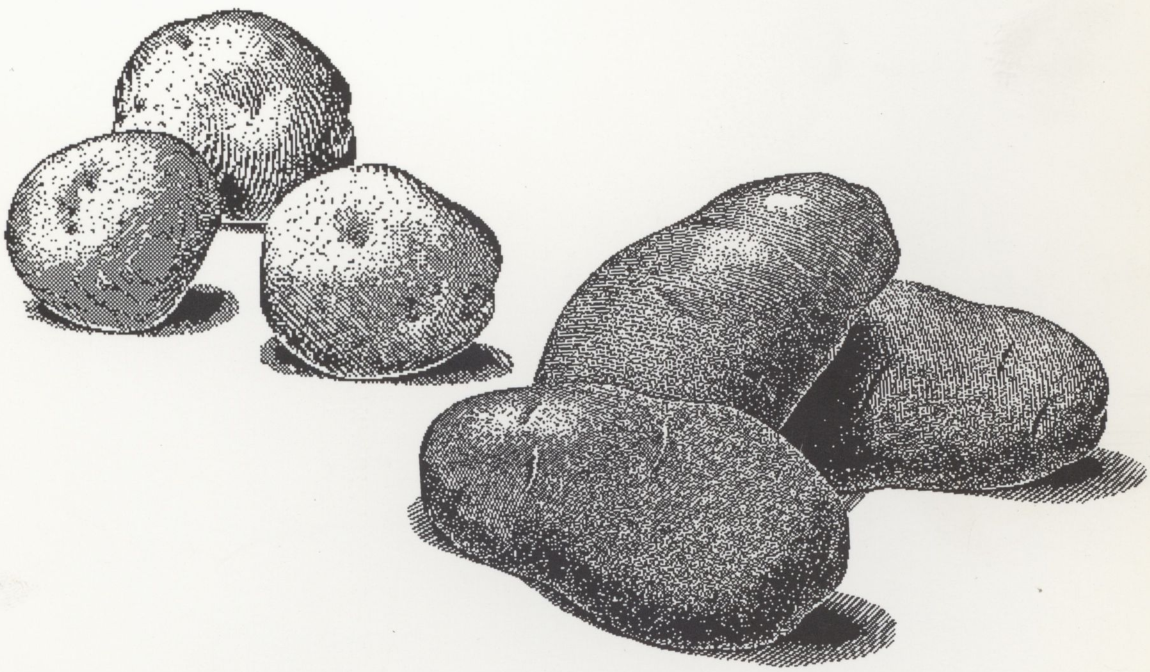
1997
MICHIGAN POTATO RESEARCH REPORT

VOLUME 29



Michigan State University
Agricultural Experiment Station

In Cooperation With

The Michigan Potato Industry Commission

THE MICHIGAN POTATO INDUSTRY COMMISSION

February 12, 1998

To All Michigan Potato Growers & Shippers:

The Michigan Potato Industry Commission, Michigan State University's Agricultural Experiment Station, and Cooperative Extension Service are pleased to provide you with a copy of the results from the 1997 potato research projects.

This report includes research projects funded by the Michigan Potato Industry Commission as well as projects funded through the USDA Special Grant, special allocations by the Commission and other sources.

Providing research funding and direction to principal investigators at MSU is a function of the Michigan Potato Industry Commission's Research Committee. The Commission is pleased to provide you with a copy of this report.

Best wishes for a prosperous 1998 season.

The Michigan Potato Industry Commission

THE MICHIGAN POTATO INDUSTRY COMMISSION • 13109 SCHAVEY RD., STE. 7 • DEWITT, MI 48820 • (517) 669-8377

TABLE OF CONTENTS

Page

1997 MSU POTATO RESEARCH REPORT

R.W. Chase, Coordinator

INTRODUCTION AND ACKNOWLEDGMENTS

The 1997 Potato Research Report contains reports of potato research projects conducted by MSU potato researchers at several different locations. The 1997 report is the 29th report which has been prepared annually since 1969. This volume includes research projects funded by the Special Federal Grant 97-34141-4185, the Michigan Potato Industry Commission and numerous other sources. The principal source of funding for each project has been noted at the beginning of each report.

We wish to acknowledge the excellent cooperation of the Michigan potato industry and the MPIC for their continued support of the MSU potato research program. We also want to acknowledge the significant impact that the funds from the Special Federal Grant have had on the scope and magnitude of several research areas.

Many other contributions to MSU potato research have been made in the form of fertilizers, pesticides, seed, supplies and monetary grants. We also acknowledge the tremendous cooperation of individual producers who cooperate with the numerous on-farm projects. It is this dedicated support and cooperation that makes for a productive research program for the betterment of the Michigan potato industry.

We further acknowledge the professionalism of the MPIC Research Committee. The Michigan potato industry should be proud of the dedication of this Committee and the keen interest they take in determining the needs and direction of Michigan's potato research.

Thanks go to Dick Crawford, for the farm management at the MSU Montcalm Research Farm; Chris Long, CSS Potato Technician and Dr. Kazimierz Jastrzebski, visiting scientist from Poland. Also, a special thanks to Jodie Schonfelder for the typing and preparation of this report and to MSU-E Don Smucker, Montcalm CED for maintaining the weather records from the Montcalm Research Farm computerized weather station.

WEATHER

The weather during the 1997 growing season was variable with below average temperatures during April and May (Table 1). June was slightly above the 15 year average, however, July and August were again cooler than normal. There was only one day, July 27, that the high temperature reached 90F.

Rainfall for the growing season was well below the 15 year average by over 5 inches (Table 2). The rainfall total for April-September was only 1.52 inches greater than in 1988 when we had the severe drought. August and September rainfall were below average and provided very good harvest conditions at the MSU Montcalm Research Farm

Table 1. The 15 year summary of average maximum and minimum temperatures during the growing season at the Montcalm Research Farm.

	April		May		June		July		August		September		6-Month Average	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1983	47	28	60	38	76	49	85	57	82	57	70	46	70	46
1984	54	34	60	39	77	54	78	53	83	55	69	45	70	47
1985	58	38	70	44	71	46	81	55	75	54	70	50	71	48
1986	60	36	70	46	77	50	82	59	77	51	72	50	73	49
1987	61	36	77	46	80	56	86	63	77	58	72	52	76	52
1988	52	31	74	46	82	53	88	60	84	61	71	49	75	50
1989	56	32	72	34	81	53	83	59	79	55	71	44	74	46
1990	NA	NA	64	43	77	55	79	58	78	57	72	47	NA	NA
1991	60	40	71	47	82	59	81	60	80	57	69	47	74	52
1992	51	34	70	42	76	50	76	54	75	51	69	46	69	46
1993	54	33	68	45	74	55	81	61	79	60	64	46	70	50
1994	57	34	66	43	78	55	79	60	75	55	73	51	71	49
1995	51	31	66	45	81	57	82	60	82	65	70	45	72	50
1996	50	31	64	44	75	57	76	55	80	59	70	51	69	50
1997	54	31	59	39	79	56	80	57	73	55	69	50	69	48
15-YR. AVG.	55	34	67	43	78	54	81	58	79	57	70	48	72	49

Table 2. The 15 year summary of precipitation (inches per month) recorded during the growing season at the Montcalm Research Farm.

Year	April	May	June	July	August	September	Total
1983	3.47	4.46	1.19	2.44	2.21	5.34	19.11
1984	2.78	5.14	2.93	3.76	1.97	3.90	20.48
1985	3.63	1.94	2.78	2.58	4.72	3.30	18.95
1986	2.24	4.22	3.20	2.36	2.10	18.60	32.72
1987	1.82	1.94	0.84	1.85	9.78	3.32	19.55
1988	1.82	0.52	0.56	2.44	3.44	5.36	14.14
1989	2.43	2.68	4.85	0.82	5.52	1.33	17.62
1990	1.87	4.65	3.53	3.76	4.06	3.64	21.51
1991	4.76	3.68	4.03	5.73	1.75	1.50	21.45
1992	3.07	0.47	1.18	3.51	3.20	3.90	15.33
1993	3.47	3.27	4.32	2.58	6.40	3.56	23.60
1994	3.84	2.63	6.04	5.16	8.05	1.18	26.90
1995	3.65	1.87	2.30	5.25	4.59	1.38	19.04
1996	2.46	3.99	6.28	3.39	3.69	2.96	22.77
1997	2.02	3.13	3.54	2.80	2.71	1.46	15.66
15-YR. AVG.	2.89	2.97	3.17	3.23	4.28	4.05	20.59

GROWING DEGREE DAYS

Table 3 summarizes the cumulative, base 50F growing degree days (GDD) for May through September. GDD for the growing season were the same as for 1992, a year in which many crops, other than potatoes, had difficulty attaining normal maturity. May 1997 had by far the least GDD for May and June since these data were initiated in 1991.

