurred for high vs. low initial nematode population in aldicarb treated soils. Jumbo yields were significantly higher for both aldicarb treated and low initial nematode population soils.

Impact of Aldicarb on Tuber Yield

Analysis for the impact of aldicarb on tuber yield was divided into average yield loss, cumulative probability distributions, and regression analysis.

Average Yield Loss. There were yield decreases for all size classes of Superior potatoes with Jumbos experiencing the greatest losses. For Russet Burbank there was an increase in B yield. Yield losses between A and Total were relatively balanced while the B yield increase apparently came at the expense of Jumbo yield. Atlantic experienced a slight increase in A yield. This was associated with decreases in B, J, and Total yields. Atlantic appears to be the most resistant variety to *P.penetrans* infestations.

Cumulative Probability Distribution. While mean yield loss does give some information regarding the impacts of aldicarb on potato variety yield, a more complete picture can be gained by inspection of a cumulative probability distribution (CPD). In addition to central tendency, a CPD also provides information about the distribution of results around that tendency. As such, the cumulative probability distribution provides the clearest representation of aldicarb impact variability. It also forces the decision maker to be explicit in regard to the level of uncertainty associated with decision making.

Pre-season Model. This model was determined based on decision making information a grower would have at time of planting. The variation explained by cultivar, initial nematode count, and planting date was low. Cultivar was the most significant variable in the model. Planting date was significant for delta total weight.

Post-Season Model. This model was determined based on information available after the growing season for use in retrospective estimation of potential yield losses. Addition of growing season length and total weight of aldicarb treated potatoes increased model r-square values.

Stepwise. Stepwise procedures provided good results for estimation of total yield loss but failed to provide for estimation of B and Jumbo yield size classes. Size class estimates could be obtained using mean proportion values discussed previously.

Summary of Regression Estimates. Of the three models tested (preseason, postseason GLM, postseason stepwise), the stepwise procedure provided the best overall results (Table 35).

Table 35. Comparison of models for percentage tuber yield loss estimation.

Tuber Size Class	Pre-Season R**2	Pre-Season PR > F	Postseason R**2	Postseason PR > F	Superior Stepwise R**2	Superior Stepwise PR > F	Rus Burb Stepwise R**2	Rus Burb Stepwise PR > F	Atlantic Stepwise R**2	Atlantic Stepwise PR > F
B	0.58	0.0007	0.61	0.0035	0.39	0.0840	.	.	0.38	0.1412
A	0.49	0.0030	0.64	0.0018	0.70	0.0003	0.74	0.0266	0.82	0.0307
Jumbo	.	.	.	.	.	.	.	.	0.73	0.0715
Total	0.49	0.0008	0.66	0.0001	0.86	0.0001	0.76	0.0133	0.97	0.0088

There was no clear pattern in variables selected by this procedure (Table 36). The coefficient on planting date was more often negative than positive. This would indicate that late planting decreases tuber yield loss. The beta estimate for average initial nematode population was more often positive, indicating increased yield loss with increasing number of nematodes. The beta estimate for growing season length was inconclusive. The coefficient on total weight of treated tubers was more often positive, indicating that relative nematode impact increases with increasing yield.

Table 36. Summary of beta coefficient signs for variables selected by regression procedures.

Tuber Size Class	APO NEG	APO POS	PJD NEG	PJD POS	GSL NEG	GSL POS	TTW NEG	TTW POS
	Beta coefficient sign							
B	0	3	3	0	1	1	0	1
A	2	0	3	2	1	1	0	1
Jumbo	0	0	1	0	0	0	1	0
Total	1	3	2	2	1	2	0	2
SUM	3	6	9	4	3	4	1	4

Impact of Aldicarb on Temporal Variation in P.penetrans Population

Although significant regressions were obtained, model predictive ability was limited. Model r-square values ranged from 0.20 to 0.86. Sample frequency, spacing, autocorrelation, and heterogeneous variance are all significant threats to the validity of these results. This analysis yielded two interesting results. The first is an apparently decreased ability to predict nematode population density, as measured by model r-square, for aldicarb treated plots. The second is substantially higher regression R-square values for nematode population density on Russet Burbank when compared to nematode population density on Superior.

Decreased r-square values are probably due to non-standardized variables. The relative variation (as measured by model r-square) in nematode population was greater for aldicarb treated than check soils, although the total variation (as measured by average residuals) was less for aldicarb treated soils. Average residual values show that the absolute variation explained in population is higher for aldicarb treated soils even thqugh the relative variation explained is lower.

Increased ability to predict nematode populations for Russet Burbank is probably due to the average number of samples taken in each of the original studies. There appears to be a relationship between the average number of samples taken per study and the regression r-square (Table 37). The relationship between variability added and predictive ability increase may not be favorable for studies with few samples.

Table 37. Relationship between average number of soil, root, and total nematode samples reported per study and ability to explain nematode population variation.

	SOIL			ROOT			TOTAL		
Cultivar	SAMP /STY	CHK R^2	ALD R^2	SAMP /STY	CHK R^2	ALD R^2	SAMP /STY	CHK R^2	ALD R^2
Russet Burbank	4.5	0.66	0.48	4.5	0.86	0.45	4.7	0.53	0.81
Superior	3.2	0.31	0.32	2.3	0.47	.	3.4	0.45	0.20
Atlantic	1.7	.	.	1.0		.	1.3	.	.

. no significant regression

<u>Minimum Sample Frequency</u>. Two pieces of information are useful in determining the minimum number of samples to be taken during a growing season. They are the apparent third order relationship between nematode population and time, and the relationship between average number of samples taken and regression r-square values.

The relationship between nematode population and time appears to be third order. If nematode sampling information is going to be used for population modeling, then logic would dictate that in addition to a pre-plant sample at least four (n+1) samples should be taken during the growing season.

The apparent relationship between average number of samples and resultant regression r-square would indicate that if five in season nematodes samples were taken model r-square values would be approximately .70.

Sample spacing. If samples were equally spaced then time series analysis could be used for forecasting. Time series analysis requires equally spaced samples with a minimum data set of 50 points. The 50 points would not have to be in the same season but should be made at equal intervals after the planting date, and be taken during growing seasons of equal length. Nematode population density measures used in this study were not equally spaced, preventing this type of analysis.

Autocorrelation. In regression analysis autocorrelation violates the independence of samples assumption. Regression analysis assumes that measures are independent. The nematode population at a given time is a function of the nematode population at previous times. There is a high degree of autocorrelation in this data set.

Impact of Temporal Variation in P.penetrans on Tuber Yield

Division of nematode sampling data into time classes eliminated some of the autocorrelation problems associated with sampling data, but also lowered the number of observations available for analysis. Even with the smaller data set, there were significant results with good predictability for delta A and total yield for Superior and delta total yield for Russet Burbank. These results appear to be better in terms of average r-square values across size categories to earlier regression models. Collapse of many sampling dates into four time classes caused some unaccounted for error, also the error associated with

population modeling had a multiplicative affect on model reliability. It appears that if a good model of P.penetrans population dynamics was available, then impact on yield estimates could be improved using this type of analysis. An increase in the number of samples taken during the growing season would increase ability to determine a window for maximum nematode impact on yield by allowing a greater number of time classes.

Impact of Temporal Variation in P.penetrans on Plant Development

The ability to explain differences in plant organ growth between treated and non-treated plots was limited. Differences in partitioning can be estimated and support the observation that above-ground portions of non-treated plants die earlier in the season than those of treated plants. This decrease in above ground partitioning is associated with an increase in relative tuber partitioning as carbohydrates are moved from above ground portions of the plant to tubers for non-treated plots. In treated plots carbohydrates are partitioned into above ground plant portions until late in growing season resulting in greater total available biomass and tuber yield. There was no apparent impact of treatment on relative partitioning to below ground portions of the plant indicating that the plant does not respond to root injury by increasing partitioning to below ground portions.

Model Parameterization

The optimal model would simulate nematode population dynamics in soils and roots and then link nematode populations with physiological damage to potato plant organs or relative plant partitioning. Relative plant partitioning functions are only available for Russet Burbank and will have to be incorporated into plant growth simulation models to determine the applicability of these relationships for decision making.

The next best model would track nematode population dynamics and correlate population levels in set time or environmental intervals with end of season yield change. The Impact of Temporal Variation on Yield section of this paper was an attempt to parameterize this type of model. Some significant results were obtained. Lack of a reliable nematode population model limits the applicability of this type of model.

The third level of model would use summary growing season information to predict the impact of aldicarb and P.penetrans on tuber yield. This is level of modeling available data currently supports. The stepwise regression procedure provided a good estimate of change in total tuber for each variety but not size categories. This estimate of change in tuber yield is coupled with the mean proportion of size class yield to total yield to estimate size categories.

Table 38. Summary of estimation procedures for impact of aldicarb on tuber yield.

	MEAN YIELD LOSS	GLM PRE-SEASON	GLM POST-SEASON	STEPWISE POST-SEASON	4 OR > SAMPLES
Superior					
n count	18	18	18	18	9
r-square		0.49	0.65	0.86	0.81
Prob > F		0.00	0.00	0.00	0.00
Ave Residual	21.5	15.9	12.5	11.5	46.6
Min Residual	6.7	1.6	0.4	0.6	1.7
Max Residual	49.7	51.6	40.0	40.2	123.5
Russet Burbank					
n count	9	9	9	9	
r-square		0.49	0.65	0.76	
Prob > F		0.00	0.00	0.01	
Ave Residual	32.2	40.8	30.6	15.7	
Min Residual	0.4	1.4	4.9	1.8	
Max Residual	75.0	93.6	59.9	43.0	
Atlantic					
n count	7	7	7	7	
r-square		0.49	0.65	0.38	
Prob > F		0.00	0.00	0.14	
Ave Residual	25.0	19.0	36.1	3.6	
Min Residual	14.2	6.3	12.2	0.0	
Max Residual	39.7	35.4	64.5	8.5	

Based on these results, three subroutines were developed for estimation of the impact of aldicarb and P.penetrans on tuber yield in SUBSTOR. An INCLUDE file, PPENE.INC, was used for data dictionary, variable initialization, and common blocks. IPPENE reads PPFILE.PAR and initializes program variables. PPIMPACT calculates estimated yield based on the results from the integrated research review previously discussed. OUTYLD writes output file containing summary yield information.

PPENE.INC contains variables used in determination of aldicarb and P.penetrans impacts on yield.

DATA DICTIONARY

VARIABLE	DEFINITION
SSYLD	SUBSTOR SIMULATED YIELD (KG/HA)
ABYLD	ESTIMATED ALDICARB B YIELD
ABYLD	ESTIMATED ALDICARB A YIELD
AJYLD	ESTIMATED ALDICARB J YIELD
CTYLD	ESTIMATED CHECK TOTAL YIELD
CBYLD	ESTIMATED CHECK B YIELD
CAYLD	ESTIMATED CHECK A YIELD
CJYLD	ESTIMATED CHECK J YIELD
ALDVAL	VALUE OF ALDICARB TREATED YIELD ($/AC)
CHKVAL	VALUE OF NON-TREATED YIELD $/AC
PDD	ESTIMATED DEGREE DAY BASE 10 AT ISOW
INIPP	INITIAL Pp/100 cm^3 SOIL
BVAL	VALUE OF B POTATOES $/CWT
AVAL	VALUE OF A POTATOES $/CWT
JVAL	VALUE OF JUMBO POTATOES $/CWT
DTOT	DELTA TOTAL YIELD DUE TO Pp
INPP35	UNIT NUMBER FOR Pp PARAMETER FILE
GSL	GROWING SEASON LENGTH IN DAYS
OUT36	UNIT NUMBER FOR OUTYIELD FILE
JPLANT	PLANTING DATE
PPFILE	NAME OF INPUT FILE CONTAINING Pp PARAMETERS
OUTYIELD	NAME OF FILE FOR SUMMARY YIELD DATA
PPFLAG	INDICATES IF Pp YIELD LOSS FUNCTIONS ARE TO BE INCLUDED 1 = YES

```
 REAL INIPP,BVAL,AVAL,JVAL,SSYLD,ABYLD,AAYLD,AJYLD,
+CTYLD,CBYLD,CAYLD,CJYLD,ALDVAL,CHKVAL,DTOT,PDD

INTEGER INPP35,GSL,OUT36,PPVAR,JPLANT
```

```
CHARACTER OUTYIELD*10,PPFILE*10,PPFLAG*1

 COMMON /PPENE/INIPP,BVAL,AVAL, JVAL, SSYLD,ABYLD,AAYLD,
+AJYLD,CTYLD,CBYLD,CAYLD, CJYLD,ALDVAL,CHKVAL,DTOT, PDD,
+INPP35,GSL,OUT36,PPVAR,JPLANT,OUTYIELD,PPFILE,PPFLAG
```

IPPENE

IPPENE is called from the MAIN program and initializes the aldicarb/P.penetrans yield impact model. IPPENE reads input parameter file number 35 named PPFILE.PAR which contains values indicating potato variety planted, initial nematode populations/100 cm^3 soil, and the values of B, A, and J tubers per hundred weight. It then opens output file 36 for summary yield information and returns to the MAIN program.

PPIMPACT

PPIMPACT is called from program MAIN after the simulation loop has been exited. It estimates yield reductions associated without the use of aldicarb based on information obtained in the integrated research review. First the SUBSTOR yield is converted from metric tonnes per hectare to hundred weight per acre.

```
SSYLD=SSYLD*(2.2046/247.105)
```

A growing season length of 140 days was assumed.

```
GSL = 140
```

The IF THEN ELSEIF ELSE statement is used to distinguish between varieties for which yield loss functions were developed. Values of 1,2,and 3 stand for Superior, Russet Burbank, and Atlantic respectively. DTOT indicates percentage yield loss estimated without the application of aldicarb. The fractional modifiers are used to distribute total yield between size categories.

```
IF (PPVAR.EQ.'1') THEN
  DTOT =
-.54616471+.00151086*INIPP+.00520185*GSL+.00047833*SSYLD
  ABYLD = SSYLD*.043
  AAYLD = SSYLD*.887
  AJYLD = SSYLD*.07
  CTYLD = SSYLD-SSYLD*DTOT
  CBYLD = CTYLD*.048
  CAYLD = CTYLD*.908
  CJYLD = CTYLD*.044
    ALDVAL = ABYLD*BVAL+AAYLD*AVAL+AJYLD*JVAL-PSTCOST
    CHKVAL = CBYLD*BVAL+CAYLD*AVAL+CJYLD*JVAL
ELSEIF (PPVAR.EQ.'2') THEN
  DTOT = .2199-.0020*ISOW+.0005*INIPP+.0016*GSL-.0002*SSYLD
  ABYLD = SSYLD*.175
  AAYLD = SSYLD*.697
  AJYLD = SSYLD*.055
  CTYLD = SSYLD-SSYLD*DTOT
  CBYLD = CTYLD*.239
  CAYLD = CTYLD*.661
  CJYLD = CTYLD*.045
    ALDVAL = ABYLD*BVAL+AAYLD*AVAL+AJYLD*JVAL-PSTCOST
    CHKVAL = CBYLD*BVAL+CAYLD*AVAL+CJYLD*JVAL
ELSE
  PDD = -1934.14+13.99*JPLANT (estimate planting degree
       days)
  DTOT = 1.20559577+ .00093791* INIPP-.00084458*PDD-
.00822848*GSL
  ABYLD = SSYLD*.071
  AAYLD = SSYLD*.813
  AJYLD = SSYLD*.116
  CTYLD = SSYLD-SSYLD*DTOT
  CBYLD = CTYLD*.070
  CAYLD = CTYLD*.867
  CJYLD = CTYLD*.063
    ALDVAL = ABYLD*BVAL+AAYLD*AVAL+AJYLD*JVAL-PSTCOST
    CHKVAL = CBYLD*BVAL+CAYLD*AVAL+CJYLD*JVAL
ENDIF
```

Once yield estimations are complete OUTYLD and TRTSUM output subroutines are called.