Table 3. Growing Degree Days* - Base 50F.

	Cumulative Monthly Totals				
	May	June	July	August	September
1991	452	1014	1632	2185	2491
1992	282	718	1210	1633	1956
1993	261	698	1348	1950	2153
1994	231	730	1318	1780	2148
1995	202	779	1421	2136	2348
1996	201	681	1177	1776	2116
1997	110	635	1211	1637	1956

*1991 and 1992 data calculated from Vestaburg weather station in Montcalm County (Dr. Jeff Andresen, Geography). 1993-1997 data from the weather station at MSU Montcalm Research Farm (Don Smucker, Montcalm County Extension Director).

PREVIOUS CROPS AND FERTILIZERS

The general research plot area was planted to rye in the fall of 1995 and harvested for seed in 1996, disced and reseeded to rye. The plot area was not fumigated and the following fertilizers were used in the general potato research plot area during 1997, the first year that liquid fertilizer was used at planting:

Application	Analysis	Rate	Nutrients
Plowdown	0-0-60	150 lbs/A	0-0-90
At-planting	18-18-0	10 gpa	20-20-0
At emergence	46-0-0	125 lbs/A	58-0-0
Sidedress	46-0-0	110 lbs/A	51-0-0
Sidedress	46-0-0	100 lbs/A	46-0-0

SOIL TESTS

Soil tests for the general plot area.

	lbs/A				Cation Exchange Capacity
pH	P_2O_5	K_2O	Ca	Mg	
6.0	616	284	762	150	4.1 me/100 g

HERBICIDES

Hilling was done in late May, followed by pre-emergence Dual and Sencor, 2 pts and 2/3 lb/A. Matrix plus Sencor, 1 oz. and 0.33 lbs/A was applied post emergence approximately three weeks later.

IRRIGATION

Irrigation was initiated on June 28 with six applications ending on August 7. The plot area had a high incidence of potato early die preventing most varieties from obtaining their normal maturity and potential yield.

INSECT AND DISEASE CONTROL

To enhance CPB resistance management, imidacloprid (Admire) was not used in 1997. Mocap at 30 lbs/A and Phorate at 15 lbs/A were banded at planting. Foliar applications of Asana, Imidan + PBO, Imidan and Monitor were used with fair control of Colorado potato beetle.

Fungicide applications were initiated on June 27 and a total of 10 applications were made during the season. Bravo, Bravo ZN, Manex and Dithane were used.

MICHIGAN STATE UNIVERSITY POTATO BREEDING PROGRAM 1997 STATUS REPORT

David S. Douches, K. Jastrzebski, Chris Long, Kim Walters and Joe Coombs
Department of Crop and Soil Sciences

Cooperators: R.W. Chase, Ray Hammerschmidt, Ed Grafius Jerry Cash and Willie Kirk

INTRODUCTION

The MSU program has a multi-faceted approach to variety development. We conduct variety trials of advanced selections, develop new genetic combinations in the breeding program and identify exotic germplasm that will enhance the varietal breeding efforts. With each cycle of crossing and selection we expect to see directed improvement towards improved varieties. We are also using the European germplasm as a source of disease resistance and quality traits. In addition, our program integrates genetic engineering to introduce traits. We feel that these in-house capacities (both conventional and biotechnological) put us in a position to respond and focus upon the most promising directions.

The breeding goals at MSU are based upon current and future needs of the Michigan potato industry. Traits of importance include yield potential, disease resistance (scab, late blight, Fusarium dry rot, soft rot, early die and virus resistance), chipping and cooking quality, bruise resistance, storability, along with shape, internal quality and appearance.

PROCEDURE

Varietal Development

Each year, during the winter months, approximately 500 crosses are made between the most promising cultivars and advanced breeding lines. The parents are chosen on the basis of yield potential, processing or tablestock quality, specific gravity, disease resistance, adaptation, bruising, lack of internal and external defects, etc. These seeds are being used as the breeding base for the program. Approximately 30,000 seedlings are grown annually for visual evaluation at the Montcalm and Lake City Research Farms as part of the first-year selection process of this germplasm each fall. Then each selection is then evaluated for specific gravity and chip-processing. These selections each represent a potential variety. This step is followed by evaluation and selection at the 8-hill, 20-hill stages. The best selections are then tested in replicated trials over time and advanced to on-farm evaluations. This generation of advanced seedlings is the initial step to breed new varieties and this step is an on-going process in the MSU program since 1988.

Integration of Genetic Engineering with Potato Breeding

Our laboratory is set up to use *Agrobacterium*-mediated transformation to introduce genes into important potato cultivars. We presently have genes that confer resistance to PVY, PLRV, Colorado potato beetle, Potato tuber moth, broad-spectrum disease resistance via glucose oxidase (GO) and cold/frost resistance. We also have the glgC16 gene (or starch gene) from Monsanto to influence starch and sugar levels in potato tubers. We have transgenic lines that express the PVYcp, Bt and GO genes. Transformations with the starch gene, Bt gene, GO and cold resistance gene are presently being conducted.

Germplasm enhancement

We have a "diploid" (2x chromosomes) breeding program in an effort to simplify the genetic system in potato (which normally has 4x chromosomes) and exploit more efficient selection of desirable traits. In general, diploid breeding utilizes haploids (half the chromosomes) from potato varieties, and diploid wild and cultivated tuber-bearing relatives of the potato. These represent a large source of valuable germplasm, which can broaden the genetic base of the cultivated potato and also provide specific desirable traits such as tuber dry matter content, cold chipping and dormancy, along with resistance to disease, insects, and virus. Even though these potatoes have only half the chromosomes of the varieties in the U.S., we can cross these potatoes to transfer the desirable genes by conventional crossing methods via 2n pollen. The diploid breeding program germplasm base at MSU is a synthesis of five species: S. tuberosum (adaptation, tuber appearance), S. phureja (cold-chipping, specific gravity), S. tarijense and berthaultii (tuber appearance, insect resistance) and S. chacoense (specific gravity, low sugars, dormancy).

We are also using other sources of germplasm to introgress disease resistance and tuber quality. Many European cultivars have high yield potential and resistance to various diseases such as scab, late blight and Erwinia soft rot. Some also have superior cooking qualities. These cultivars are being used in the crossing block each year. Dr. John Helgeson (USDA/ARS) has developed somatic fusion hybrids that have resistance to Erwinia soft rot, PLRV, early blight or late blight. We have those lines and have been crossing them to our best lines to initiate the adaptation of this germplasm source to Michigan.

RESULTS AND DISCUSSION

For the 1997 field season over 500 crosses have been planted and evaluated. Of those 15% of the crosses were between long types, 70% between round whites, and 15% to select red-skinned and yellow-flesh varieties. During the 1997 harvest, approximately 1800 selections were made from the 35,000 seedlings grown at the Montcalm Research Farm and Lake City Experiment Station. The extra 5,000 seedlings evaluated in 1997 was to emphasize the late blight breeding effort. In addition to the single hill selections, 300 selections were made from 1,400 8-hill plots and 80 selections from 300 20-hill plots. Following harvest, specific gravity was measured and chip-processing was conducted. Chipping out of 42 and 40F storage will be conducted later this winter. The best selections from the 20-hill plots will be advanced to replicated trials in 1998.

A high priority objective of the breeding program is to identify sources of late blight resistance and use these sources for breeding varieties with late blight resistance. Based upon greenhouse screenings, we have been using USDA/ARS and European sources of late blight resistance in our crossing block. We have made selections from these crosses and, in preliminary greenhouse screenings, some selections show some resistance to late blight. The late blight field trial results corroborated the greenhouse results. The advanced selection MSG274-3 is the most promising seedling with strong late blight resistance. We will continue to evaluate these selections for resistance and agronomic performance. The best overall parents for late blight breeding are Zarevo, Tollocan and B0718-3. As a result of the extra 5,000 seedlings for evaluation in 1997, approximately 425 selections were made. Late blight screening will take place in the greenhouse this winter.

One of our objectives is to develop improved cultivars for the tablestock industry. Efforts have been made to identify lines with good appearance, low internal defects, high marketable yield and resistance to scab. From our efforts we have identified mostly round white lines, but we have a number of yellow fleshed and russet selections which carry many of the characteristics mentioned above. We are also looking for a dual-purpose russet. Some of the tablestock lines were tested in on-farm trials in 1997, while others were tested under replicated conditions at MRF. Our goal now is to 1) improve further on the level of scab resistance, 2) incorporate resistance to late blight, 3) select more russet lines and introduce the CryIII-Bt gene into Yukon Gold, Norwis, Onaway and MSE018-1.

Another one of the objectives is to develop potato varieties that will not accumulate reducing sugars in cold storage (40F). We commonly call these varieties "cold chippers". There is a question as to which temperature is most appropriate to screen for cold-chipping. This storage season we have lowered the storage temperature from 45F to 42F, as our initial screen, to chip-process directly out of cold storage. We feel there is no long-term value in 2-4 week reconditioning out of 40F storage. We lowered the screening temperature because we felt that we have been identifying many selections from that process from 45F and we need to differentiate the good chippers more stringently. As desirable cold-chipping genes accumulate in the breeding program, we will reduce the storage temperature for screening to 40F.

Some of the parents used extensively in the crossing block over the past few years has included Snowden, ND860-2, MS702-80, Atlantic, NorValley, S440, S438, Lemhi Russet, Pike, Chipeta, W877, W870, NDA2031-2, NDO1496-1 and Brodick. In addition, we have advanced into the crossing block new MSU selections that have enhanced chip quality directly out of 45F storage. These clones constitute a diverse genetic base from which to combine good chipping quality with agronomic performance. As a result of this crossing strategy, many of our advanced selections have two or more chip-processing parents in their pedigree.

Performance of 50 and 55 advanced selections was tested in the Adaptation and 2x23 Trials, respectively. The most promising selections are summarized in Tables 1 and 2. The yield of the plots in the trials at Montcalm Research Farm were below average in 1997, however many promising selections surfaced. The most promising selections from these trials with tablestock potential are MSE228-1, MSF373-8, MSG104-6, MSG050-2. MSG274-3 has strong resistance to late blight, while MSE226-5Y and MSG077-7Y are some yellow-fleshed selections with an attractive appearance. We also identified a high-yielding blue-fleshed potato that makes a novelty chip. The most promising chip-processing lines are MSF014-9, MSE263-10, MSF099-

3, MSE230-6, MSE250-2, MSF313-3 and MSG227-2. The selections MSG007-1 and MSG141-3 have reduced susceptibility to late blight. All promising selections are targeted for tissue culture this winter and seed increase in 1998. The Late Blight and Fusarium dry rot tests, scab trial results and blackspot bruise tests for these selections are summarized in the 1997 Potato Variety Evaluation Report.

In the diploid germplasm about 20 of the best lines with differing pedigrees formed the crossing block to generate new populations in 1995. From this material we expect to find improved diploid *Solanum* species parents to be used in crosses to select new varieties (4x-2x crosses). In 1996 selections were made in these crosses at Lake City. These lines were tested as 8-hill plots in 1997. The best lines will be used in the diploid crossing block this winter, along with clones from other breeding programs for verticillium, Colorado potato beetle and PLRV resistance in addition to cold-chipping clones.

We added to the germplasm enhancement program a number of genetic lines that are derivatives of cell (protoplast) fusions between *S. brevidens* (from Argentina) and the cultivated potato. These lines were developed by J. Helgeson at the University of Wisconsin and have been noted for their *Erwinia* soft rot, early blight and PLRV resistance. Through further crossing and evaluation we hope to incorporate these resistances into the breeding populations we have been selecting for chip-processing. These populations were in the field since 1995. Selections have been made and we are advancing some through the breeding program. Special attention will be placed upon these selections for disease resistance. This germplasm enhancement (diploid and protoplast fusion) is the base from which long-term genetic improvement of the potato varieties in the MSU breeding program is generated.

In 1998 we plan to field test Yukon Gold, Lemhi Russet and Spunta lines with the CryIII-Bt gene for CPB resistance. In addition, various varieties with the GO gene will be field tested for late blight resistance.

TABLE 1

ADAPTATION TRIAL
MONTCALM RESEARCH FARM
SEPTEMBER 18, 1997
(135 DAYS)

	CWT/A		PERCENT OF TOTAL[1]							TUBER QUALITY[2]				TOTAL	
LINE	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[†]	HH	VD	IBS	BC	CUT	SCAB[3]
MSE228-1	358	388	92	7	82	10	1	1.076	2.0	0	11	0	0	40	2.7
MSF373-8	326	345	95	2	58	36	3	1.084	2.0	10	0	0	6	40	3.0
MSF014-9	243	264	92	8	84	8	0	1.070	1.5	1	0	2	0	40	1.2
MSF019-11	240	308	78	22	74	4	0	1.081	1.5	7	8	1	0	40	2.8
ONAWAY	234	271	86	11	73	14	3	1.064	3.5	0	10	0	2	40	1.0
MSE263-10	220	241	91	8	84	8	0	1.075	1.0	0	3	0	0	40	1.3
MSE080-4	219	245	90	10	73	16	0	1.074	2.0	0	9	0	1	40	1.8
ATLANTIC	217	246	88	8	74	15	4	1.089	-	6	1	0	1	40	3.3
MSF099-3	215	254	85	15	71	14	0	1.090	1.5	0	3	0	1	40	2.5
MSE230-6	210	297	71	27	71	0	2	1.091	1.5	0	1	0	0	30	1.5
MSE245-B	206	233	89	11	78	11	0	1.082	2.0	0	9	0	0	40	1.5
MSF001-2	190	251	76	24	75	1	1	1.078	1.0	1	1	1	0	40	2.0
SNOWDEN	190	253	75	24	73	2	1	1.087	-	3	8	0	0	40	2.6
MSE009-1	188	250	75	24	73	2	1	1.075	1.5	0	15	0	0	40	1.5
MSE250-2	176	213	83	17	80	3	0	1.091	1.0	1	2	0	0	40	3.2
MSE246-5	151	217	70	30	68	1	0	1.097	1.0	0	9	1	0	40	1.4
MSF165-6RY	129	195	66	32	65	1	2	1.070	2.0	1	1	0	0	40	3.5
MEAN	219	263						1.081							
$LSD_{0.05}$	57	56						0.003							

[1]<u>SIZE</u>
B: < 2"
A: 2 - 3.25"
OV: > 3.25"
PO: PICKOUTS

[2]<u>QUALITY</u>
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

[3]<u>SCAB DISEASE RATING</u>
1: NO INFECTION
3: INTERMEDIATE
5: HIGHLY SUSCEPTABLE

[†]<u>SNACK FOOD ASSOCIATION CHIP SCORE</u>
OUT OF THE FIELD
RATINGS: 1 - 5
1: EXCELLENT
5: POOR

PLANTED MAY 6, 1997

TABLE 2

MSU BREEDING LINE EVALUATION
MONTCALM RESEARCH FARM
SEPTEMBER 23, 1997
(140 DAYS)