<u>OUTYLD</u>

OUTYLD is called by PPIMPACT and writes yield summary information to output file 36. Total yield with and without aldicarb application is reported along with size category yields. The program returns to PPIMPACT.

TRTSUM

TRTSUM is called from PPIMPACT at the end of the simulation. TRTSUM writes a summary of treatment information to output file 39. Output variables include cumulative rainfall, irrigation, number of irrigation events, total drainage out of soil profile, nitrate and pesticide leached, as well as yield information and treatment value.

Summary

The documentation of model development procedures, development of yield loss functions, and an expansion of SUBSTOR to include the value of aldicarb to potato production were the results of work completed under Thesis Objective 5. The estimated value term may be used as a measure of the benefit of aldicarb application to growers. Aldicarb application value was intended to be compared to application risk values determined under Thesis Objective 3. Work completed under Thesis Objective 4 also showed limitations in the current information base. Improvements were suggested.

CHAPTER VI

NITRATE AND ALDICARB LEACHING EXPERIMENT

To obtain nitrate and aldicarb leaching information, two non-weighing lysimeters were installed at the Montcalm Potato Research Farm in 1986. In 1988, research was conducted using these lysimeters to test the impact of alternate management practices on nitrogen and aldicarb leaching. Results of this field experiment were used for comparison with simulation modeling results.

Materials and Methods

Two non-weighing lysimeters were installed in June of 1986 at the Michigan State University Potato Research Farm. The lysimeters are 48 inches wide, 68 inches long and 72 inches deep. They were constructed of welded 3/16 inch sheet metal. An epoxy material was sprayed on all lysimeter surfaces for rust reduction. Access chambers were located at the long end of the lysimeters to facilitate sample collection (Figure 23).

Installation

To determine the preinstallation soil profile, a six-foot deep soil core was taken. The soil was predominately a McBride sandy loam. Soil layers were removed separately using a back hoe, and placed on plastic tarps to prevent mixing.

Sufficient soil was removed so that the lysimeter tops were buried 12 inches below the soil surface. This burial

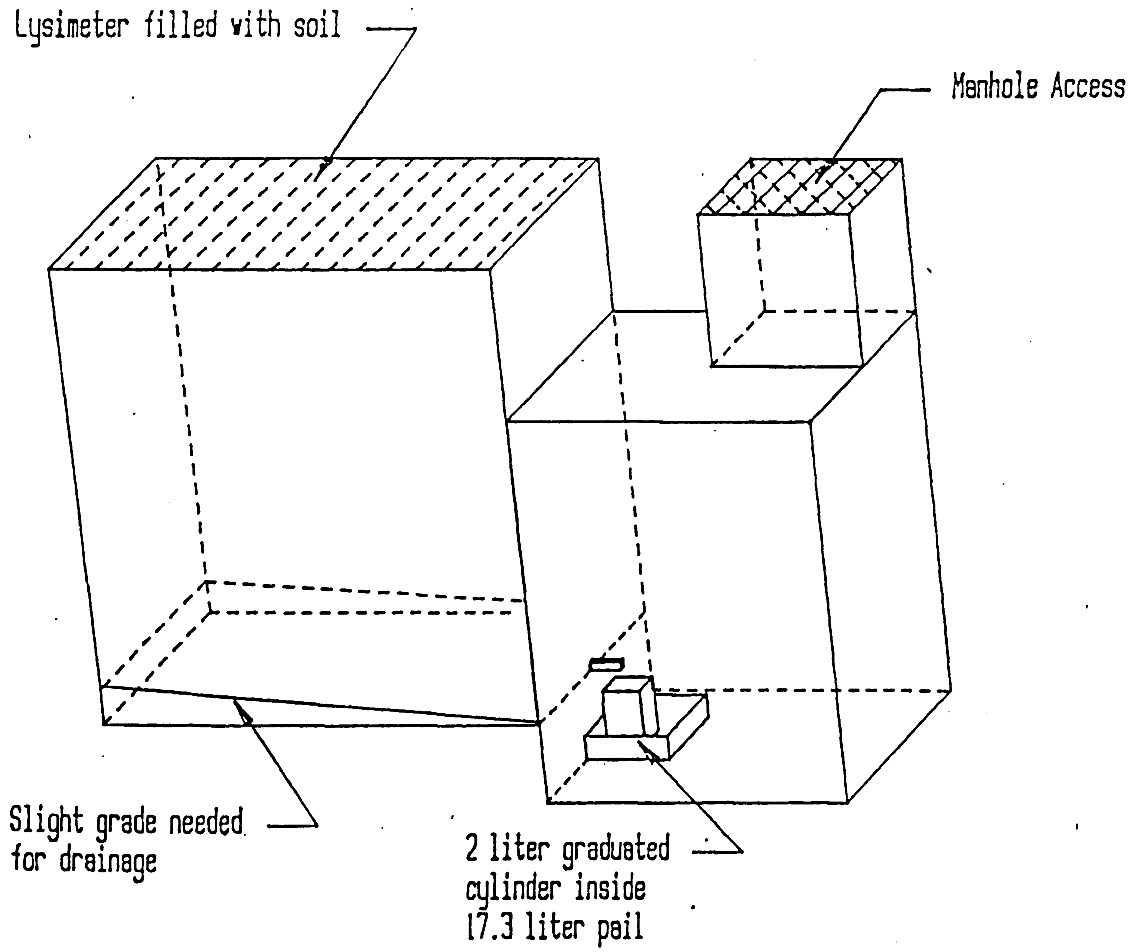

Figure 23. Isometric projection of non-weighing lysimeter.

depth allowed farm implement use. Once the lysimeters were placed into the soil and leveled, two inches of P stone were placed on the slanted metal drainage floors. A layer of drain tile cloth was placed over the stone to improve infiltration. After being sieved through a one half inch screen, the removed soil was placed directly on the drain tile cloth. Stones larger than one half inch were removed.

The soil was periodically packed while the lysimeters were being filled. The average depth of each soil layer was calculated and the soil was replaced accordingly. After the lysimeters were filled and covered, four inches of water were applied to ensure settling in and around the lysimeters.

Treatments

The treatments in the nitrate/aldicarb leaching experiment included the impact of at planting fertilizer, in-season fertilizer, and irrigation management. Sampling for aldicarb and nitrates began January 18, 1988.

Planting

Russet Burbank potatoes were planted on May 11, 1988. Seed pieces were placed four inches deep and 12 inches apart using 34 inch row spacing. Aldicarb was applied as TEMIK 15G in the furrow at 20.0 lbs./acre. At planting, fertilizer was applied to both standard and conservation treatments (Table 39).

Table 39. Nitrate/aldicarb leaching experiment at-plant fertilizer treatments.

Treatment	N lb/acre	P lb/acre	K lb/acre
Standard	75	50	75
Conservation	28	56	84

Fertilizer

All nitrogen was applied as urea. The standard management strategy received 75 lbs./acre nitrogen at planting followed by 69 lbs./acre 54 days after planting, and 55 lbs./acre 77 days after planting. The conservation management strategy received 28 lbs. nitrogen at planting followed by 54 lbs./acre 63 days after planting, and 31 lbs./acre 77 days after planting (Table 40).

Table 40. Nitrate/aldicarb leaching experiment nitrogen fertilizer treatments (lbs./acre).

Standard			Conservation		
Date	Rate	Cumulative	Date	Rate	Cumulative
5-11	75	75	5-11	28	28
7-04	69	144	.	.	28
.	.	144	7-13	54	82
7-27	55	199	7-27	31	113

Irrigation

If natural rainfall was insufficient to meet plant needs irrigation was applied using overlapping solid set sprinklers. The intent was to apply one inch per application to the standard treatment every three to five days and one half inch per application every two to three days to the conservation treatment. Actual irrigation rates were limited by the volume of available water (Table 41). The many irrigation volumes was less than intended.

Table 41. Nitrate/aldicarb leaching experiment irrigation treatments in (inches).

	Standard		Conservation	
Date	Rate	Cumulative	Rate	Cumulative
06/14	0.3	0.3	0.3	0.3
06/20	0.9	1.2	.	0.3
06/26	1.0	2.2	1.0	1.3
06/29	.	2.2	0.5	1.8
07/03	0.5	2.7	0.5	2.3
07/04	.	2.7	0.5	2.8
07/07	1.1	3.8	0.8	3.6
07/12	.	3.8	0.5	4.1
07/15	0.3	4.1	0.3	4.4
07/20	1.4	5.5	.	4.4
07/21	.	5.5	0.5	4.9
07/26	0.7	6.2	0.4	5.3
07/28	0.1	6.3	.	5.3
08/01	1.2	7.5	.	5.3
08/04	.	7.5	0.2	5.5
08/11	0.7	8.2	.	5.5
Average	0.7			0.5

Leachate Analysis

Leachate samples were collected and analyzed for concentrations of nitrate nitrogen and aldicarb.

Sampling

Leachate was collected in the lysimeter access hole using a nested collection device. A two liter graduated cylinder was placed inside a 17.3 liter pail inside a 125 liter plastic tub. This system was used so that the relative accuracy of measure would be consistent with the volume of the sample. Leachate collected was thoroughly mixed and two 100 cm^3 polypropylene samples bottles were filled. Samples were kept cool and out of sunlight during transportation to the MSU campus where they were stored in a freezer at -15^{o} C. Leachate volume was recorded. Leachate not used for analysis was taken off-site for disposal.

Nitrate

Nitrate analysis was performed using a Lachat flow injection analyzer QuikChem Method No. 12-107-04-1 A (Lachat, 1988). A 10 ppm reference standard was used for calibration. The minimum detection level was 0.01 ppm. The standard error of this procedure at 10 ppm was two percent.

Aldicarb

The frozen aldicarb samples were sealed in styrofoam coolers and sent by over-night mail to Rhone-Poulenc Ag Company. The samples were analyzed using high performance liquid chromatography. This method allows for the determination of carbamate residues (Aldicarb, Aldicarb-sulfoxide, and Aldicarb-sulfone) at one part-per-billion with a relative standard deviation of 10% at five parts-per-billion (Hudson, 1988).

Results

Leachate samples were collected on 17 dates (Table 42). Analysis of leachate samples indicated that no aldicarb, aldicarb sulfoxide, or aldicarb sulfone leached out of the soil profile during the growing season.

Aldicarb Degradation and Movement

Simulations of aldicarb degradation in soil indicated that aldicarb is rapidly converted to aldicarb sulfoxide which is then slowly converted to aldicarb sulfone and non-toxic hydrolysis products (Figure 24).

Table 42. Nitrate/aldicarb leaching experiment sampling results for leachate volume, nitrate concentration, and aldicarb metabolite concentrations.

	Conservation					Standard				
		Concentration					Concentration			
	Volume	ppm	ppb			Volume	ppm	ppb		
Date	liters	NO3-	ALD	ASO	ASN	liters	NO3-	ALD	ASO	ASN
18-Jan	26.9	35.1	nd	nd	nd	22.1	42.5	nd	nd	nd
23-Feb	110.4	3.2	nd	nd	nd	147.8	3.8	nd	nd	nd
25-Mar	31.6	2.5	nd	nd	nd	11.8	22.1	nd	nd	nd
19-Apr	31.6	0.8	nd	nd	nd	16.3	29.2	nd	nd	nd
08-Jun	8.6	9.8	nd	nd	nd	8.7	34.3	nd	nd	nd
23-Jun	4.8	33.9	nd	nd	nd	5.8	39.9	nd	nd	nd
03-Jul	2.6	35.9	nd	nd	nd	2.0	39.8	nd	nd	nd
12-Jul	0.9	30.4	nd	nd	nd	1.7	38.2	nd	nd	nd
20-Jul	0.1	.	.	.	.	0.1	.	.	.	.
26-Jul	0.1	.	nd	nd	nd	1.4	105.4	nd	nd	nd
31-Jul	0.1	.	.	.	.	0.1	.	.	.	.
11-Aug	0.1	.	.	.	.	1.7	87.1	nd	nd	nd
24-Aug	0.1	60.2	.	.	.	2.2	81.2	nd	nd	nd
31-Aug	0.0	.	.	.	.	1.0	105.0	nd	nd	nd
21-Sep	3.6	65.3	nd	nd	nd	20.6	60.7	*	*	*
28-Sep	41.8	100.4	nd	nd	nd	44.2	120.2	nd	nd	nd
06-Oct	43.0	59.7	nd	nd	nd	46.0	78.8	nd	nd	nd

nd - not detected (<1ppb) . - Insufficient volume
* - Cracked sample bottle

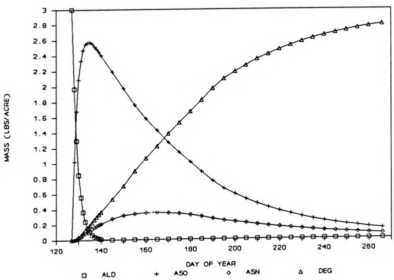

Figure 24. Simulated mass of aldicarb (ALD), aldicarb-sulfoxide (ASO), aldicarb-sulfone (ASN) total mass degraded (DEG) vs. day of year.

Because of this rapid degradation the movement of aldicarb within the soil profile is best shown as percentage of total toxic residue (TTR) remaining in each soil layer. For simulations representing the lysimeter experiment aldicarb was applied into layer 1 of the 6 layer representation of McBride soil. By mid season there was little difference in the distributions of aldicarb in the soil of conservation and standard treatments (Figure 25).

By the end of the simulated season the distribution of TTR in the soil had changed with a greater percentage of the TTR at leachable depths in lower layers of the standard management practice (Figure 26).

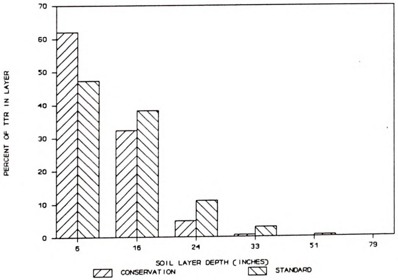

Figure 25. Mid-season (July 13) distribution of TTR in the soil profile for simulated conservation and standard treatments.