LINE	CWT/A US#1	CWT/A TOTAL	PERCENT OF TOTAL[1] US#1	Bs	As	OV	PO	SP GR	SFA[†]	TUBER QUALITY[2] HH	VD	IBS	BC	TOTAL CUT	PARENTS	SCAB[3]
MSG124-8P	453	510	89	4	44	45	8	1.072	2.0	13	0	0	0	20	Saginaw Gold x A199-1	1.5
MSG104-6	352	375	94	6	65	29	0	1.075	2.0	4	0	0	0	20	Portage x MS702-80	3.3
ONAWAY	350	392	89	9	78	11	2	1.066	3.0	0	3	0	3	20		1.0
MSF313-3	342	387	88	10	75	14	2	1.080	1.0	0	0	0	0	20	Spartan Pearl x NY88	1.8
MSG119-1RD	332	357	93	5	86	7	2	1.074	1.0	0	0	0	0	20	Reddale x NY88	2.0
MSE033-1RD	326	353	92	6	75	17	1	1.070	2.0	0	1	0	0	20	Reddale x Spartan Pearl	1.0
MSG301-9	324	371	87	12	83	4	1	1.080	1.5	3	3	0	1	20	Spartan Pearl x S440	1.0
MSG050-2	319	359	89	9	80	9	2	1.074	3.0	3	1	2	0	20	Eramosa x L235-4	2.0
MSG251-10	313	331	95	3	80	14	3	1.079	1.0	0	0	0	0	20	B1254-1 x MSC135-5	3.0
MSG227-2	306	330	93	7	86	7	0	1.084	1.0	9	0	0	0	20	Prestile x MSC127-3	1.0
MSA105-1	302	337	90	8	78	12	2	1.084	1.5	9	0	0	0	20	MS716-15 x 700-83	3.1
MSG274-3Y	286	416	69	31	68	1	1	1.085	1.5	0	0	0	0	20	Tollocan x Chaleur	-
MSB054-4	282	328	86	12	77	9	2	1.083	2.0	0	0	1	0	20	Atlantic x Nooksack	4.0
ATLANTIC	278	313	89	6	63	26	5	1.089	1.0	14	0	0	0	20		3.3
YUKON GOLD	272	293	93	7	73	20	1	1.078	3.0	16	0	2	0	20		3.0
SNOWDEN	271	342	79	19	73	6	2	1.090	1.0	10	0	1	0	20		2.6
MSE226-5Y	265	323	82	17	81	1	0	1.071	1.0	0	0	0	1	20	Sag Gold x MS702-80	1.5
MSG261-3	265	291	91	9	87	4	0	1.082	1.0	0	2	0	0	20	NY95 x MSE251-1	3.0
MSF373-A	253	278	91	9	85	6	0	1.067	2.0	0	0	1	0	20	MS702-80 x NY88	1.8
MSB094-1	218	263	83	13	81	2	4	1.079	1.5	0	4	1	0	20	Superior x Michigold	3.0
MSG010-11	214	273	78	21	78	0	1	1.071	2.0	2	4	0	0	20	A199-1 x Yukon Gold	3.3
MSG141-3	212	254	83	16	82	1	0	1.090	1.5	0	1	0	0	20	Spartan Pearl x Zarevo	-
MSG007-1	211	247	86	14	81	4	0	1.092	1.0	5	0	0	0	20	Atlantic x Zarevo	-
MSG077-7Y	203	246	83	13	80	3	4	1.077	1.5	7	1	0	0	20	MS702-80 x Yukon Gold	2.5
MEAN	290	332						1.079								
$LSD_{0.05}$	77	77						0.005								

[1]SIZE
B: < 2"
A: 2 - 3.25"
OV: > 3.25"
PO: PICKOUTS

[2]QUALITY
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

[3]SCAB DISEASE RATING
1: NO INFECTION
3: INTERMEDIATE
5: HIGHLY SUSCEPTABLE

[†]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD
RATINGS: 1 - 5
1: EXCELLENT
5: POOR

PLANTED MAY 6, 1997

Funding Fed. Grant/MPIC

1997 POTATO VARIETY EVALUATIONS

**D.S. Douches, R.W. Chase, K. Jastrzebski, R. Hammerschmidt,
W. Kirk, C. Long, K. Walters and J. Coombs**

**Departments of Crop and Soil Sciences
and Botany and Plant Pathology
Michigan State University
East Lansing, MI 48824**

The objectives of the evaluations are to identify superior varieties for fresh market or for processing and to develop recommendations for the growing of those varieties. The varieties were compared in groups according to the tuber type and skin color and to the advancement in selection. Each season, total and marketable yields, specific gravity, tuber appearance, incidence of external and internal defects, chip color (from field, 42 and 50 F storage), dormancy (at 50F), as well as susceptibilities to late blight, common scab, Fusarium dry rot, Erwinia soft rot and blackspot bruising are determined.

Six field experiments were conducted at the Montcalm Research Farm in Entrican, MI. They were planted in randomized complete block design with four replications. The plots were 23 feet long and spacing between plants was 12 inches. Inter-row spacing was 34 inches. Supplemental irrigation was applied as needed.

Both round and long variety groups were harvested at two dates. They are referred to as the Date-of-Harvest trials. The other two field experiments were the North Central Regional and European trials. In each of these trials the yield was graded into four size classes, incidence of external and internal defects in > 3.25 in. diameter or 10 oz. potatoes were recorded, and samples for specific gravity, chipping, dormancy, disease tests, bruising and cooking tests were taken. Chip quality was assessed on 25-tuber samples, taking two slices from each tuber. Chips were fried at 365°F. The color was measured visually with the SFA 1-5 color chart. Tuber samples were also stored at 42 or 50°F for chip-processing out of storage in January and March.

Results

A. Round White Varieties

Six varieties and 19 breeding lines were compared at two harvest dates. Atlantic, Snowden, Pike and Onaway were used as checks. The trials were subject to early die. As a result, the plot yields were below average. The results are presented in Tables 1 and 2. In the early harvest trial (95 days), NY101, Onaway, MSE228-9, MSE228-11, NY103, Atlantic and Atlantic NewLeaf had the highest yields of the 25 entries. At the later harvest (127 days), NY101 and

MSE228-11 were still the top yielders. The MSU advanced seedlings MSE018-1 and MSB107-1 were also high yielding. These two lines were also the top yielding MSU selections in the on-farm trials in 1997. Internal brown spot and hollow heart incidence were low within the trial, however vascular discoloration was more prevalent than in previous years.

Variety Characteristics

Atlantic NewLeaf - a selection from NatureMark which expresses the CryIII-Bt gene for beetle control. It performs similar to Atlantic.

NY103 - a chip-processing/fresh market selection from New York which has high yield potential, excellent internal quality and smooth, bright appearance, but the specific gravity is too low for chip-processing. NY103 is equivalent to Atlantic for scab reaction. This selection has had excellent yield potential in on-farm trials. It is expected to be named by New York.

NY101 - a light-yellow-fleshed selection from New York. This line has an excellent shape, with netted tubers and very high yield potential. It is resistant to scab. In general, internal defects are low, but in 1995 we observed IBS in the oversize tubers.

Pike - an average yielding selection from New York. It chip-processes well and is resistant to scab similar to Superior. At times it has shown IBS in the tubers.

MSA091-1 - an MSU selection for chip-processing with scab resistance. Yields have been variable, but it has performed well in other states and the late blight trials indicate a reduced susceptibility to late blight.

MSB076-2 - this MSU selection has high yield potential, has very high specific gravity, acceptable chip quality and resistant to scab. It is between Atlantic and Snowden in maturity and we observed, in some instances, a tendency for hollow heart in oversize tubers. It has a large and upright vine type. This selection had the highest overall merit rating in the 1996 and 1997 North Central Regional Trials.

MSB107-1 - an MSU selection for the tablestock market. It is a bright-skinned with large, round tubers with excellent internal quality. This selection performed well in grower trials in 1996 and 1997.

MSC103-2 - an MSU selection for the tablestock market. It performed well in the 1996 and 1997 on-farm trials. It's maturity is late, scab tolerance is intermediate, and has a reduced susceptibility to late blight.

MSE018-1 - an MSU chip-processing selection with high yield potential. It was an outstanding yielder in the 1997 on-farm trials. Specific gravity is high and it has a good general appearance. Scab tolerance is intermediate and it has a reduced susceptibility to late blight. This line is targeted for the 1998 SFA Trials.

MSE221-1 - an MSU tablestock selection. It has high yield potential, but it did not perform well in the 1997 MRF trials due to early die. General appearance is good and has strong resistance to scab.

MSE228-9 - an MSU selection for the tablestock/chip-processing market. Yield potential is above average, maturity is mid-season and scab tolerance is good. It was in the 1997 on-farm trials.

MSE228-11 - an MSU selection for the tablestock/chip-processing market. It has high yield potential, mid-season maturity and good scab tolerance. It was in the 1997 on-farm trials.

MSNT-1 - an MSU chip-processing selection. It has above average yield potential, excellent chip quality and strong resistance to scab. It is targeted for the 1998 SFA trials.

B. Long Varieties

Five varieties and seven breeding lines were tested. Russet Burbank and Shepody were grown as check varieties. The first date-of-harvest trial was dug 120 days from planting rather than 95 days to give the trial greater time for tuber bulking. Most of the entries in the long-type trial were late maturing resulting in low yields and small tuber size at the first date-of-harvest (Table 3). At the second harvest on September 18 (136 days), yields for all entries had not changed due to potato early die (Table 4). Yields were below average. Within the 12 long-type entries, Umatilla Russet (AO82611-7), Century Russet and Shepody produced the highest yields at both harvest dates. Internal defects were not significant.

Variety Characteristics

Century Russet - a russet variety from Oregon/USDA-Aberdeen with high yield potential. It has excellent internal quality and bulks early despite a late vine maturity. It is susceptible to scab.

JS111-28 - provided by J.R. Simplot. JS111-28 has high yield potential with good general appearance, good russeting and shallow eyes. It is a somaclonal derivative of Lemhi Russet selected for lower incidence of blackspot bruise. It is also highly scab resistant.

A7961-1 - is an USDA-Aberdeen entry with above average yield. It has uniform appearance, heavier russeting than Russet Burbank and minimal internal defects. It can be used for frozen-processing.

Umatilla Russet (AO82611-7) - this selection was the top performing line in 1997, but was below average in 1996. It is reported to have some resistance to early dying. Tuber shape is long but tuber width is narrow.

Newleaf Russet Burbank - a variety from NatureMark which expresses the Bt gene for beetle control. Yield was below average this year despite good vine growth.

MSE202-3Rus - an MSU selection with strong scab resistance. It has good appearance and may be suitable for tablestock or processing. Yield was low in 1997.

C. North Central Regional Trial

The North Central Trial is conducted in a wide range of environments, in 9 states to provide adaptability data for the release of new varieties from North Dakota, Minnesota, Wisconsin, and Michigan. Twelve breeding lines and seven varieties were tested in Michigan. The results are presented in Table 5. The range of yields were wide. The MSU selections, MSB076-2 and MSB106-7, performed well in 1996 and 1997. W1313, a Wisconsin seedling, had the highest yield but had over 50% of its oversize tubers with hollow heart and was the most bruise susceptible line in all the trials. The Minnesota selection, MN16489, had a high overall merit in the trial, but it has a blush skin which may limit its marketability. The North Dakota seedling, ND2676-10, has a nice appearance, some scab resistance and a good chip score, but it had a below average yield and a specific gravity under the industry standards.

D. European/Yellow Trial

Five European varieties and advanced selections were tested along with three yellow-fleshed MSU seedlings. Snowden, Yukon Gold, Michigold and Saginaw Gold were used as checks. The results are summarized in Table 6. Typically, most of the European selections and varieties are late to very-late in maturity, but in 1997, the vines died early and yields were down considerably. The best performing lines in 1997 were MSE222-5Y, MSE048-2Y, MSE149-5Y, and MSE226-4Y. MSE149-5Y is a light yellow-fleshed selection which will be advanced to the date-of-harvest round white trial in 1998 because of its processing potential. Pickouts were high in Latona, Obelix, Dali, MSA097-1Y and MSA222-5Y.

E. Potato Scab Evaluation

Each year a replicated field trial at the MSU Soils Farm is conducted to assess resistance to common and pitted scab. The varieties are ranked on a 1-5 scale based upon a combined score for scab coverage and lesion severity. Usually examining one year's data does not indicate which varieties are resistant but it should begin to identify ones that can be classified as susceptible to scab. Our goal is to evaluate important advanced selections and varieties in the study at least three years to obtain a valid estimate of the level of resistance in each line. We now have had four years of good scab trials (i.e. high levels of infection in susceptible lines).

Table 7A categorizes many of the varieties and advanced selections tested. Scab results are also found in the Trial Summaries (Tables 2,4,5 and 6). Table 7B summarizes the 1994-6 scab trial results for the lines in these trials. Many russet lines showed resistance to scab infection with Century Russet an exception to this trend. The MSU lines MSE192-8Rus and MSE202-3Rus, showed some resistance to scab in 1996 and 1997. Some round white tablestock clones have resistance such as Superior, Onaway, MSB040-3, MSE228-9, MSE228-11 and MSE221-1. Yellow-fleshed selections with resistance are NY101, MSE226-4Y, MSE226-5Y and MSC120-1Y and MSA097-1Y. Scab resistance was also identified in the chip-processing clones Pike and

MSU selections MSB076-2, MSA091-1, MSB073-2, MSNT-1, MSE230-6, MSF014-9, MSF313-3 and MSG227-2.

F. Blackspot Susceptibility

Increased evaluations of advanced seedlings and new varieties for their susceptibility to blackspot bruising has been implemented in the variety evaluation program. Check samples of 25 tubers were collected (a composite of 4 reps) from each cultivar at the time of grading. A second 25 tuber sample was similarly collected and was placed in a hexagon plywood drum and tumbled 10 times to provide a simulated bruise. Both samples were peeled in an abrasive peeler in October and individual tubers were assessed for the number of blackspot bruises on each potato. These data are shown in Tables 8A and 8B.

Table 8A summarizes the data for the samples receiving the simulated bruise and Table 8B, the check samples. The bruise data are represented in two ways: percentage of bruise free potatoes and average number of bruises per tuber. A high percentage of bruise-free potatoes is the desired goal; however, the numbers of blackspot bruises per potato is also important. Cultivars which show blackspot incidence of 3 or more spots per tuber from the simulated bruise are approaching the bruise-susceptible rating. In addition, the data is grouped by trial, since the bruise levels can vary between trials. These results become more meaningful when evaluated over 3 years which reflects different growing seasons and harvest conditions. Bruising was more severe in 1996 than in 1997 and 1995.

G. Late Blight Trial

In 1997 a late blight trial was conducted at the Muck Soils Research Farm. Over 175 entries were evaluated in replicated plots. The field was inoculated on July 22 and ratings were taken during July and August. Most lines were highly susceptible to the US-8 genotype of late blight. Lines with the least infection were AWN86514-1, B0767-2, B0718-3 and MSG274-3. The good agronomic qualities of MSG274-3 (see Table 2 of Breeding Report) makes this selection a strong candidate for commercial testing when enough seed is produced. Foliar susceptibility of all the lines tested against the US-8 genotype of late blight is summarized in Table 9.

H. Post-harvest Disease Evaluation: Fusarium Dry Rot

As part of the postharvest evaluation, resistance to *Fusarium sambucinum* (fusarium dry rot) was assessed by inoculating 8 whole tubers post-harvest from each line in the variety trials. The tubers were held at 20°C for approximately three weeks and then scored for dry rot infection depth and width. These data are summarized in Table 10. The clones in this table are grouped according to infection levels (low: < 8mm infection depth, moderate: 8-16mm infection depth, high: > 16mm infection depth). Few clones have low levels of infection. The best lines in this experiment were Snowden, B1004-8, MSG236-1, MSE030-4 and MSF105-10. The results of this experiment continue to support the low dry rot infection levels observed in Snowden and that the low infection level can be transmitted to progeny such as MSG236-1, MSE030-4 and MSF105-10.