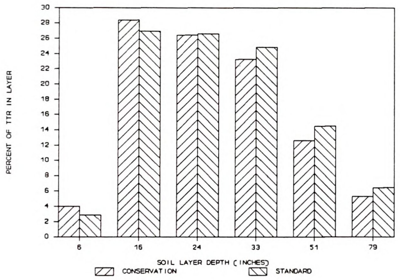

Figure 26. End of season (Sept 23) distribution of TTR in soil layer for simulated conservation and standard treatments.

Simulated vs. Observed Results

Yield results for simulated and observed compared favorably. Simulation analysis of leaching parameters was ended on the sixth of October. Simulation results indicated a greater mass of nitrate leached than observed. A small amount of TTR leached out of both the conservation and standard treatment soil profile. Ability to compare aldicarb results is limited. An estimate of simulation accuracy using the analysis minimum detection limit and amount of water leached out of the lowest layer of the soil profile indicated an over estimation of aldicarb mass leached (Table 43).

Table 43. Comparison of per acre simulated and observed results for risk-benefit parameters.

	Conservation		Standard	
Parameter	Simulated	Observed	Simulated	Observed
Yield cwt	237.0	241.5	253.8	244.8
NO3- lbs	40.84	0.26	56.54	1.25
TTR lbs	0.0162	<0.000022[1]	0.0219	<0.000026[1]

1 - Estimated based on minimum detection limit and leachate volumes

Plant Stress Factors

Observed yield showed a one percent decrease associated with the conservation management strategy while the simulation indicated a seven percent loss. As part of its operation SUBSTOR calculates water and nitrogen stress factors for each of four simulated plant growth stages. Growth stage 1 lasts from plant emergence to the beginning of tuber growth. Growth stage 2 lasts from the beginning of tuber growth until linear tuber bulking begins. Growth stage 3 lasts from the beginning of linear tuber bulking until the tuber becomes the dominant sink for photosynthates. Growth stage 4 lasts from dominant sink to maturity.

These stress factors range from 0 to 1 and can be used to explain the yield differences between conservation and standard treatments. SUBSTOR estimated that there was considerable water stress in both treatments explaining why the yields in the lysimeter were relatively low (Table 44). Water stress under the standard management strategy was greater than water stress under the conservation management strategy during growth stage 3.

Table 44. Simulated water stress factors for conservation and standard management strategies in the nitrate/aldicarb leaching experiment.

Growth	CSD1		CSD2	
Stage	Conservation	Standard	Conservation	Standard
1	0.14	0.16	0.18	0.19
2	0.32	0.36	0.43	0.48
3	0.39	0.48	0.47	0.57
4	0.13	0.13	0.18	0.18

Nitrogen stress factors showed greater nitrogen stress under the conservation strategy than under the standard strategy, particularly during growth stage two (Table 45). Apparently early nitrogen stress (low at-plant nitrogen application) allowed the plants in the conventional treatment to become larger and therefore require more water during growth stage three. The stresses must have counter balanced each other so that the combined impact was low.

Table 45. Simulated nitrogen stress factors for conservation and standard treatments in the nitrate/aldicarb leaching experiment.

Growth	CNSD1		CNSD2	
Stage	Conservation	Standard	Conservation	Standard
1	0.01	0.00	0.01	0.01
2	0.19	0.13	0.31	0.22
3	0.01	0.01	0.03	0.01
4	0.00	0.00	0.01	0.00

Comparison of simulated and observed nitrate mass leached was favorable in terms of the relationship between mass leached and day of year but not in terms of total mass leached. Simulation results indicated an increase in cumulative mass leached on day of year 170 and 230 (Figure 27). Observed results indicated an increase in cumulative mass leached on day of year 177 and 244 (Figure 28).

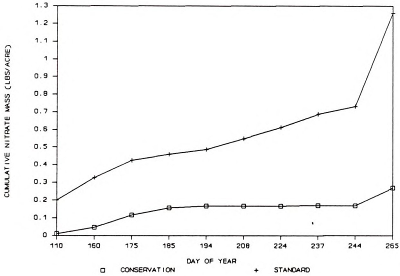

Figure 27. Nitrate/aldicarb leaching experiment observed nitrate mass leached vs. day of year.

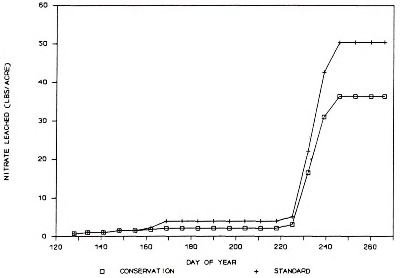

Figure 28. Nitrate/aldicarb leaching experiment simulated nitrate mass leached vs. day of year.

Part of the difference in total mass leached between simulated and observed may be found in the relationship between cumulative drainage volume and cumulative nitrate mass leached. Simulated results indicated little difference between management strategies (Figure 29). Observed results indicated greater masses leached per unit of drainage in the standard management strategy than in the conservation management strategy (Figure 30). Mixing in the soil profile may be mitigating changes in nitrate concentration at lower soil layers.

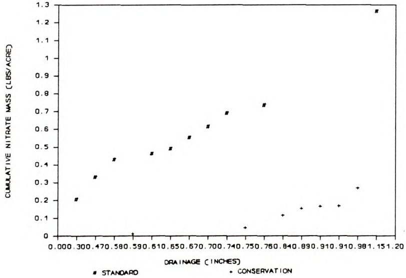

Figure 29. Nitrate/aldicarb leaching experiment observed cumulative nitrate mass leached vs. cumulative drainage.

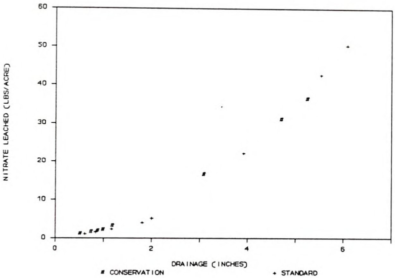

Figure 30. Nitrate/aldicarb leaching experiment simulated cumulative nitrate mass leached vs. cumulative drainage.

The relationship between simulated aldicarb total toxic residue mass leached and day of year was similar to that of simulated nitrate mass leached (Figure 31). Leaching events occurred on day 170 and day 230. No aldicarb residues were observed in lysimeter leachate.

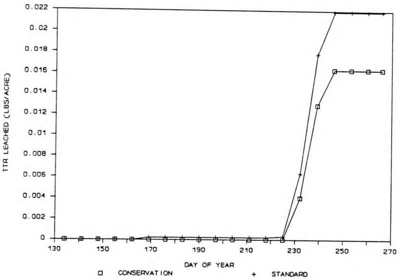

Figure 31. Nitrate/aldicarb leaching experiment simulated total toxic residue mass leached vs. day of year.

The percentage differences between estimated and observed values show the relative accuracy of simulation results (Table 46). Percentage differences for nitrate mass leached did not compare favorably. Accuracy of percentage difference for total toxic metabolite fell between values for yield and nitrate mass leached.

Table 46. Comparison of simulated and observed percentage decrease in yield, nitrated leaching, and aldicarb leaching parameters associated with a switch to the conservation strategy.

	Percentage Decrease	
Parameter	Simulated	Observed
Yield	7	1
Nitrate	28	79
TTR	26	15[1]

1 - estimated based on minimum detection limit and leachate volume

Implications of Lysimeter Experiment Results

Comparison of observed versus simulated results for the lysimeter experiment indicated that the risk-benefit analysis simulation results were fairly accurate for McBride soil in 1988. This increases the credibility of the risk-benefit analysis results but can not be considered a full model validation. Estimations of the impact of management practices on nitrate are questionable. For the lysimeter experiment, the model over estimated the mass of nitrate moving out of the soil profile. The nitrate leached overestimation assumption is further backed by the magnitude of leaching losses in comparison to the amounts applied. The reliability of the aldicarb model is uncertain. Simulated aldicarb mass leached was greater than observed, although the relative impact of management strategies on mass leached was small. If aldicarb mass leached is overestimated it may be explained by unaccounted volatilized mass.

CHAPTER VII

SIMULATION MODELING FOR REGIONAL RISK-BENEFIT ANALYSIS

Work completed under Thesis Objective 5 represents the application of results from Thesis Objectives 1-4. Revised SUBSTOR was used to estimate impacts of selected potato production management factors, including irrigation scheduling, nitrogen fertilizer application, and aldicarb application on potato yield, nitrate leaching and aldicarb leaching. This was done under each set of environmental conditions, soil type and land use identified in the prototype study area.

Crop yield, nitrogen costs and aldicarb costs were used to determine management strategy profitability. Mass of nitrate leached below the soil profile was used as a measurement of ground water nitrate contamination risk for each management strategy. Mass of aldicarb leached below the soil profile was used as a measurement of ground water aldicarb contamination risk for each management strategy.

Materials and Methods

Results from study Thesis Objective 1 indicated that potato production occurred on five soil types between 1986 and 1988. For each soil type and year combination, the impacts of alternate management strategies were compared using the revised version of SUBSTOR. SUBSTOR modifications were described in Chapter IV and Chapter V.

SUBSTOR

Revised SUBSTOR was used for risk-benefit analysis simulations. The model was used to estimate the impacts of irrigation and nitrogen application on nitrate movement and aldicarb movement through simulation of soil water movement, plant growth and development, and plant water uptake. The impact of aldicarb on plant development was not a part of the revised version of SUBSTOR used. The impact of aldicarb on potato tubers was estimated at the end of each simulation. This was done using the model developed in Chapter V. The impact of delayed aldicarb application on tuber yield was not estimated (Table 47).

Table 47. Sensitivity of revised SUBSTOR in relation to production system variables.

Output	Input timing and application rate		
Parameter	Irrigation	Nitrogen	Aldicarb
Water movement	Yes	Yes	No
Nitrate Movement	Yes	Yes	No
Aldicarb Movement	Yes	Yes	Yes
Plant Growth	Yes	Yes	No
Tuber Yield	Yes	Yes	Yes[1]

1 For at-plant application of aldicarb only

Forty SUBSTOR simulations were performed. Twenty of these simulations were used for comparative risk-benefit analysis. These twenty simulations represented the ten sets of environmental conditions (soils and weather) determined under Thesis Objective 1 and the two management strategies (standard and experimental) determined under Thesis Objective 2. Aldicarb was applied at planting in both standard and experimental management strategies. Twenty simulations represented the standard and conservation management strategies with aldicarb applied at plant emergence. These twenty simulations were used to show the impact of delayed application on leaching, but could not be used for risk-benefit analysis because impact on yield was undetermined.

Estimated yields, nitrate mass leached, and aldicarb mass leached were recorded. Aldicarb mass leached was reported as the sum of aldicarb plus aldicarb-sulfoxide plus aldicarb-sulfone (total toxic residue (TTR)).

Weather. Weather information was obtained from a Licor 2000 data logger and CR-21 weather station. Each day, readings were taken for maximum and minimum temperature, precipitation, and solar radiation. This data was recorded and used for SUBSTOR modeling.

Soils. Soil profile properties were defined for five soils using Soil Conservation Service 232 forms. These forms describe chemical and physical characteristics of soils. If not available in the SCS 232 form values were estimated using procedures defined in CERES-Maize model documentation.

Management Strategies Data files representing irrigation management strategies were developed for 1986 - 1988. Standard treatments involved one inch of irrigation water applied every three to five days, whereas conservation treatments had one half inch applied every two to three days. The nitrogen fertilizer applications determined under

Thesis Objective 2 were used for the risk-benefit analysis system. Aldicarb application was simulated by modification of the ALDIC.PAR input file described in Chapter IV. For the risk-benefit analysis system, aldicarb was applied at planting for standard and conservation management strategies. Additional simulations were performed showing the impact of delayed aldicarb application on mass leached.

Benefit. Management system benefit was estimated using the price of nitrogen fertilizer, the cost of aldicarb, and the market value of tubers (Table 48).

Table 48. Market prices used in management strategy benefit analysis.

Year	Nitrogen $/lb.[1]	Aldicarb $/3.0 lb.ai.[2]	Tubers $/CWT[3]
1986	0.18	47.00	8.00
1987	0.15	47.00	4.50
1988	0.19	47.00	8.40

1 Mason Elevator 2 Grower Services 3 Spud Pack

Economic value was estimated for the standard and conservation management strategies using at-plant aldicarb application. Management strategy value was calculated by multiplying the marketable tuber yield by market value and then subtracting nitrogen and aldicarb costs.

Risk. Risk to ground water from agricultural non-point source contamination was estimated by simulation of the mass of nitrate nitrogen, aldicarb, and aldicarb metabolites leaching out of the soil profile. Nitrate risk measures were estimated for both standard and conservation (at-plant aldicarb) management schemes. Aldicarb risk measures were estimated for standard and conservation management with at-

plant and at-emergence aldicarb application.

Results

During the three years for which simulation analysis was performed, there was large variation in growing season precipitation. The fall of 1986 was inordinately wet. The 1987 growing season was moderate, with a fairly even rainfall distribution. The 1988 growing season was dry. This variation in precipitation distribution was fortunate, impact of alternate management practices could be estimated for a wet, a normal, and a dry growing season (Figure 32).

Irrigation volume for conservation and standard management strategies changed for each year of the study with the conservation management strategy being more sensitive to rainfall distribution than the standard management strategy (Table 49).

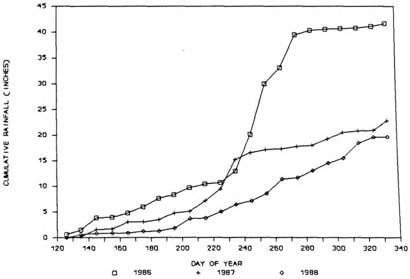

Figure 32. Cumulative rainfall during 1986, 1987, and 1988.

Table 49. Cumulative water applied in standard and conservation management strategies.

Year	Rain	Irrigation (inches) Standard	Conservation
1986	34.8	13.0	9.5
1987	17.4	16.0	11.0
1988	11.4	17.0	13.5

Simulation

Simulation results indicated that weather, soil type, and alternate management practices impacted water, nitrate, aldicarb leaching, and the yield of marketable tubers (Table 50).

Table 50. 1986-1988 Simulation results for five soil types and two management strategies.