TABLE 1

ROUND WHITES: EARLY HARVEST
MONTCALM RESEARCH FARM
AUGUST 8, 1997
(95 DAYS)

	CWT/A		PERCENT OF TOTAL[1]							TUBER QUALITY[2]				TOTAL	3-YR AVG US#1
LINE	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[†]	HH	VD	IBS	BC	CUT	CWT/A
NY101	186	235	79	20	77	2	1	1.084	1.5	0	0	0	0	24	288
ATLANTIC	160	199	80	17	73	7	3	1.094	1.5	1	2	0	0	24	263
ONAWAY	149	206	73	26	69	4	1	1.069	4.0	0	3	0	0	24	259
MSE228-9	149	189	79	20	77	2	1	1.089	1.0	0	0	0	0	24	-
ATL NEWLEAF	139	173	80	20	79	1	0	1.094	1.0	0	3	0	2	24	-
NY103	139	192	73	26	73	0	2	1.076	2.5	0	0	0	0	24	254
MSE228-11	139	239	58	41	58	0	0	1.088	2.0	0	4	0	0	24	-
MSE221-1	132	182	73	25	71	2	2	1.071	2.5	0	4	0	0	24	-
FL1833	132	167	79	20	76	3	1	1.088	1.5	1	14	0	0	24	236
FL1879	121	161	75	24	71	4	1	1.084	2.0	0	8	0	0	24	-
MSNT-1	117	187	62	38	62	0	0	1.090	1.0	0	0	0	0	24	-
SNOWDEN	95	192	50	50	48	1	0	1.089	1.0	0	6	0	0	24	167
MSC103-2	93	112	83	16	80	3	1	1.071	3.0	0	4	0	0	24	-
PIKE	88	134	66	34	66	0	0	1.084	1.0	0	0	0	0	24	167
FL1831	83	136	61	33	60	1	6	1.095	1.0	1	0	0	0	24	-
REBA (NY87)	83	137	60	39	60	0	0	1.074	2.0	0	1	0	0	24	-
MSE018-1	82	147	56	44	56	0	0	1.093	2.0	0	2	0	0	24	-
MSB057-2	79	141	56	44	56	0	0	1.084	1.5	0	4	0	0	24	-
MSC148-A	75	160	47	52	47	0	1	1.081	2.0	0	5	2	0	24	-
FL1869	73	149	49	50	49	0	1	1.087	1.0	0	2	0	0	24	-
MSA091-1	71	152	47	51	47	0	2	1.084	1.0	0	3	0	0	24	136*
MSB107-1	67	107	63	37	62	1	1	1.074	2.5	0	1	0	0	24	153
MSB040-3	64	134	48	50	48	0	2	1.075	2.5	0	1	0	0	24	-
MSB076-2	56	148	38	62	36	2	0	1.086	2.0	1	1	0	0	24	193
MSB073-2	31	135	23	76	23	0	1	1.092	2.0	0	2	0	0	24	-
MEAN	104	165						1.084							
$LSD_{0.05}$	29	31													

[1]SIZE
B: < 2"
A: 2 - 3.25"
OV: > 3.25"
PO: PICKOUTS

[2]QUALITY
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

[†]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD
RATINGS: 1 - 5
1: EXCELLENT
5: POOR

* TWO-YEAR AVERAGE
PLANTED MAY 5, 1997

TABLE 2

ROUND WHITES: LATE HARVEST
MONTCALM RESEARCH FARM
SEPTEMBER 9, 1997
(127 DAYS)

LINE	CWT/A US#1	CWT/A TOTAL	PERCENT OF TOTAL[1] US#1	Bs	As	OV	PO	SP GR	SFA[†]	TUBER QUALITY[2] HH	VD	IBS	BC	TOTAL CUT	SCAB[3]	3-YR AVG US#1 CWT/A
NY101	276	312	89	11	86	2	0	1.077	1.5	0	8	0	0	40	1.0	448
MSE228-11	252	337	75	24	73	1	1	1.086	2.0	0	13	0	0	40	1.5	278*
MSE018-1	248	295	84	15	76	8	1	1.110	1.5	2	4	0	0	40	2.6	407*
MSB107-1	224	254	88	11	80	9	0	1.080	1.0	1	2	0	0	40	1.8	332
FL1833	217	241	90	9	75	15	1	1.083	1.5	1	13	1	0	40	1.7	369
ATLANTIC	211	252	84	14	74	10	3	1.089	1.5	3	5	0	1	40	3.3	352
ATL NEWLEAF	199	232	86	14	79	7	0	1.088	1.5	3	10	3	2	40	-	-
MSE228-9	197	231	86	14	82	3	1	1.082	1.5	0	3	0	0	40	1.8	233*
ONAWAY	192	238	80	19	75	6	1	1.062	3.5	0	10	0	1	40	1.0	315
REBA (NY87)	183	219	83	17	74	9	0	1.076	1.0	0	1	1	0	40	2.3	-
MSA091-1	178	231	77	21	75	2	2	1.083	1.5	0	8	0	0	40	1.8	247*
MSNT-1	171	236	73	27	73	0	1	1.085	1.0	1	0	1	0	40	1.0	252*
MSE221-1	165	202	82	13	74	8	5	1.066	3.0	0	5	2	0	40	1.0	284*
MSC103-2	164	180	91	7	78	13	2	1.076	3.0	0	5	0	0	40	1.8	264*
NY103	162	197	82	18	82	0	0	1.069	1.5	0	2	1	0	40	2.5	356
FL1879	157	187	84	16	78	5	0	1.078	1.5	4	7	1	0	40	3.0	-
SNOWDEN	141	221	64	36	63	1	0	1.083	1.0	0	15	0	0	40	2.5	296
MSB057-2	139	195	71	29	69	2	0	1.081	2.0	0	10	0	0	40	4.1	246*
MSB073-2	132	217	61	39	61	0	0	1.084	1.0	0	7	0	0	40	1.8	241*
FL1831	131	183	72	23	72	0	5	1.091	1.0	0	9	2	0	40	1.5	-
PIKE	125	171	73	27	73	0	0	1.081	1.0	0	1	0	0	40	1.7	214*
MSB076-2	113	193	59	41	59	0	0	1.085	1.5	0	2	1	1	40	1.8	301
MSB040-3	88	151	58	41	58	0	0	1.058	1.5	0	2	0	0	20	1.8	188*
FL1869	87	149	58	40	58	0	2	1.078	1.0	1	0	0	0	40	1.3	-
MSC148-A	67	166	40	58	39	1	1	1.075	1.0	1	0	1	0	10	2.4	146*
MEAN	169	220						1.080								
$LSD_{0.05}$	38	36						0.005								

[1]SIZE
B: < 2"
A: 2 - 3.25"
OV: > 3.25"
PO: PICKOUTS

[2]QUALITY
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

[3]SCAB DISEASE RATING
1: NO INFECTION
3: INTERMEDIATE
5: HIGHLY SUSCEPTABLE

* TWO-YEAR AVERAGE
PLANTED MAY 5, 1997

[†]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD
RATINGS: 1 - 5
1: EXCELLENT
5: POOR

TABLE 3

LONG TYPES: EARLY HARVEST
MONTCALM RESEARCH FARM
SEPTEMBER 2, 1997
(120 DAYS)

	CWT/A		PERCENT OF TOTAL[1]						TUBER QUALITY[2]				TOTAL	3-YR AVG US#1
LINE	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	HH	VD	IBS	BC	CUT	CWT/A
UMATILLA R. (A082611-7)	222	345	65	34	59	6	2	1.084	1	0	0	0	16	234
CENTURY RUSSET	192	287	67	33	63	4	1	1.082	2	1	0	0	7	284*
SHEPODY	188	250	75	24	67	8	1	1.075	2	2	0	0	15	221
A84118-3	130	222	59	41	57	2	0	1.086	2	0	0	0	4	122
RUSSET BURBANK	111	197	56	41	55	1	3	1.073	0	1	0	0	2	177
A8495-1	106	245	43	56	43	0	0	1.084	0	0	0	0	0	85*
MSE192-8RUS	96	208	46	50	44	2	4	1.067	0	0	0	0	2	-
JS111-28	92	177	52	47	52	0	1	1.074	0	0	0	0	0	178
P88-13-4	91	292	31	69	31	0	0	1.087	0	0	0	0	1	-
RB NEWLEAF	90	197	46	52	46	0	2	1.071	0	0	0	0	0	127*
MSB106-7	88	188	47	53	47	0	0	1.057	0	0	0	0	0	-
A7961-1	77	218	36	64	35	1	0	1.085	0	0	0	0	2	203
MEAN	124	235						1.077						
$LSD_{0.05}$	27	29						0.0025						

[1]SIZE
B: < 4 oz.
A: 4 - 10 oz.
OV: > 10 oz.
PO: PICKOUTS

[2]QUALITY
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

* TWO-YEAR AVERAGE
PLANTED MAY 5, 1997

TABLE 4

LONG TYPES: LATE HARVEST
MONTCALM RESEARCH FARM
SEPTEMBER 18, 1997
(136 DAYS)

	CWT/A		PERCENT OF TOTAL[1]						TUBER QUALITY[2]				TOTAL		3-YR AVG US#1
LINE	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	HH	VD	IBS	BC	CUT	SCAB[3]	CWT/A
UMATILLA R. (A082611-7)	225	320	70	24	62	9	6	1.082	5	0	0	0	40	1.0	276
CENTURY RUSSET	199	272	73	27	66	8	0	1.081	2	5	0	0	40	3.1	304*
SHEPODY	187	233	80	18	69	11	2	1.074	1	4	0	0	40	3.8	270
MSE202-3RUS	139	212	66	32	64	2	2	1.078	2	1	0	0	40	1.0	272*
A84118-3	125	216	58	42	57	1	0	1.084	7	8	0	0	40	1.0	182
A8495-1	118	224	53	47	51	2	0	1.083	4	3	0	0	40	1.0	107*
MSB106-7	115	195	59	41	56	2	1	1.057	0	8	2	0	40	1.3	270*
A7961-1	105	214	49	50	47	2	1	1.084	6	8	0	0	40	1.0	270
P88-13-4	97	248	39	61	39	0	0	1.087	0	1	0	0	40	3.0	-
RUSSET BURBANK	95	185	51	39	51	0	10	1.071	1	13	0	1	40	1.0	219
JS111-28	87	157	55	40	55	0	5	1.073	3	10	1	0	40	1.0	279
RB NEWLEAF	78	168	47	46	46	1	8	1.066	2	5	0	1	40	-	143*
MEAN	131	220						1.077							
$LSD_{0.05}$	45	47						0.003							

[1]SIZE
B: < 4 oz.
A: 4 - 10 oz.
OV: > 10 oz.
PO: PICKOUTS

[2]QUALITY
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

[3]SCAB DISEASE RATING
1: NO INFECTION
3: INTERMEDIATE
5: HIGHLY SUSCEPTABLE

* TWO-YEAR AVERAGE
PLANTED MAY 5, 1997

TABLE 5

NORTH CENTRAL REGIONAL TRIAL
MONTCALM RESEARCH FARM
SEPTEMBER 23, 1997
(140 DAYS)

LINE	CWT/A US#1	CWT/A TOTAL	PERCENT OF TOTAL[1] US#1	Bs	As	OV	PO	SP GR	SFA[†]	TUBER QUALITY[2] HH	VD	IBS	BC	TOTAL CUT	SCAB[3]	MERIT RATING
W1313	313	349	90	9	80	10	1	1.094	1.5	23	0	2	0	40	3.0	2
ATLANTIC	277	302	92	7	72	19	1	1.089	1.5	19	2	0	0	40	3.3	4
MN16489	265	301	88	11	82	6	1	1.077	1.0	3	0	0	0	40	1.9	1
RED PONTIAC	256	288	89	5	60	29	6	1.061	3.0	30	1	0	0	40	2.6	
MSB076-2	244	314	78	22	75	2	1	1.094	1.5	3	0	0	0	40	1.8	3
MN16966	238	313	76	22	75	1	2	1.087	1.5	4	6	0	0	40	3.0	5
NORCHIP	209	260	81	14	75	6	6	1.075	1.5	0	14	0	0	40	1.8	
SNOWDEN	192	247	78	22	76	2	0	1.084	1.0	3	5	0	0	40	2.5	
MSB106-7	186	258	72	24	68	4	4	1.059	3.0	0	10	0	0	40	1.3	
ND2676-10	181	249	73	27	72	0	0	1.074	1.0	1	13	0	0	40	1.5	
ND3828-15	173	231	75	18	72	3	7	1.065	1.5	0	8	2	6	40	2.7	
RED NORLAND	172	197	87	11	83	5	2	1.055	3.0	2	3	0	0	40	1.0	
MSB073-2	172	254	68	31	67	0	2	1.085	1.5	2	4	0	0	40	1.8	
MN16180	148	232	64	36	63	1	0	1.065	2.0	0	19	0	0	40	2.3	
W1151RUS	136	207	65	34	62	3	1	1.064	3.0	9	2	0	0	40	1.3	
RUSSET BURBANK	131	225	58	28	48	11	13	1.073	2.0	16	1	1	0	40	1.0	
RUSSET NORKOTAH	127	203	63	37	54	8	0	1.066	3.0	8	6	0	2	40	1.8	
W1348RUS	124	225	55	44	52	3	1	1.075	2.0	14	0	0	0	40	1.0	
ND2225-1R	100	172	58	41	58	0	0	1.056	3.0	0	4	0	0	40	3.3	
MEAN	192	254						1.074								
$LSD_{0.05}$	55	50						0.003								

[1]SIZE
B: < 2"
A: 2 - 3.25"
OV: > 3.25"
PO: PICKOUTS

[2]QUALITY
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

[3]SCAB DISEASE RATING
1: NO INFECTION
3: INTERMEDIATE
5: HIGHLY SUSCEPTABLE

[†]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD
RATINGS: 1 - 5
1: EXCELLENT
5: POOR

PLANTED MAY 6, 1997

TABLE 6

EUROPEAN / YELLOW TRIAL
MONTCALM RESEARCH FARM
SEPTEMBER 10, 1997
(128 DAYS)

	CWT/A		PERCENT OF TOTAL[1]							TUBER QUALITY[2]				TOTAL	
LINE	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[†]	HH	VD	IBS	BC	CUT	SCAB[3]
MSE222-5Y	228	290	79	16	71	8	6	1.077	3.0	0	0	1	1	40	3.0
MSE048-2Y	217	249	87	12	81	6	2	1.087	2.0	8	1	0	0	30	2.1
MSE149-5Y	181	235	77	21	73	4	2	1.076	1.0	2	0	0	0	39	2.0
MSE226-4Y	180	242	74	23	69	5	3	1.066	2.0	1	0	0	0	40	1.9
LATONA	168	265	63	27	62	2	10	1.081	2.5	0	5	0	0	40	2.0
OBELIX	167	238	70	23	66	4	7	1.063	2.5	0	8	1	0	40	3.0
MICHIGOLD	149	211	70	29	70	0	1	1.083	1.5	0	6	0	0	40	2.8
YUKON GOLD	143	175	82	16	79	3	2	1.076	2.5	1	23	0	0	40	3.0
SAGINAW GOLD	138	213	65	34	64	1	1	1.074	1.0	0	0	0	0	40	1.5
IS. SUNSET	136	202	67	32	66	1	0	1.069	3.0	0	5	0	0	40	3.0
MSA097-1Y	129	189	68	25	68	1	7	1.079	2.0	0	1	0	0	40	1.7
MSC120-1Y	107	169	63	35	63	0	1	1.076	2.0	0	8	0	0	40	1.5
SNOWDEN	107	196	54	45	54	0	1	1.085	1.0	0	13	0	0	40	2.5
DALI	76	200	38	53	38	0	9	1.066	3.0	0	9	0	0	40	2.5
MSD029-3Y	70	124	57	42	57	0	1	1.072	-	0	5	0	0	40	2.4
MATILDA	65	201	32	68	32	0	0	1.088	2.5	0	9	0	0	35	2.3
MSD040-4RY	63	161	39	60	39	0	1	1.086	-	0	0	0	0	30	2.0
MSE048-1Y	24	99	25	75	25	0	0	1.073	-	0	0	0	0	5	3.3
MEAN	130	203						1.077							
$LSD_{0.05}$	34	35						0.003							

[1]SIZE
B: < 2"
A: 2 - 3.25"
OV: > 3.25"
PO: PICKOUTS

[2]QUALITY
HH: HOLLOW HEART
BC: BROWN CENTER
VD: VASCULAR DISCOLORATION
IBS: INTERNAL BROWN SPOT

[3]SCAB DISEASE RATING
1: NO INFECTION
3: INTERMEDIATE
5: HIGHLY SUSCEPTABLE

[†]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD
RATINGS: 1 - 5
1: EXCELLENT
5: POOR

PLANTED MAY 5, 1997

Table 7A Ranking of Important Potato Varieties and Advanced Breeding Lines in Scab Trial (1997)