			Leached			Market tuber	
			(in.)	(lbs./acre)		(CWT/acre)	
Year	Soil Type	Manag[1]	Water	NO3-	Aldicarb	Aldicarb	Check
1986	Epoufette	Cons	28	237	0.4510	264	216
1986	Epoufette	Stan	32	292	0.6096	266	217
1986	Grayling	Cons	26	203	0.4179	305	252
1986	Grayling	Stan	31	240	0.5495	354	297
1986	Mancelona	Cons	27	151	0.7584	220	178
1986	Mancelona	Stan	31	194	1.0126	264	216
1986	McBride	Cons	27	92	0.5069	339	283
1986	McBride	Stan	31	131	0.6603	366	309
1986	Montcalm	Cons	27	165	0.2952	315	261
1986	Montcalm	Stan	31	204	0.4000	340	284
1987	Grayling	Cons	8	153	0.1025	415	354
1987	Grayling	Stan	12	161	0.2508	545	484
1987	Mancelona	Cons	9	82	0.3322	389	330
1987	Mancelona	Stan	13	112	0.5364	451	390
1987	McBride	Cons	8	33	0.1618	477	415
1987	McBride	Stan	12	47	0.3493	571	510
1987	Montcalm	Cons	8	78	0.0484	440	379
1987	Montcalm	Stan	12	112	0.1311	506	444
1988	McBride	Cons	8	26	0.0869	470	408
1988	McBride	Stan	11	27	0.1391	571	511

1 Management strategy Stan -Standard Cons -Conservation

Estimated grower profitability was affected by year, soil type, and management practices (Table 51). The average value of aldicarb to growers was $307 for the conservation management strategy and $327 for the standard management strategy.

Table 51. Estimated management strategy profitability in dollars by year, soil type, and management practice.

		Conservation		Standard	
Year	Soil Type	Aldicarb	No Aldicarb	Aldicarb	No Aldicarb
1986	Epoufette	2038	1701	2045	1700
1986	Grayling	2366	1989	2749	2340
1986	Mancelona	1686	1397	2029	1692
1986	McBride	2638	2237	2845	2436
1986	Montcalm	2446	2061	2637	2236
1987	Grayling	1798	1571	2376	2148
1987	Mancelona	1681	1463	1953	1725
1987	McBride	2077	1845	2493	2265
1987	Montcalm	1911	1683	2200	1968
1988	McBride	3873	3399	4711	4254

For the conservation management strategy, simulation results indicated that in 1986 for all soils except McBride more nitrogen was leached out of the soil profile than was applied as fertilizer. In the standard management strategy with exceptions of Mancelona and McBride more nitrate nitrogen was leached out of the profile (Table 52). This would indicate that leaching caused by heavy fall rains extracted residual soil nitrogen from the soil profile. With the exception of Grayling sand, percentage nitrate leaching in 1987 and 1988 was closer to the expected 17 to 54 percent loss predicted by Hubbard (1984) and Hallberg (1986).

Table 52. Summary of nitrate mass leached and percentage of mass applied (%AP) by year, soil type, and management strategy.

		Conservation		Standard	
Year	Soil Type	Mass	%AP	Mass	%AP
1986	Epoufette	237	158	292	146
1986	Grayling	203	135	240	120
1986	Mancelona	151	101	194	97
1986	McBride	92	61	131	66
1986	Montcalm	165	110	204	102
1987	Grayling	153	102	161	81
1987	Mancelona	82	55	112	56
1987	McBride	33	22	47	24
1987	Montcalm	78	52	112	56
1988	McBride	26	17	27	14
	Average	122	81	152	76

Estimated aldicarb mass movement out of the soil profile was also impacted by management practices (Table 53). Aldicarb mass leached decreased with the use of conservation irrigation management practices, but increased with emergence application. The increase in mass leached associated with emergence application of aldicarb may be due to greater masses in the soil at the end of the season which are susceptible to movement with heavy fall rains.

Table 53. Summary of aldicarb TTR mass leached and percentage of mass applied (%AP) by aldicarb application timing, management practice, soil type, and year.

	At Plant				At Emergence			
	Research		Standard		Research		Standard	
	Mass	%AP	Mass	%AP	Mass	%AP	Mass	%AP
1986 Epoufette	0.4510	15	0.6096	20	0.4848	16	0.6575	22
1986 Grayling	0.4179	14	0.5495	18	0.4630	15	0.6037	20
1986 Mancelona	0.7584	25	1.0126	34	0.6869	23	0.9656	32
1986 McBride	0.5069	17	0.6603	22	0.6869	23	0.6928	23
1986 Montcalm	0.2952	10	0.4000	13	0.3273	11	0.4470	15
1987 Grayling	0.1025	3	0.2508	8	0.1309	4	0.3334	11
1987 Mancelona	0.3322	11	0.5364	18	0.4353	15	0.7025	23
1987 McBride	0.1618	5	0.3493	12	0.2093	7	0.4563	15
1987 Montcalm	0.0484	2	0.1311	4	0.0515	2	0.1701	6
1988 McBride	0.0869	3	0.1391	5	0.1201	4	0.1924	6
AVG	0.3161	11	0.4639	15	0.3596	12	0.5221	17

Risk-Benefit Analysis

Of the forty simulations performed for risk-benefit analysis twenty may be directly compared. Comparable management strategies for risk-benefit analysis were conservation and standard irrigation and nitrogen strategies with aldicarb applied at planting to both management strategies.

The use of conservation management practices decreased the profitability of potato production but also decreased risk to ground water contamination (Table 54). The impact of alternate management practices differed for each year of the study. In 1986, yield loss associated with the conservation strategy was the least while the percentage decrease in nitrate and aldicarb mass leached was the greatest. In 1988, yield loss associated with the conservation management strategies was the greatest while

impact on nitrate and aldicarb mass leaching was the least.

Table 54. Decrease in profit and leaching measures (standard - conservation) associated with a switch to the conservation management strategy.

			Leached		
		Profit	(in.)	(lb./acre)	
Year	Soil Type	($/acre)	H2O	NO3-	TTR
1986	Epoufette	7	4	55	0.1586
1986	Grayling	383	5	37	0.1316
1986	Mancelona	343	4	43	0.2542
1986	McBride	207	4	39	0.1534
1986	Montcalm	191	4	39	0.1048
1987	Grayling	578	4	8	0.1483
1987	Mancelona	272	4	30	0.2042
1987	McBride	416	4	14	0.1875
1987	Montcalm	290	4	34	0.0827
1988	McBride	839	3	1	0.0522
Average		352	4	30	0.1477

These management practice impact values may also be expressed as a percent decrease associated with a switch to the conservation strategy (Table 55).

Table 55. Percentage decrease in profit and leaching measures (1.0-conservation/standard) associated with a switch to the conservation management strategy.

		Profit	Leached		
		Decrease	(in.)	(lb./acre)	
Year	Soil Type	($/acre)	H2O	NO3-	TTR
1986	Epoufette	<1	13	19	26
1986	Grayling	14	16	15	24
1986	Mancelona	17	13	22	25
1986	McBride	7	13	30	23
1986	Montcalm	7	13	19	26
1987	Grayling	24	33	5	59
1987	Mancelona	14	31	27	38
1987	McBride	17	33	30	54
1987	Montcalm	13	33	30	63
1988	McBride	18	27	4	38
AVG		13	23	20	38

The impact of a regional shift to the conservation management strategy was displayed by integrating changes in profitability, nitrate mass and aldicarb mass over the prototype study area (Table 56). If the total mass of nitrate leached was transported into water supplies, it would be sufficient to raise the nitrate concentration of 210,567 gallons of pure water to the health advisory level. If the total mass of aldicarb leached was transported into water supplies, it would be sufficient to raise the aldicarb concentration of 52,475,563 gallons of pure water to the health advisory level. Further degradation of both compounds would be expected in the unsaturated zone below the soil profile, so actual risk to ground water would be decreased.

Table 56. Total decrease in profits, nitrate mass leached, and aldicarb mass leached associated with a switch to conservation management strategy in the prototype study area.

			($)	(lbs.)	
Year	Soil Type	Acres	Profit	NO3-	TTR
1986	Epoufette	3	21	165	0.4758
1986	Grayling	9	3447	333	1.1844
1986	Mancelona	24	8232	1032	6.1008
1986	McBride	100	20700	3900	15.3400
1986	Montcalm	8	1528	312	0.8384
1987	Grayling	2	1156	16	0.2966
1987	Mancelona	8	2176	240	1.6336
1987	McBride	57	23712	798	10.6875
1987	Montcalm	30	8700	1020	2.4810
1988	McBride	91	76349	91	4.7502
	TOTAL	332	146021	7907	43.7883

Summary

The conservation management practice was associated with decreases in yields, nitrate mass leached, and aldicarb mass leached. Differences in yield and masses leached were inversely proportional and seem to be a function of weather characteristics. Large yield differences and small leaching differences were associated with 1988, a dry season. Smaller yield differences and larger leaching differences were associated with 1986, a wet year. The conservation management strategies resulted in average profitability decrease of $352/acre, an average nitrate reduction of 30 lbs/acre, and an average aldicarb reduction of 0.1477 lbs./acre.

CHAPTER VIII

DISCUSSION AND RECOMMENDATIONS

Discussion and recommendations are organized based on thesis objectives.

Regional Data Base

The digitization portion of the geocoding process was completed using complete polygon techniques which require the majority of boundaries to be digitized twice. Operator time would be reduced if arc-node digitization procedures were used. Arc-node digitization also provides a cleaner output file for display. GIS analysis proved valuable in determining spatial variation in factors important to regional potato production.

ERDAS Matrix operations using soil type,, land use, and weather could be expanded to include land ownership (Platt map). A mail survey of growers could then be used to more accurately parameterize simulations representing grower practices.

Alternate Management Practices

The conservation management strategies used in this study was only one of many possible alternatives. Lack of information on yield impact of emergence applied aldicarb limited the scope of risk-benefit analysis. Application of one-half inch per application every two to three days may be insufficient to meet plant needs.

Future irrigation management practices should be more carefully defined and linked to soil water content. Precipitation forecasts could be used in an expected precipitation value format (probability of rainfall multiplied by expected precipitation) to optimize soil water relationships. Current SUBSTOR routines for irrigation at soil water threshold fill the whole soil profile and should be modified to fill the soil profile to the irrigation management depth.

Future conservation should include an integrated research review addressing the impact of management strategies on crop yield and compound movement. Information obtained could then be used in a quadratic programing format for crop management optimization including profitability and ground water risk.

Aldicarb Movement and Degradation

The aldicarb movement and degradation model was limited by lack of information on systemic uptake of aldicarb and great variability in degradation rate estimates. One year of lysimeter data is insufficient for proper validation of model functions. An increase in precipitation and leaching in 1988 would have improved the reliability of simulated versus observed comparisons. Mass values of zero are difficult to compare.

A major problem faced in integration of aldicarb movement and degradation function with existing models was the level of existing program documentation. There are

three main categories of documentation: source code, documentation of code operation, and documentation of information and processes used in code development. With standard FORTRAN code it is very difficult to understand the implications of parameter modification. Documentation of code operation allows for understanding of how parameter modifications impact simulation results but does little to link simulation modeling to the processes being simulated. If information and processes used in code development are documented, then simulation modeling becomes a condensation of the current level of system interaction understanding. The impact of variable modification is known as well as the source of coefficients which modify the variables. When combined with a hierarchal modeling structure, integrated research review and meta-analysis techniques may be successfully used for third level documentation.

Addition research is needed showing the fate of aldicarb at the soil surface. Does aldicarb evaporate in solution with soil water, precipitate at the soil surface, or volatilize and leave the application site in a gaseous state?

Studies dealing with systemic uptake of aldicarb focused on the concentration remaining in tubers at harvest. Additional information is needed on the mass uptake of aldicarb by the potato plant during the growing season. Is aldicarb or its metabolites taken up in proportion to concentration in translocated soil waters, excluded, or

preferentially absorbed?

Research review results showed large variation in estimates for decay rates. Decay rate is very important in estimation of risk to ground waters. Three sites of study are needed: the biologically active root zone, the unsaturated zone, and in ground water. Growth chamber experiments should be conducted for ranges of microbial population density, solution pH, temperature, organic matter content, and soil texture. In addition to statistical hypothesis testing, probability distributions should be developed to emphasize the uncertainty associated with degradation rate estimation.

A data base should be developed using integrative research review methods containing the results of field experiments showing the impact of management practices on potato plant growth and development, soil water balance, nitrate movement, and aldicarb movement. This data base should represent a range of management practices and site locations.

For each field experiment in the data base SUBSTOR simulations should be performed. Independent management variables should then be analyzed in conjunction with output dependant variables using residual analysis. Residual values (simulated - observed) should be graphed versus each independent variable. This procedure can be used to provide a quantified measure of simulation accuracy, and to show which model functions are the least accurate.

Aldicarb/Root-lesion Nematode Impact

Integrated research review and meta-analysis techniques where highly valuable for determination of the yield impact model. A reliable nematode population model could not be developed because an insufficient number of samples taken per season were available and violation of statistical assumptions. Aldicarb was applied at planting in all studies used in the integrated research review. This limited ability to estimate the impact of at plant emergence aldicarb application.

The impact of aldicarb on plant partitioning was estimated for Russet Burbank potatoes. Partitioning ratios showed a decrease in partitioning to above ground portions of the plant without aldicarb. Aldicarb may be stimulating growth or suppressing Potato Early Die disease. Partitioning information was not integrated into SUBSTOR because it was available for only one cultivar and would have required a substantial change in program operation.

Additional data needs to be collected for the determination of the impact of aldicarb and P.penetrans on crop production. Five or more evenly spaced nematode population density samples are needed to represent nematode population dynamics. Daily air and soil temperature measurements should be taken. Leaf, stem, root, and tuber biomass should be recorded for each sampling date. Collection of this data should allow for quantitative estimation of in-season nematode population impacts on plant

growth, and tuber yield.

Growth chamber experiments should be conducted to provide information for distributed delay modeling of P.penetrans populations. Growth chamber temperatures should be regulated to represent mean and mean plus and minus one standard deviation of diurnal temperature. Population density should be recorded by temperature treatment, life stage, and location (soil or root).

The impact of delayed aldicarb application on plant growth and tuber yield is currently unknown. Multiple year field experiments should be performed testing the impact of no aldicarb application, aldicarb applied at planting, and aldicarb applied at plant emergence on tuber yield for several cultivars.

Risk-Benefit analysis

Risk benefit analysis system results are subject to a great deal of uncertainty. Of the five soil types on which potatoes were produced during the three years of the study, data for risk-benefit model validation were available for one soil type during one year. This problem was further compounded by the fact that 1988 was a dry year and little leaching occurred. Simulated and observed yield estimates did not compare favorably. Simulated yield indicated much greater losses associated with the conservation management strategies than lysimeter experiment results.

The over-all methodology for regional risk-benefit analysis worked quite well. GIS analysis provided the

necessary information on soil type and land use for simulation modeling of risks and benefits in heterogenous environments. If simulation modeling results were validated, then the integration of geographic information systems with simulation modeling could prove to be a very useful tool for estimation of the regional impact of alternate management practices on associated risks and benefits.

Cost and time requirements prohibit the use of non-weighing lysimeters for validation on multiple soil types. Non-weighing lysimeters can not be used to determine concentrations within the soil profile. Procedures have been developed using tensiometers and suction lysimeters for quantitative pesticide analysis. In 1986, Sandra C. Cooper published procedures for the design and installation of a monitoring network for measuring the movement of aldicarb and its residues in the unsaturated and saturated zones. These procedures were developed under the auspices of the U.S. Geologic Survey, Water Resource Division and should be considered in the design of validation experiments.

Summary

The risk-benefit analysis system developed in this thesis can be used to analyze the impact of irrigation, nitrogen, and aldicarb management practices but can not be used to estimated the impact of crop rotation or other pest mangement practices. Additional research is needed to determine optimal potato produciton managment practices.

This risk-benefit analysis system uses mass of nitrate and aldicarb leached out of the lowest layer of the soil profile as a measure of risk. This measure of risk could be improved by expansion of model abilities to include movement of nitrate and aldicarb through the remainder of the unsaturated zone, into ground water supplies, and into drinking water. Then the presence of nitrate and aldicarb in drinking water must be linked to its impact on health and environmental quality.

Another question that needs to be addressed is that of private cost vs. public benefit. The cost of switching to a management strategy which decreases grower profitability is of private concern. Contamination of ground water is a public concern. Who should absorb the cost of protecting ground water quality? Are growers responsible for protecting water or should the public contribute in mitigating profitability decreases.

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APPENDIX A

STUDY AREA LAND USE 1986-1988

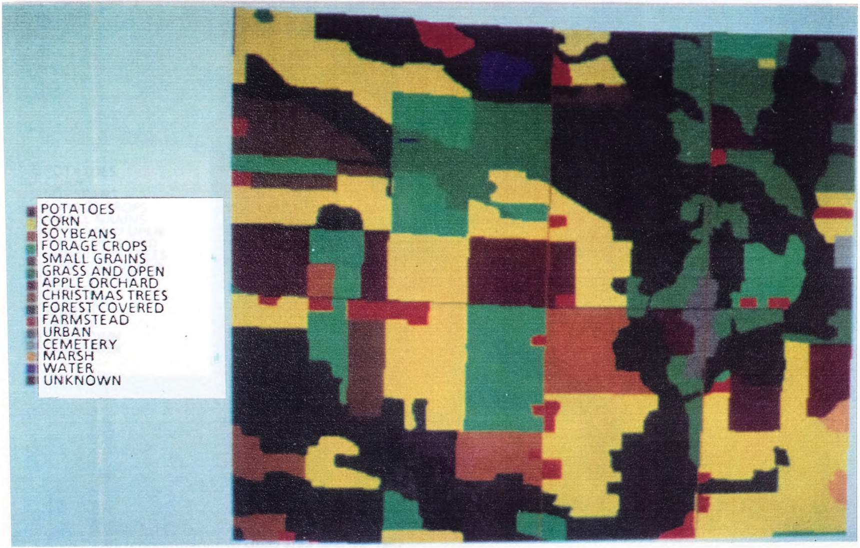

Figure 1. GIS representation of study area land use 1986.

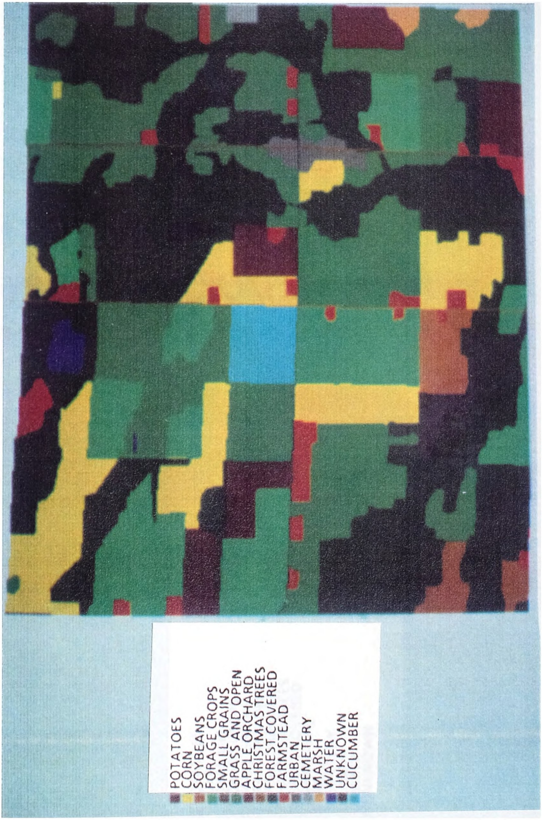

Figure 2. GIS representation of study area land use 1987.

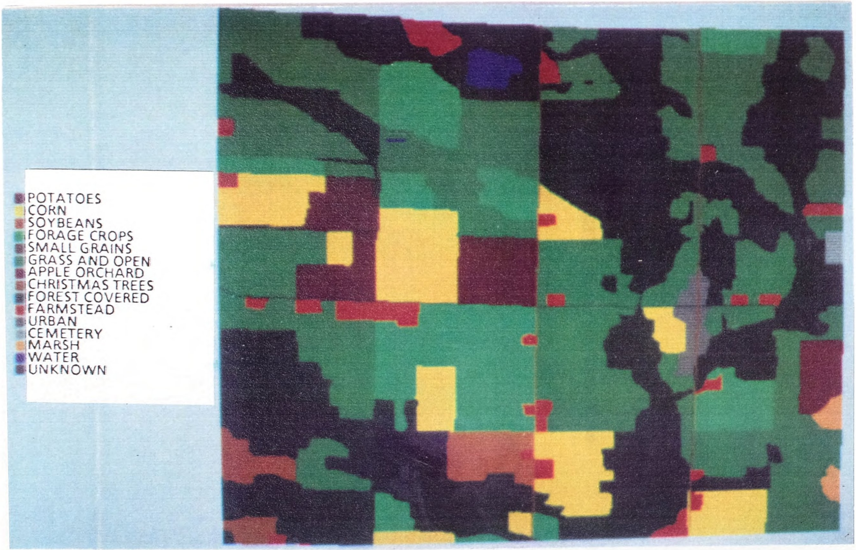

Figure 3. GIS representation of study area land use 1988.

APPENDIX B

PRATYLENCHUS penetrans DATA BASE

Table 1. Pratylenchus penetrans data base pre-plant measures.

Study NO#	Cultivar	Year	Jdate	DD10	P.p./100 cc Soil Aldicarb	Check
1	SUP	1986	133	20.3	32.0	38.0
2	SUP	1982	148	43.1	12.0	16.0
3	SUP	1982	149	43.1	16.0	9.0
4	SUP	1982	133	223.3	14.0	7.0
5	SUP	1981	134	131.0	3.6	3.6
6	SUP	1981	134	131.0	2.0	3.6
7	SUP	1981	134	131.0	5.6	2.0
8	SUP	1981	134	131.0	3.2	5.2
9	SUP	1980	134	164.3	45.2	28.6
10	SUP	1979	148	46.6	30.4	28.2
11	SUP	1979	148	46.6	23.0	42.4
12	SUP	1979	148	46.6	42.0	54.6
13	SUP	1978	121	139.2	6.0	14.0
14	SUP	1978	121	139.2	12.0	24.0
15	SUP	1978	121	139.2	24.0	22.0
16	SUP	1977	130	0.0	24.0	43.0
17	SUP	1977	130	0.0	24.0	43.0
18	SUP	1977	130	0.0	24.0	43.0
19	RB	1986	141	116.0	3.2	20.2
20	RB	1982	122	0.0	17.0	7.0
21	RB	1982	122	0.0	24.0	11.0
22	RB	1982	122	0.0	29.0	45.0
23	RB	1982	122	0.0	54.0	67.0
24	RB	1977	130	0.0	51.0	55.0
25	RB	1977	130	0.0	51.0	55.0
26	RB	1977	130	0.0	51.0	55.0
27	RB	1985	129	131.0	3.8	3.8
28	ATL	1983	131	94.9	9.9	11.0
29	ATL	1983	131	94.9	2.5	4.0
30	ATL	1983	131	94.9	23.0	21.5
31	ATL	1983	131	94.9	47.0	15.5
32	ATL	1982	116	0.0	11.0	23.0
33	ATL	1982	116	0.0	57.0	51.0
34	ATL	1981	136	171.4	18.0	16.0

Table 2. Pratylenchus penetrans data base harvest measures.

Study NO#	J date	B CWT/Acre Treat	B CWT/Acre Check	A CWT/Ac Treat	A CWT/Ac Check	J CWT/Ac Treat	J CWT/Ac Check	Knob CWT/Ac Treat	Knob CWT/Ac Check	Total CWT/Ac Treat	Total CWT/Ac Check
1	251			493.0	449.0						
2	252	11.0	11.0	193.0	177.0	13.0	7.0			217.0	195.0
3	250	13.0	12.0	193.0	177.0	13.0	7.0			219.0	196.0
4	250	18.0	19.0	205.0	163.0	9.0	3.0			232.0	185.0
5	237	11.2	10.4	343.5	289.6	36.8	22.7			391.5	322.7
6	237	11.6	9.1	367.7	307.3	65.3	38.5			444.6	354.9
7	237	20.7	20.2	277.5	249.5	9.1	7.5			307.3	277.2
8	237	14.8	13.0	326.3	276.7	38.2	15.6			379.3	305.3
9	230			214.2	117.4	2.3	0.0				
10	243	11.7	9.7	220.8	191.8	17.8	9.3			250.3	210.8
11	243	10.0	9.4	246.6	221.0	25.6	13.4			282.2	243.8
12	243	10.6	10.4	281.7	252.2	32.5	17.3			324.8	279.9
13	233	10.8	8.4	264.6	212.0	4.1	4.3			279.5	224.7
14	233	9.4	6.9	285.3	235.0	10.2	7.2			304.9	249.1
15	233	8.4	8.0	301.1	224.5	22.5	5.8			332.0	238.3
16	265									172.0	119.0
17	265									196.0	105.0
18	265									174.0	86.0
19	281	31.3	32.8	277.8	157.8	38.5	29.8			411.1	271.1
20	252	88.0	99.0	231.0	166.0	8.0	3.0	16.0	6.0	343.0	274.0
21	252	63.0	73.0	313.0	287.0	38.0	27.0	24.0	14.0	428.0	394.0
22	252	76.0	95.0	216.0	193.0	5.0	1.0	20.0	4.0	318.0	293.0
23	252	64.0	71.0	293.0	254.0	21.0	12.0	27.0	10.0	405.0	347.0
24	265									256.0	200.0
25	265									245.0	213.0
26	265									270.0	194.0
27	267	3.3	4.4	334.5	212.2	42.2	8.7	26.9	14.6	444.1	280.3
28	271	28.0	28.0	291.0	300.0	14.0	6.0			333.0	334.0
29	271	28.0	30.0	329.0	366.0	46.0	25.0			403.0	421.0
30	271	30.0	32.0	353.0	372.0	48.0	24.0			431.0	428.0
31	271	34.0	25.0	339.0	365.0	38.0	22.0			411.0	412.0
32	252	34.0	30.0	360.0	348.0	61.0	28.0			455.0	406.0
33	252	36.0	31.0	354.0	326.0	42.0	18.0			432.0	375.0
34	254	13.2	13.2	275.1	272.0	81.2	45.2			369.5	330.4

Table 3. Pratylenchus penetrans data base agronomic measures.

Study NO#	N kg/ha	P kg/ha	Rotation	Citation NO#	Citation Study
1				2	G.W.BIRD,1986
2				7	G.W.BIRD,1982
3				8	G.W.BIRD,1982
4				9	G.W.BIRD,1982
5	84		ALFAL	10	H.C.OLSON,1984
6	252		ALFAL	10	H.C.OLSON,1984
7	84		CORN	11	H.C.OLSON,1984
8	252		CORN	11	H.C.OLSON,1984
9				13	H.C.OLSON,1980
10		0		14	J. NOLING, 1981
11		56		14	J. NOLING, 1981
12		168		14	J. NOLING, 1981
13	84			14	J. NOLING, 1981
14	168			14	J. NOLING, 1981
15	336			14	J. NOLING, 1981
16	86			15	M.L.VITOSH,1980
17	168			15	M.L.VITOSH,1980
18	336			15	M.L.VITOSH,1980
19				1	Model VALIDATION,1986
20	84		CORN	16	M.L.VITOSH,1982
21	253		CORN	16	M.L.VITOSH,1982
22	84		ALFAL	16	M.L.VITOSH,1982
23	253		ALFAL	16	M.L.VITOSH,1982
24	86			15	M.L.VITOSH,1980
25	168			15	M.L.VITOSH,1980
26	336			15	M.L.VITOSH,1980
27				18	Model VALIDATION,1985
28	84		CORN	4	M.L.VITOSH,1983
29	253		CORN	4	M.L.VITOSH,1983
30	84		ALFALFA	5	M.L.VITOSH,1983
31	253		ALFALFA	5	M.L.VITOSH,1983
32	253		CORN	16	M.L.VITOSH,1982
33	253		ALFALFA	16	M.L.VITOSH,1982
34				12	G.W.BIRD, 1981

Table 4. Pratylenchus penetrans data base in-season nematode population densities for Superior.

			SOIL		ROOT		TOTAL	
Study			P.p/100 cc		P.p/1.0 g.		Soil + Root	
NO#	Jdate	DD10	Treat	Check	Treat	Check	Treat	Check
1	174	370.1					7.0	42.0
1	209	668.6					17.0	182.0
1	240	933.0					3.0	124.0
1	251	1026.8					4.0	126.0
2	196	557.8			4.0	47.0		
3	197	1103.5	0.0	3.0	4.0	48.0	4.0	51.0
3	250	1925.1	2.0	44.0				
4	192	998.5	2.0	16.0	3.0	92.0	5.0	108.0
4	250	1925.1	2.0	50.0				
5	174	635.0	0.0	3.6	3.2	14.8	3.2	18.4
5	208	1063.0	0.8	6.4	2.8	84.8	3.6	91.2
5	237	1476.0	1.2	18.8				
6	174	635.0	0.8	1.2	0.4	17.2	1.2	18.4
6	208	1063.0	0.0	6.4	0.4	72.8	0.4	79.2
6	237	1476.0	1.2	20.0				
7	208	1063.0	0.0	6.4	0.4	80.0	0.4	86.4
7	237	1476.0			0.0	30.0		
8	208	1063.0	0.4	6.8	0.0	55.6	0.4	62.4
8	237	1476.0			1.6	17.7		
9	182	940.3					8.4	48.6
9	209	1398.1					1.8	172.4
9	230	1692.1					2.0	180.1
10	165	212.3	36.0	41.0				
10	167	233.7	17.4	20.6	2.6	19.2	20.0	39.8
10	188	442.7	2.0	19.6	11.0	56.2	13.0	75.8
10	216	723.2	85.0	78.2	6.4	178.2	91.4	256.4
10	243	995.5	2.6	39.0	6.0	94.6	8.6	133.6
11	165	212.3	24.0	39.2				
11	167	233.7	9.6	20.2	7.0	18.6	16.6	38.8
11	188	442.7	3.0	12.4	14.0	24.2	17.0	36.6
11	216	723.2	23.6	120.8	5.6	205.2	29.2	326.0
11	243	995.5	4.2	55.6	25.2	181.6	29.4	237.2
12	165	212.3	36.8	50.0				
12	167	233.7	12.0	19.4	2.8	24.6	14.8	44.0
12	188	442.7	2.8	20.6	10.8	36.0	13.6	56.6
12	216	723.2	25.8	80.4	9.0	175.0	34.8	255.4
12	243	995.5	8.4	40.6	5.6	213.8	14.0	254.4
13	145	241.2	4.0	6.0				
13	176	373.5	8.0	12.0	0.0	68.0	8.0	80.0
13	193	543.8	0.0	20.0	0.0	88.0	0.0	108.0
13	213	769.0	0.0	44.0	0.0	100.0	0.0	144.0
13	233	983.3	4.0	16.0	6.0	30.0	10.0	46.0
14	145	241.2	4.0	6.0				
14	176	373.5	4.0	88.0	8.0	62.0	12.0	150.0
14	193	543.8	4.0	34.0	2.0	70.0	6.0	104.0
14	213	769.0	0.0	20.0	0.0	158.0	0.0	178.0
14	233	983.3	0.0	68.0	4.0	32.0	4.0	100.0

Table 4 (cont). Pratylenchus penetrans data base in-season nematode population densities for Superior.

			SOIL P.p/100 cc		ROOT P.p/1.0 g.		TOTAL Soil + Root	
Study NO#	Jdate	DD10	Treat	Check	Treat	Check	Treat	Check
15	145	241.2	2.0	87.0				
15	176	373.5	0.0	10.0	16.0	58.0	16.0	68.0
15	193	543.8	6.0	20.0	4.0	102.0	10.0	122.0
15	213	769.0	0.0	32.0	48.0	100.0	48.0	132.0
15	233	983.3	2.0	38.0	0.0	42.0	2.0	80.0
16	181	709.5					1.0	166.0
16	199	959.7					13.0	155.0
16	213	1154.3					15.0	118.0
16	220	1251.6					10.0	132.0
16	265	1877.1					5.0	67.0
17	181	709.5					1.0	166.0
17	199	959.7					13.0	155.0
17	213	1154.3					15.0	118.0
17	220	1251.6					10.0	132.0
17	265	1877.1					5.0	67.0
18	181	709.5					1.0	166.0
18	199	959.7					13.0	155.0
18	213	1154.3					15.0	118.0
18	220	1251.6					10.0	132.0
18	265	1877.1					5.0	67.0

Table 5. Pratylenchus penetrans data base in-season nematode population densities for Russet Burbank.

			SOIL		ROOT		TOTAL	
Study			P.p/100 cc		P.p/1.0 g.		Soil + Root	
NO#	Jdate	DD10	Treat	Check	Treat	Check	Treat	Check
19	149	143.3	0.8	11.2	1.0	14.6	1.8	25.8
19	155	190.5	0.8	11.8	0.8	44.2	1.6	56.0
19	161	231.7	2.4	15.8	1.0	44.6	3.4	60.4
19	174	335.2	1.0	20.0	0.8	52.0	1.8	72.0
19	188	461.8	2.0	63.4	0.2	50.4	2.2	113.8
19	202	629.8	1.8	62.4	1.8	69.4	3.6	131.8
19	216	782.4	1.0	185.8	0.6	147.2	1.6	333.0
19	230	917.2	3.2	106.2	5.8	135.0	9.0	241.2
19	245	1014.3	0.8	129.6	3.4	235.0	4.2	364.6
19	258	1074.3	1.2	83.0	0.8	269.0	2.0	352.0
19	280	1196.9	0.6	102.6				
20	130	0.0	16.0	6.0				
20	196	974.4					1.0	70.0
20	252	2014.8	31.0	132.0				
21	130	0.0	4.0	7.0				
21	196	974.4					1.0	36.0
21	252	2014.8	10.0	104.0				
22	130	0.0	22.0	16.0				
22	196	974.4			2.0	50.0		
22	252	2014.8	14.0	268.0				
23	130	0.0	4.0	8.0				
23	196	974.4			2.0	35.0		
23	252	2014.8	13.0	150.0				
24	181	709.5					9.0	128.0
24	199	959.7					22.0	222.0
24	213	1154.3					8.0	73.0
24	220	1251.6					15.0	202.0
24	265	1877.1					30.0	50.0
25	181	709.5					9.0	128.0
25	199	959.7					22.0	222.0
25	213	1154.3					8.0	73.0
25	220	1251.6					15.0	202.0
25	265	1877.1					30.0	50.0
26	181	709.5					9.0	128.0
26	199	959.7					22.0	222.0
26	213	1154.3					8.0	73.0
26	220	1251.6					15.0	202.0
26	265	1877.1					30.0	50.0
27	157	276.0	0.2	3.7	0.4	12.1	0.5	15.8
27	170	329.9	0.1	2.5	0.0	12.3	0.1	14.8
27	182	422.1	0.0	6.5	0.1	9.7	0.2	16.1
27	197	568.6	0.5	16.3	0.3	30.0	0.8	46.3
27	211	709.3	0.7	35.7	0.2	23.2	1.0	58.9
27	239	924.6	1.2	38.6	0.4	16.5	1.6	55.1
27	254	1082.7	0.4	45.6				
27	267	1153.0	1.7	44.3				

Table 6. Pratylenchus penetrans data base in-season nematode population densities for Atlantic.

Study			SOIL P.p/100 cc		ROOT P.p/1.0 g.		TOTAL Soil + Root	
NO#	Jdate	DD10	Treat	Check	Treat	Check	Treat	Check
28	214	1421.0	0.0	29.7	18.8	0.3	18.8	30.0
28	271	2359.8	14.7	60.8				
29	214	1421.0	0.7	13.7	18.8	0.1	19.5	13.8
29	271	2359.8	16.3	50.3				
30	214	1421.0	0.3	60.7	19.4	0.4	19.7	61.1
30	271	2359.8	10.7	95.8				
31	214	1421.0	0.7	35.0	15.2	0.1	15.9	35.1
31	271	2359.8	25.3	127.0				
32	130	0.0	14.0	5.0				
32	196	974.4					2.0	34.0
32	252	2014.8	19.0	132.0				
33	130	0.0	13.0	12.0				
33	196	974.4			0.0	37.0		
33	252	2014.8	12.0	237.0				
34	191	866.8					3.0	13.0
34	223	1276.3					1.0	78.0
34	254	1673.0					4.0	70.0

Table 7. Model validation data base nematode population data.

	J		SOIL		ROOT		SOIL+ROOT		STOLON	
YEAR	DATE	DAP	ALD	CHK	ALD	CHK	ALD	CHK	ALD	CHK
1987	121	0	14.0	13.0						
1987	133	12	2.5	13.0						
1987	166	45	3.3	9.5	4.0	42.8	7.3	52.3	0.0	0.0
1987	181	60	2.0	14.3	0.0	32.0	2.0	46.3	0.0	1.0
1987	193	72	0.5	12.0	0.8	23.3	1.3	35.3	0.0	2.3
1987	222	101	12.0	42.0	5.5	31.8	17.5	73.8	0.1	19.0
1987	243	122	1.0	17.8	0.8	41.0	1.8	58.8	0.8	26.0
1985	120	-9	3.8	3.8						
1985	157	28	0.2	3.7	0.4	12.1	0.5	15.8		
1985	170	41	0.1	2.5	0.0	12.3	0.1	14.8		
1985	182	53	0.0	5.4	0.1	9.7	0.2	15.1		
1985	197	68	0.5	16.3	0.3	30.0	0.8	46.3		
1985	211	82	0.7	35.7	0.2	13.1	1.0	48.8		
1985	239	110	1.2	38.6	0.4	16.5	1.6	55.1		
1985	254	125	0.4	45.6						
1985	267	138	1.7	44.3						

ALD - ALDICARB TREATED CHK - NON-TREATED CONTROL

Table 8. Model validation data base plant growth data

		DRY WEIGHTS IN GRAMS											
		BELOW GROUND		ABOVE GROUND		ROOT		STOLON		TUBER		UG STEM	
Year	DAP	ALD	CHK	ALD	CHK	ALD	CHK	ALD	CHK	ALD	CHK	ALD	CHK
1987	0												
1987	12												
1987	45	0.5	0.4	6.3	5.1	0.4	0.4	0.1	0.0	0.0	0.0	1.0	1.0
1987	60	3.1	1.9	50.7	36.6	1.7	1.3	1.4	0.5	2.0	1.0	3.2	2.9
1987	72	3.7	2.8	121.7	78.1	2.5	2.2	1.2	0.6	25.4	25.0	6.9	4.6
1987	101	4.2	3.8	136.4	113.2	3.1	2.9	1.1	1.0	191.0	159.2	8.1	8.9
1987	122	1.0	0.6	70.3	64.4	0.7	0.5	0.3	0.1	156.3	145.3	3.9	3.4
1985	-9												
1985	28	0.7	0.8	2.3	1.9	0.2	0.3	0.0	0.0	0.0	0.0	0.5	0.5
1985	41	2.1	2.0	8.6	7.5	0.5	0.5	0.2	0.2	0.0	0.0	1.3	1.0
1985	53	4.4	4.7	50.1	36.2	1.1	1.1	0.5	0.8	12.5	10.7	2.9	2.6
1985	68	6.3	6.3	101.2	68.0	1.6	1.6	0.7	0.6	69.0	60.1	4.0	3.3
1985	82	6.7	6.2	104.6	63.3	1.3	1.3	0.8	0.3	118.0	103.5	4.6	3.5
1985	110	4.6	4.6	84.4	25.6			0.4	0.3	191.4	125.3	4.2	2.5
1985	125	4.2	2.7	54.5	29.9			1.6	0.2	192.0	134.4	2.5	1.5
1985	138												

APPENDIX C

BASIC DESCRIPTIVE STATISTICS FOR PPDB

Table 1. Descriptive statistics for varibales in P.p data base - cultivar Superior.

VAR	LABEL	N	MISS	MEAN	STD	MIN	MAX
PJD	PLANTING JDATE	18	0	130.67	15.37	104.00	149.00
PDD	PLANTING DD10	18	0	87.47	67.07	0.00	223.30
PTN	PREPLANT TEMIK NEMATODE	18	0	19.06	13.03	2.00	45.20
PCN	PREPLANT CHECK NEMATODE	18	0	23.73	17.05	2.00	54.60
HJD	HARVEST JDATE	18	0	244.67	11.52	230.00	265.00
GSL	GROWING SEASON LENGTH	18	0	114.00	22.78	95.00	161.00
TBW	TEMIK B WT	13	5	12.40	3.51	8.40	20.70
CBW	CHECK B WT	13	5	11.35	4.01	6.90	20.20
TAW	TEMIK A WT	15	3	280.89	80.03	193.00	493.00
CAW	CHECK A WT	15	3	236.20	77.77	117.40	449.00
TJW	TEMIK JUMBO WT	14	4	21.39	17.18	2.30	65.30
CJW	CHECK JUMBO WT	14	4	11.33	9.91	0.00	38.50
TTW	TEMIK TOTAL WT	16	2	281.65	80.11	172.00	444.60
CTW	CHECK TOTAL WT	16	2	224.54	76.69	86.00	354.90
DBWT	B % YIELD LOSS	13	5	0.10	0.10	-0.06	0.27
DAWT	A % YIELD LOSS	15	3	0.16	0.09	0.08	0.45
DJWT	J % YIELD LOSS	14	4	0.47	0.25	-0.05	1.00
DTWT	T % YIELD LOSS	16	2	0.22	0.12	0.10	0.51
STS	SAMPLE TEMIK SOIL	42	25	8.13	15.42	0.00	85.00
SCS	SAMPLE CHECK SOIL	42	25	31.93	27.67	1.20	120.80
STR	SAMPLE TEMIK ROOT	35	32	6.10	9.08	0.00	48.00
SCR	SAMPLE CHECK ROOT	35	32	77.06	57.10	14.80	213.80
STT	SAMPLE TEMIK TOTAL	54	13	11.32	14.56	0.00	91.40
SCT	SAMPLE CHECK TOTAL	54	13	117.97	66.28	18.40	326.00

Table 2. Descriptive statistics for variable in P.p. data base-cultivar Russet Burbank.

VAR	LABEL	N	MISS	MEAN	STD	MIN	MAX
PJD	PLANTING JDATE	9	0	127.22	12.38	122.00	141.00
PDD	PLANTING DD10	9	0	27.44	54.59	0.00	131.00
PTN	PREPLANT TEMIK NEMATODE	9	0	31.56	20.88	3.20	54.00
PCN	PREPLANT CHECK NEMATODE	9	0	35.44	24.68	3.80	67.00
HJD	HARVEST JDATE	9	0	261.22	10.05	252.00	281.00
GLS	GROWING SEASON LENGTH	9	0	145.00	12.07	136.00	161.00
TBW	TEMIK B WT	6	3	54.27	31.33	3.30	88.00
CBW	CHECK B WT	6	3	62.53	36.96	4.40	99.00
TAW	TEMIK A WT	6	3	277.55	46.25	216.00	334.50
CAW	CHECK A WT	6	3	211.67	50.60	157.80	287.00
TJW	TEMIK JUMBO WT	6	3	25.45	16.44	5.00	42.20
CJW	CHECK JUMBO WT	6	3	13.58	12.16	1.00	29.80
TNW	TEMIK KNOBBY WT	5	4	22.78	4.74	16.00	27.00
CNW	CHECK KNOBBY WT	5	4	9.72	4.71	4.00	14.60
TTW	TEMIK TOTAL WT	9	0	346.69	78.21	245.00	444.10
CTW	CHECK TOTAL WT	9	0	274.04	66.83	194.00	394.00
DBWT	B % YIELD LOSS	6	3	-0.17	0.10	-0.33	-0.05
DAWT	A % YIELD LOSS	6	3	0.23	0.15	0.08	0.43
DJWT	J % YIELD LOSS	6	3	0.53	0.25	0.23	0.80
DNWT	K % YIELD LOSS	5	4	0.59	0.15	0.42	0.80
DTWT	T % YIELD LOSS	9	0	0.20	0.11	0.08	0.37
STS	SAMPLE TEMIK SOIL	27	19	4.97	7.75	0.00	31.00
SCS	SAMPLE CHECK SOIL	27	19	62.07	66.47	2.50	268.00
STR	SAMPLE TEMIK ROOT	18	28	1.20	1.44	0.00	5.80
SCR	SAMPLE CHECK ROOT	18	28	69.45	76.96	9.70	269.00
STT	SAMPLE TEMIK TOTAL	33	13	8.76	9.47	0.10	30.00
SCT	SAMPLE CHECK TOTAL	33	13	123.89	100.12	14.80	364.60

Table 3. Descriptive statistics for variables in P.p. Data base - cultivar Atlantic.

VAR	LABEL	N	MISS	MEAN	STD	MIN	MAX
PJD	PLANTING JDATE	7	0	127.43	8.02	116.00	136.00
PDD	PLANTING DD10	7	0	78.71	60.59	0.00	171.40
PTN	PREPLANT TEMIK NEMATODE	7	0	24.06	20.35	2.50	57.00
PCN	PREPLANT CHECK NEMATODE	7	0	20.29	14.97	4.00	51.00
HJD	HARVEST JDATE	7	0	263.14	9.82	252.00	271.00
GLS	GROWING SEASON LENGTH	7	0	135.71	8.04	118.00	140.00
TBW	TEMIK B WT	7	0	29.03	7.66	13.20	36.00
CBW	CHECK B WT	7	0	27.03	6.51	13.20	32.00
TAW	TEMIK A WT	7	0	328.73	33.19	275.10	360.00
CAW	CHECK A WT	7	0	335.57	38.02	272.00	372.00
TJW	TEMIK JUMBO WT	7	0	47.17	20.67	14.00	81.20
CJW	CHECK JUMBO WT	7	0	24.03	11.76	6.00	45.20
TTW	TEMIK TOTAL WT	7	0	404.93	41.61	333.00	455.00
CTW	CHECK TOTAL WT	7	0	386.63	40.78	330.40	428.00
DBWT	B % YIELD LOSS	7	0	0.05	0.12	-0.07	0.26
DAWT	A % YIELD LOSS	7	0	-0.02	0.07	-0.11	0.08
DJWT	J % YIELD LOSS	7	0	0.50	0.06	0.42	0.57
DTWT	T % YIELD LOSS	7	0	0.04	0.07	-0.04	0.13
STS	SAMPLE TEMIK SOIL	12	5	10.55	8.36	0.00	25.30
SCS	SAMPLE CHECK SOIL	12	5	71.58	67.27	5.00	237.00
STR	SAMPLE TEMIK ROOT	5	12	14.44	8.24	0.00	19.40
SCR	SAMPLE CHECK ROOT	5	12	7.58	16.44	0.10	37.00
STT	SAMPLE TEMIK TOTAL	8	9	10.48	8.65	1.00	19.70
SCT	SAMPLE CHECK TOTAL	8	9	41.80	24.88	13.00	78.00

APPENDIX D

ANALYSIS OF VARIANCE RESULTS

Table 1. Analysis of variance results for dependant variable: B yield.

Source	DF	SUM OF SQUARES
Model	11	20135.23
Error	42	10571.84
C Total	53	30707.08

F Value	7.27	r-Square	0.66
Pr > F	0.0001	BWT MEAN	26.91

Source	DF	F Value	Pr > F
PPCODE	1	4.56	0.0386
TRE	1	0.12	0.7312
CUL	2	33.87	0.0001
PPCODE*TRE	1	0.00	0.9809
PPCODE*CUL	2	2.86	0.0686
TRE*CUL	2	0.90	0.4162
PPCODE*TRE*CUL	2	0.03	0.9685

Table 2. Analysis of variance results for dependant variable: A yield.

Source	DF	SUM OF SQUARES
Model	11	179106.35
Error	56	313065.02
C Total	67	492171.37

F Value	2.91	r-Square	0.36
Pr > F	0.0042	AWT MEAN	250.62

Source	DF	F Value	Pr > F
PPCODE	1	3.88	0.0537
TRE	1	5.36	0.0243
CUL	2	9.69	0.0002
PPCODE*TRE	1	0.24	0.6264
PPCODE*CUL	2	0.52	0.5979
TRE*CUL	2	0.96	0.3903
PPCODE*TRE*CUL	2	0.11	0.8937

Table 3. Analysis of variance results for dependent variable: Jumbo yield.

Source	DF	SUM OF SQUARES
Model	11	8084.83
Error	56	10926.90
C Total	67	19011.74

F Value	3.77	r-Square	0.42
PR > F	0.0005	JWT MEAN	20.14

Source	DF	F Value	Pr > F
PPCODE	1	3.45	0.0685
TRE	1	14.80	0.0003
CUL	2	9.73	0.0002
PPCODE*TRE	1	0.19	0.6656
PPCODE*CUL	2	0.48	0.6241
TRE*CUL	2	1.21	0.3059
PPCODE*TRE*CUL	2	0.08	0.9211

Table 4. Analysis of variance results for Dependent variable: Total yield.

Source	DF	SUM OF SQUARES
Model	11	267161.22
Error	56	413065.25
C Total	67	680226.46

F Value	3.29	r-Square	0.39
PR > F	0.0016	TWT MEAN	303.38

Source	DF	F Value	Pr > F
PPCODE	1	3.50	0.0665
TRE	1	7.53	0.0081
CUL	2	11.13	0.0001
PPCODE*TRE	1	0.15	0.7012
PPCODE*CUL	2	0.77	0.4676
TRE*CUL	2	0.52	0.5972
PPCODE*TRE*CUL	2	0.10	0.9044

APPENDIX E

PERCENTAGE YIELD REDUCTION USING PRESEASON INFORMATION

Table 1. Results of preseason regression analysis for percentage B tuber yield loss.

Source	DF	SS	r-Square	
Model	4	0.3268	0.58	
Error	21	0.2322	F Value	Pr > F
C Total	25	0.5591	7.39	0.0007
DV1	1	0.1360	12.30	0.0021
DV2	1	0.1642	14.85	0.0009
APO	1	0.0090	0.82	0.3754
PJD	1	0.0175	1.58	0.2220
Parameter		Estimate	T For H0:	PR>¦T¦
Intercept		0.1353	0.50	0.6233
DV1		0.3124	5.15	0.0001
DV2		0.2410	4.05	0.0006
APO		0.0011	0.83	0.4186
PJD		-0.0027	-1.26	0.2220

Table 2. Results of preseason regression analysis for percentage A tuber yield loss.

Source	DF	SS	r-Square	
Model	4	0.244650	0.49	
Error	23	0.257046	F Value	Pr > F
C Total	27	0.501697	5.47	0.0030
DV1	1	0.031659	2.83	0.1059
DV2	1	0.210184	18.81	0.0002
APO	1	0.001342	0.12	0.7320
PJD	1	0.001463	0.13	0.7207
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		0.340994	1.25	0.2238
DV1		-0.061507	-1.04	0.3088
DV2		-0.251830	-4.21	0.0003
APO		-0.000482		0.7103
PJD		-0.000784	-0.36	0.7207

Table 3. Results of preseason regression analysis for percentage Total tuber yield loss.

Source	DF	SS	r-Square	
Model	4	0.244812	0.49	
Error	27	0.250441	F Value	Pr > F
C Total	31	0.495254	6.60	0.0008
DV1	1	0.053313	5.75	0.0237
DV2	1	0.102765	11.08	0.0025
APO	1	0.004827	0.52	0.4768
PJD	1	0.083906	9.05	0.0056
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		0.710082	3.89	0.0006
DV1		0.062287	1.39	0.1756
DV2		-0.120866	-2.37	0.0254
APO		-0.000552	-0.49	0.6281
PJD		-0.004188	-3.01	0.0056

APPENDIX F

PERCENTAGE YIELD REDUCTION USING POST SEASON INFORMATION

Table 1. Results of post season regression analysis for percentage B tuber yield loss.

Source	DF	SS	r-Square	
Model	6	0.3392	0.61	
Error	19	0.2198	F Value	Pr > F
C Total	25	0.5591	4.86	0.0035
DV1	1	0.1360	11.76	0.0028
DV2	1		14.19	0.0013
APO	1	0.0090	0.78	0.3871
PJD	1	0.0175	1.51	0.2336
GSL	1	0.0000	0.01	0.9362
TTW	1	0.0123	1.06	0.3154
Parameter		Estimate	T For H0:	PR>¦T¦
Intercept		-0.1838	-0.21	0.8350
DV1		0.3534	2.48	0.0226
DV2		0.2326	3.78	0.0013
APO		0.0013	0.92	0.3675
PJD		-0.0019	-0.72	0.4814
GSL		0.0004	0.10	0.9192
TTW		0.0004	1.03	0.3154

Table 2. Results of post season regression analysis for percentage A tuber yield loss.

Source	DF	SS	r-Square	
Model	6	0.2511	0.64	
Error	19	0.1436	F Value	Pr > F
C Total	25	0.3947	5.54	0.0018
DV1	1	0.0168	2.23	0.1514
DV2	1	0.2101	27.80	0.0001
APO	1	0.0092	1.23	0.2813
PJD	1	0.0010	0.14	0.7139
GSL	1	0.0046	0.62	0.4425
TTW	1	0.0090	1.20	0.2874
Parameter		Estimate	T For H0:	PR>¦T¦
Intercept		-0.4487	-0.64	0.5312
DV1		0.0322	0.28	0.7824
DV2		-0.2615	-5.26	0.0001
APO		-0.0007	-0.58	0.5657
PJD		0.0009	0.43	0.6733
GSL		0.0032	0.97	0.3463
TTW		0.0003	1.09	0.2874

Table 3. Results of post season regression analysis for percentage total tuber yield loss.

Source	DF	SS	r-Square	
Model	6	0.3265	0.66	
Error	25	0.1687	F Value	Pr > F
C Total	31	0.4952	8.06	0.0001
DV1	1	0.0533	7.90	0.0095
DV2	1	0.1027	15.23	0.0006
APO	1	0.0048	0.72	0.4057
PJD	1	0.0839	12.43	0.0017
GSL	1	0.0567	8.41	0.0077
TTW	1	0.0249	3.70	0.0660
Parameter		Estimate	T For H0:	Pr > T
Intercept		-1.0097	-1.94	0.0639
DV1		0.2048	3.35	0.0026
DV2		-0.1542	-3.42	0.0021
APO		0.0001	0.04	0.9675
PJD		0.0014	0.71	0.4872
GSL		0.0059	3.48	0.0019
TTW		0.0005	1.92	0.0660

APPENDIX G

PERCENTAGE YIELD REDUCTION USING STEPWISE PROCEDURE ON POSTSEASON INFORMATION

Table 1. Results of stepwise regression analysis for percentage B tuber yield loss on Superior.

Source	DF	SS		
			r-Square	
Model	2	0.04425814	0.39	
Error	10	0.06901162	F Value	Pr > F
TOTAL	12	0.11326975	3.21	0.0850
Parameter		Estimate	F Value	Pr > F
Intercept		2.46427187		
PJD		-0.00920442	6.34	0.0305
GSL		-0.01068368	3.65	0.0852

Table 2. Results of stepwise regression analysis for percentage A tuber yield loss on Superior.

Source	DF	SS		
			r-Square	
Model	1	0.02323454	0.70	
Error	11	0.00985222	F Value	Pr > F
Total	12	0.03308676	25.94	0.0003
Parameter		Estimate	F Value	Pr > F
Intercept		0.69449382		
PJD		-0.00401257	25.94	0.0003

Table 3. Results of stepwise regression analysis for percentage total tuber yield loss on Superior.

Source	DF	SS		
			r-Square	
Model	3	0.18393066	0.84	
Error	12	0.03367982	F Value	Pr > F
Total	15	0.21761048	21.84	0.0001
Parameter		Estimate	F Value	Pr > F
Intercept		-0.89946955		
APO		0.00260579	5.44	0.0378
GSL		0.00845263	48.99	0.0001
TTW		0.00047707	4.17	0.0638

Table 4. Results of stepwise regression analysis for percentage A tuber yield loss on Russet Burbank.

Source	DF	SS		
			r-Square	
Model	1	0.08052799	0.74	
Error	4	0.02745202	F Value	Pr > F
Total	5	0.10798001	11.73	0.0266
Parameter		Estimate		
Intercept		-1.242186		
PJD		0.012063		

Table 5. Results of stepwise regression analysis for percentage B tuber yield loss on Russet Burbank.

Source	DF	SS	r-Square	
Model	2	0.04947403	0.54	
Error	6	0.04288437	F Value	Pr > F
Total	8	0.09235837	8.08	0.0250
Parameter		Estimate	F Value	Pr > F
Intercept		-0.86773480		
PJD		0.00858743	8.08	0.0250

Table 6. Results of stepwise regression analysis for percentage B tuber yield loss on Atlantic.

Source	DF	SS	r-Square	
Model	1	0.03477225	0.38	
Error	5	0.05700278	F Value	Pr > F
Total	6	0.09177503	3.05	0.1412
Parameter		Estimate	F Value	Pr > F
Intercept		-0.047219		
APO		0.004598	3.05	0.1412

Table 7. Results of stepwise regression analysis for Percentage A tuber yield loss on Atlantic.

Source	DF	SS	r-Square	
Model	2	0.02198049	0.82	
Error	4	0.00467399	F Value	Pr > F
Total	6	0.02665448	9.41	0.0307
Parameter		Estimate	F Value	Pr > F
Intercept		1.56674469		
PJD		-0.00692642	14.84	0.0183
GSL		-0.00519901	8.40	0.0442

Table 8. Results of stepwise regression analysis for Percentage Jumbo tuber yield loss on Atlantic.

Source	DF	SS	r-Square	
Model	2	0.01700639	0.72	
Error	4	0.00620640	F Value	Pr > F
Total	6	0.02321279	5.18	0.0776
Parameter		Estimate	F Value	Pr > F
Intercept		2.06771987		
PJD		-0.00883309	10.34	0.0324
TTW		-0.00109020	4.24	0.1084

Table 9. Results of stepwise regression analysis for percentage Total tuber yield loss on Atlantic.

Source	DF	SS	r-Square	
Model	3	0.02832836	0.97	
Error	3	0.00087822	F Value	Pr > F
Total	6	0.02920659	32.26	0.0088
Parameter		Estimate	F Value	Pr > F
Intercept		1.65479822		
APO		0.00093791	3.45	0.1604
PJD		-0.00577644	28.73	0.0127
GSL		-0.00660447	52.81	0.0052

APPENDIX H

POPULATION DENSITY REGRESSION RESULTS

Table 1. Regression results for P.penetrans population density in Superior check soils.

Source	DF	SS	r-Square	
Model	5	9829.55	0.31	
Error	36	21569.86	F Value	Pr > F
C Total	41	31399.41	3.28	0.0153
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		1414.9608	1.231	0.2262
PCN		0.8695	3.160	0.0032
PJD		-0.1878	-0.461	0.6479
SJD		-21.3332	1.141	0.2498
SJD2		0.1068	1.141	0.2613
SJD3		-0.0002	-1.097	0.2799

Table 2. Regression results for P.penetrans population density in Superior aldicarb soils.

Source	DF	SS	r-Square	
Model	5	3113.168	0.3192	
Error	36	6641.364	F Value	Pr > F
C Total	41	9754.533	3.375	0.0133
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		913.6875	1.438	0.1591
PTN		0.3592	1.727	0.0927
PJD		0.4706	2.009	0.0520
SJD		-15.4558	-1.534	0.1338
SJD2		0.0806	1.557	0.1281
SJD3		-0.0001	-1.008	0.1224

Table 3. Regression results for P.penetrans population density in Superior check root.

Source	DF	SS	r-Square	
Model	5	51871.50	0.47	
Error	29	58994.65	F Value	Pr > F
C Total	34	110866.16	5.10	0.0018
Parameter		Estimate	T For H0:	Pr >¦T¦
Intercept		-3875.3	-0.582	0.5648
PCN		1.68820	3.082	0.0045
PJD		-0.01830	-0.024	0.9809
SJD		48.12584	0.486	0.6304
SJD2		-0.19235	-0.395	0.6954
SJD3		0.00025	0.317	0.7539

Table 4. Regression results for P.penetrans population density in Superior aldicarb root.

Source	DF	SS	r-Square	
Model	5	478.085	0.17	
Error	29	2326.981	F Value	Pr > F
C Total	34	2805.067	1.19	0.3376
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		-711.40	-0.539	0.5940
PTN		0.33714	2.317	0.0278
PJD		-0.14818	-0.947	0.3516
SJD		10.56815	0.580	0.5944
SJD2		-0.05057	-0.524	0.6042
SJD3		0.00008	0.511	0.6132

Table 5. Regression results for P.penetrans population density in Superior check total.

Source	DF	SS	r-Square	
Model	5	105279.945	0.45	
Error	48	127575.992	F Value	Pr > F
C Total	53	232855.938	7.922	0.0001
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		-294.76	-0.082	0.9350
PCN		1.72541	3.397	0.0014
PJD		0.49251	0.608	0.5458
SJD		-6.11271	-0.121	0.9045
SJD2		0.07516	0.317	0.7527
SJD3		-0.00018	-0.503	0.6175

Table 6. Regression results for P.penetrans population density in Superior aldicarb total.

Source	DF	SS	r-Square	
Model	5	2219.8205	0.20	
Error	48	9029.1520	F Value	Pr > F
C Total	53	11248.9725	2.36	0.0450
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		155.7447	0.162	0.8717
PTN		0.19691	1.099	0.2771
PJD		0.46261	2.049	0.0460
SJD		-3.85622	-0.285	0.7769
SJD2		0.02212	0.349	0.7285
SJD3		-0.00004	-0.412	0.6819

Table 7. Regression results for P.penetrans population density in Russet Burbank check soils.

Source	DF	SS		r-Square	
Model	5	75791.81		0.66	
Error	21	39114.85	F Value		Pr > F
C Total	26	114906.67	8.14		0.0002
Parameter		Estimate	T For H0:		Pr > |T|
Intercept		614.2715	0.627		0.5372
PCN		1.5133	2.936		0.0079
PJD		-0.2393	-0.222		0.8264
SJD		-12.1800	-0.744		0.4648
SJD2		0.0741	0.902		0.3773
SJD3		-0.0001	-0.994		0.3314

Table 8. Regression results for P.penetrans population density in Russet Burbank aldicarb soils.

Source	DF	SS		r-Square	
Model	5	747.654		0.48	
Error	21	815.571	F Value		Pr > F
C Total	26	1563.226	3.850		0.0124
Parameter		Estimate	T For H0:		Pr > |T|
Intercept		165.1576	1.131		0.2710
PTN		0.00278	0.021		0.9834
PJD		-0.41923	-2.203		0.0389
SJD		-1.64485	-0.696		0.4942
SJD2		0.00813	0.685		0.5007
SJD3		-0.00001	-0.665		0.5132

Table 9. Regression results for P.penetrans population density in Russet Burbank check roots.

Source	DF	SS		r-Square	
Model	5	86160.043		0.86	
Error	12	14529.221	F Value		Pr > F
C Total	17	100689.264	14.23		0.0001
Parameter		Estimate	T For H0:		Pr > |T|
Intercept		-3943.97	-1.562		0.1442
PCN		1.4165	2.534		0.0262
PJD		3.7970	3.345		0.0058
SJD		53.8211	1.418		0.1815
SJD2		-0.2813	-1.483		0.1639
SJD3		0.0005	1.586		0.1387

Table 10. Regression results for P.penetrans population density in Russet Burbank aldicarb roots.

Source	DF	SS	r-Square	
Model	5	15.96340	0.45	
Error	12	19.33659	F Value	Pr > F
C Total	17	35.30000	1.98	0.1540
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		134.78	1.463	0.1692
PTN		0.06556	1.884	0.0840
PJD		0.08617	1.576	0.1411
SJD		-2.27402	-1.643	0.1263
SJD2		0.01154	1.669	0.1210
SJD3		-0.00002	-1.679	0.1189

Table 11. Regression results for P.penetrans population density in Russet Burbank check total.

Source	DF	SS	r-Square	
Model	5	168993.248	0.53	
Error	27	151776.480	F Value	Pr > F
C Total	32	320769.729	6.01	0.0007
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		425.299	0.107	0.9156
PCN		0.69121	1.055	0.3009
PJD		7.63305	3.443	0.0019
SJD		-30.4704	-0.535	0.5967
SJD2		0.19341	0.702	0.4884
SJD3		-0.00036	-0.844	0.4063

Table 12. Regression results for P.penetrans population density in Russet Burbank aldicarb total.

Source	DF	SS	r-Square	
Model	5	2316.64063	0.81	
Error	27	557.50907	F Value	Pr > F
C Total	32	2874.14970	22.44	0.0001
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		-292.542	-1.219	0.2334
PTN		0.300664	7.361	0.0001
PJD		0.206827	1.443	0.1606
SJD		4.224125	1.225	0.2312
SJD2		-0.022299	-1.336	0.1926
SJD3		0.000038	1.469	0.1535

APPENDIX I

IMPACT OF IN-SEASON NEMATODE POPULATION DENSITY

(Two Classes) ON PERCENTAGE TUBER YIELD LOSS

Table 1. Regression results for Superior percentage A yield loss based on early and late delta root nematode population density.

Source	DF	SS	r-Square	
Model	2	0.014989	0.82	
Error	4	0.003210	F Value	Pr > F
C Total	6	0.0182	9.34	0.0311
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		0.233590	7.219	0.0020
ER		0.000546	1.122	0.3246
LR		-0.000835	-4.191	0.0138

Table 2. Regression results for Superior percentage total yield loss based on early and late delta root nematode population density.

Source	DF	SS	r-Square	
Model	2	0.00895872	0.63	
Error	4	0.00521270	F Value	Pr > F
C Total	6	0.01417143	3.44	0.1353
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		0.257403	6.243	0.0034
ER		0.000121	0.196	0.8538
LR		-0.000665	-2.617	0.0590

Table 3. Regression results for Superior percentage A yield loss based on early and late delta total nematode population density.

Source	DF	SS	r-Square	
Model	2	0.0840136	0.35	
Error	9	0.1546780	F Value	Pr > F
C Total	11	0.2386916	2.44	0.1420
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		0.213133	1.593	0.1457
ET		0.001242	1.794	0.1064
LT		-0.000555	-0.769	0.4618

Table 4. Regression results for Russet Burbank percentage Jumbo yield loss based on early and late delta total nematode population density.

Source	DF	SS	r-Square	
Model	2	0.18625	0.96	
Error	2	0.00726	F Value	Pr > F
C Total	4	0.19352	25.61	0.0375
Parameter		Estimate	T For H0:	Pr > |T|
Intercept		0.951758	11.831	0.0071
ET		-0.003617	-5.115	0.0362
LT		-0.001423	-4.732	0.0419

APPENDIX J

IMPACT OF IN-SEASON TOTAL NEMATODE DENSITY ON PERCENTAGE YIELD LOSS ON SUPERIOR TUBERS

Table 1. Regression results for percentage B wt reduction based on early season total nematode population density.

Source	DF	SS		
			r-Square	
Model	1	0.11795	0.73	
Error	7	0.04359	F Value	Pr > F
C Total	8	0.16155	18.93	0.0033
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		0.031151	0.659	0.5312
DTN1		0.001859	4.352	0.0033

Table 2. Regression results for percentage A wt reduction based on early mid and late season total nematode population density.

Source	DF	SS		
			r-Square	
Model	2	0.12293	0.83	
Error	6	0.02415	F Value	Pr > F
C Total	8	0.14728	15.14	0.0045
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		-0.181061	-1.580	0.1651
DTN2		0.003307	5.061	0.0023
DTN4		0.000787	1.653	0.1493

Table 3. Regression results for percentage Jumbo wt reduction based on preplant and late mid season total nematode population density.

Source	DF	SS		
			r-Square	
Model	2	0.26320	0.58	
Error	6	0.19434	F Value	Pr > F
C Total	8	0.45755	4.06	0.0766
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		0.281040	1.348	0.2263
APO		0.015459	2.602	0.0406
DTN3		-0.001642	-1.737	0.1330

Table 4. Regression results for percentage Total wt reduction based on early mid and late season total nematode population density.

Source	DF	SS		
			r-Square	
Model	2	0.10731	0.81	
Error	6	0.02617	F Value	Pr > F
C Total	8	0.13168	13.209	0.0063
Parameter		Estimate	T For H0:	Pr > ¦T¦
Intercept		-0.166225	-0.1450	0.1971
DTN2		0.003185	4.873	0.0028
DTN4		0.000919	1.931	0.1017

APPENDIX K

IMPACT OF ALDICARB ON PLANT GROWTH PARAMETERS

Table 1. Regression results for delta above ground growth on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	2334.18	0.58	
Error	9	1706.73	F Value	Pr > F
C Total	10	4040.85	12.31	0.0066
Parameter		Estimate	F Value	Pr > F
Intercept		2.155202		
DSOIL		1.208126	12.31	0.0066

Table 2. Regression results for delta tuber growth on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	2794.51	0.68	
Error	9	1331.68	F Value	Pr > F
C Total	10	4126.19	18.89	0.0019
Parameter		Estimate	F Value	Pr > F
Intercept		-8.868531		
DSOIL		1.321916	18.89	0.0019

Table 3. Regression results for percentage below ground growth.

Source	DF	SS	r-Square	
Model	1	0.18143	0.58	
Error	9	0.13048	F Value	Pr > F
C Total	10	0.31191	12.51	0.0063
Parameter		Estimate	F Value	Pr > F
Intercept		1.163256		
DROOT		-0.012029	12.51	0.0063

Table 4. Regression results for percentage above ground growth.

Source	DF	SS	r-Square	
Model	1	0.11140	0.38	
Error	9	0.17677	F Value	Pr > F
C Total	10	0.02881	5.67	0.0411
Parameter		Estimate	F Value	Pr > F
Intercept		0.85379		
DSOIL		-0.00834	5.67	0.0411

Table 5. Regression results for percentage stolon growth on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	0.94017	0.48	
Error	9	1.00832	F Value	Pr > F
C Total	10	1.94850	8.39	0.0177
Parameter		Estimate	F Value	Pr > F
Intercept		1.325927		
DROOT		-0.027383	8.39	0.0177

Table 6. Regression results for below ground partitioning in aldicarb treatments on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	0.05414	0.88	
Error	10	0.00643	F Value	Pr > F
C Total	11	0.06058	70.72	0.0001
Parameter		Estimate	F Value	Pr > F
Intercept		-0.001133		
1/DAP2		201.0538	70.72	0.0001

Table 7. Regression results for below ground partitioning in check treatments on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	0.07970	0.91	
Error	10	0.00777	F Value	Pr > F
C Total	11	0.08748	102.54	0.0001
Parameter		Estimate	F Value	Pr > F
Intercept		-0.005222		
1/DAP2		246.3776	102.54	0.0001

Table 8. Regression results for above ground partitioning in aldicarb treatments on Russet Burbank.

Source	DF	SS	r-Square	
Model	2	0.48155	0.87	
Error	8	0.07002	F Value	Pr > F
C Total	10	0.55158	27.51	0.0003
Parameter		Estimate	F Value	Pr > F
Intercept		0.783252		
DAP2		-0.000050	54.99	0.0001
DROOT		0.006510	5.40	0.0486

Table 9. Regression results for above ground partitioning in check treatments on Russet Burbank.

Source	DF	SS	r-Square	
Model	2	0.56562	0.88	
Error	8	0.09931	F Value	Pr > F
C Total	10	0.66494	22.78	0.0005
Parameter		Estimate	F Value	Pr > F
Intercept		0.696241		
DAP2		-0.000054	45.15	0.0001
DROOT		0.009451	8.03	0.0220

Table 10. Regression results for tuber partitioning in aldicarb treatment on Russet Burbank.

Source	DF	SS	r-Square	
Model	2	0.72728	0.91	
Error	8	0.06880	F Value	Pr > F
C Total	10	0.79608	42.28	0.0001
Parameter		Estimate	F Value	Pr > F
Intercept		-0.286863		
DAP		0.006744	19.28	0.0023
DSOIL		0.006370	3.05	0.1189

Table 11. Regression results for tuber partitioning in check treatments on Russet Burbank.

Source	DF	SS	r-Square	
Model	2	0.85890	0.91	
Error	8	0.08736	F Value	Pr > F
C Total	10	0.94626	39.33	0.0001
Parameter		Estimate	F Value	Pr > F
Intercept		-0.278207		
DAP		0.006394	16.65	0.0061
DSOIL		0.009343	5.17	0.0526

Table 12. Regression results for above ground partitioning in aldicarb treatments w/o nematode parameters on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	0.59569	0.84	
Error	10	0.11756	F Value	Pr > F
C Total	11	0.71326	50.67	0.0001
Parameter	Estimate		F Value	Pr > F
Intercept	0.899615			
DAP2	-0.000044		50.67	0.0001

Table 13. Regression results for above ground partitioning in check treatments w/o nematode parameters on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	0.62309	0.76	
Error	10	0.20001	F Value	Pr > F
C Total	11	0.82310	31.15	0.0002
Parameter	Estimate		F Value	Pr > F
Intercept	0.861812			
DAP2	-0.000045		31.15	0.0002

Table 14. Regression results for tuber partitioning in aldicarb treatments w/o nematode parameters on Russet Burbank.

Source	DF	SS	r-Square	
Model	1	0.90453	0.90	
Error	10	0.09504	F Value	Pr > F
C Total	11	0.99957	95.17	0.0001
Parameter	Estimate		F Value	Pr > F
Intercept	-0.330985			
DAP	0.008797		95.17	0.0001

Table 15. Regression results for tuber partitioning in check treatments w/o nematode parameters on Russet Burbank.

Source	DF	SS	r-square	
Model	2	0.90453	0.90	
Error	8	0.09504	F Value	Pr > F
C Total	10	0.99957	95.17	0.0001
Parameter	Estimate		F Value	Pr > F
Intercept	-0.330985			
DAP	0.008797		95.17	0.0001