Low Infection	Intermediate	Highly Susceptible
A082611-7	Atlantic	B0984-3
A7961-1	Century Russet	B1004-8
A84118-3	FL1879	MSB054-4
BC0894-2	Island Sunset	MSB057-2
FL1833	Michigold	MSE011-10
MSA091-1	MSB094-1	MSE041-1
MSB040-3	MSC148-A	MSF165-6RY
MSB073-2	MSE018-1	MSF349-1
MSB076-2	MSE048-2Y	MSG049-4
MSB107-1	MSE149-5Y	MSG049-7
MSC103-2	MSE222-5	P83-6-18
MSC120-1Y	MSE228-1	Shepody
MSE009-1	MSE230-3	
MSE192-8Rus	MSE234-3	
MSE202-3Rus	MSE250-2	
MSE221-1	MSF001-2	
MSE226-4Y	MSF002-1	
MSE226-5Y	MSF019-11	
MSE228-11	MSF099-3	
MSE228-9	MSF100-1	
MSE230-13	MSF105-10	
MSE230-6	MSF194-3	
MSE245-B	MSF373-8	
MSE246-5	MSG077-7Y	
MSE263-10	MSG104-6	
MSF014-9	MSG135-5	
MSF015-1	MSG261-3	
MSF087-3	NY103	
MSF313-3	NY115	
MSG124-8P	P63-1	
MSG227-2	Snowden	
MSG236-1	W1313	
MSG301-9	Yukon	
MSNT-1		
ND2676-10		
NY101		
Onaway		
P32-3		
Q8-2		
Russet Burbank		
W1151		

Table 7B

1994-97 MICHIGAN SCAB TRIAL RESULTS
MSU Soils Farm

Line	1994 Rating[1]	1995 Rating	1996 Rating	1997 Rating
A082611-7	2.5	1.0	1.0	1.0
A7961-1	1.0	1.0	1.0	1.0
A84118-3	-	1.5	1.0	1.0
A8495-1	1.5	1.0	-	1.0
AF1433-4	1.0	-	3.0	1.8
ATLANTIC	2.5	3.0	3.5	3.3
ATX 85404-8	-	-	3.0	1.6
BC0894-2	-	-	2.0	1.3
C0083008-1	1.0	1.0	1.0	-
CENTURY RUSSET	2.5	-	3.5	3.1
CHALEUR	1.5	3.0	-	-
FL1533	2.5	3.0	-	-
FL1833	3.0	2.0	1.5	1.7
FL1863	-	3.0	2.0	-
FL1867	-	-	2.0	1.3
GOLDRUSH	1.5	1.0	1.0	-
ISLAND SUNSHINE	-	2.5	4.5	-
JS111-28	-	-	1.0	1.0
LEMHI RUSSET	1.0	1.0	-	-
MAINESTAY	4.0	3.0	4.5	-
MATILDA	-	2.0	2.0	2.3
MICHIGOLD	2.0	-	4.0	2.8
MN16180	-	-	3.0	2.3
MN16489	-	-	2.0	1.9
MSA091-1	2.0	1.5	1.0	1.8
MSA097-1Y	1.5	-	2.0	1.7
MSB027-1R	3.0	-	4.0	1.5
MSB040-3	1.0	-	1.0	1.8
MSB057-2	3.0	-	3.0	4.1
MSB073-2	-	-	1.5	1.8
MSB076-2	1.0	1.5	1.5	1.8
MSB083-1	1.5	2.5	3.0	-
MSB094-1	2.0	-	3.0	3.0
MSB106-7	1.0	-	3.0	1.3
MSB107-1	2.5	2.5	2.5	1.8
MSC010-20Y	-	1.5	2.0	-
MSC098-2	2.0	-	3.5	-
MSC103-2	3.0	-	2.0	-
MSC120-1Y	1.0	-	2.5	1.5
MSC121-7	3.0	-	4.0	-
MSC122-1	1.5	-	1.5	-
MSC125-8	1.0	-	2.0	-
MSC148-A	-	2.5	2.5	2.4
MSE018-1	-	3.5	3.0	2.6
MSE041-1	-	3.0	3.5	4.3

Line	1994 Rating	1995 Rating	1996 Rating	1997 Rating
MSE048-2Y	-	1.5	2.0	2.1
MSE149-5Y	-	-	2.0	2.0
MSE192-8	-	1.0	-	1.3
MSE202-3	-	-	2.0	1.0
MSE221-1	-	1.5	1.0	1.0
MSE222-5Y	-	2.0	-	3.0
MSE226-4Y	-	1.5	1.5	1.9
MSE228-1	-	2.0	-	2.7
MSE228-9	-	1.5	1.5	1.8
MSE228-11	-	3.5	3.0	1.5
MSE230-6	-	2.5	1.5	1.5
MSE250-2	-	2.0	-	3.2
MSNT-1	3.0	-	1.0	1.0
ND2225-1R	-	-	2.0	3.3
ND2676-10	-	-	1.5	1.5
ND860-2	3.5	-	3.0	3.0
NEWLEAF-RB	-	-	1.0	-
NORCHIP	1.5	-	3.0	1.8
NORVALLEY	3.5	3.5	3.5	-
NY101	1.5	1.0	1.0	1.0
NY103	-	3.5	3.0	2.5
ONAWAY	1.0	1.5	1.5	1.0
P84-13-12	1.0	1.5	3.0	-
P88-13-4	-	2.0	-	3.0
P88-15-1	2.5	3.5	-	3.0
PENTA	3.0	4.5	-	-
PICASSO	-	-	1.5	-
PIKE	-	1.0	1.5	1.7
PORTAGE	3.5	2.5	-	-
PREMIER	-	-	3.5	-
PRESTILE	1.0	1.0	-	-
R. BURBANK	2.0	2.0	1.0	1.0
R. NORKOTAH	1.5	-	-	1.8
RED NORLAND	2.0	-	2.0	1.0
RED PONTIAC	5.0	2.5	4.0	2.6
REDDALE	-	-	2.0	-
SAGINAW GOLD	3.0	3.0	2.5	1.5
SANTE	3.5	3.0	-	-
SHEPODY	-	4.5	4.0	3.8
SNOWDEN	2.0	3.5	3.0	2.5
ST. JOHNS	3.0	3.0	4.0	-
SUPERIOR	1.0	1.5	-	-
W1151	-	-	1.5	1.3
W1313	-	-	2.5	3.0
YUKON GOLD	-	3.5	2.0	3.0

[1] SCAB RATING
1 = practically no infection
2 = low infection
3 = avg. susc. (i.e. Atlantic)
4 = susc. (high)
5 = severe susc.

Table 8A **1997 BLACKSPOT BRUISE SUSCEPTIBILITY TEST**

A. SIMULATED BRUISE SAMPLES*

VARIETY	NUMBER OF SPOT PER TUBER 0	1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
DATE OF HARVEST: LONG-LATE									
SHEPODY	24						24	100	0.000
A7961-1	23	1					24	96	0.042
CENTURY RUSSET	23	1					24	96	0.042
MSE202-3RUS	23	1					24	96	0.042
R. BURBANK	23	1					24	96	0.042
RB NEWLEAF	23	1					24	96	0.042
JS111-28	24	2					26	92	0.077
A84118-3	22	2					24	92	0.083
MSB106-7	22	2					24	92	0.083
A8495-1	21	4					25	84	0.160
P88-13-4	20	4					24	83	0.167
UMATILLA RUS.	17	6	1				24	71	0.333
DATE OF HARVEST: ROUND WHITES-LATE									
MSE221-1	24						24	100	0.000
NY103	24	1					25	96	0.040
MSC103-2	23	1					24	96	0.042
FL1879	23	1					24	96	0.042
MSB040-3	22	2					24	92	0.083
MSB073-2	21	3					24	88	0.125
MSE228-11	21	3					24	88	0.125
MSE228-9	21	3					24	88	0.125
NY101	21	2	1				24	88	0.167
REBA	20	4					24	83	0.167
PIKE	21	2		1			24	88	0.208
ONAWAY	20	2		1			23	87	0.217
FL1833	17	7					24	71	0.292
SNOWDEN	15	9					24	63	0.375
MSA091-1	15	8	1				24	63	0.417
FL1831	14	6	4				24	58	0.583
MSNT-1	13	7	4				24	54	0.625
MSB076-2	12	8	4				24	50	0.667
FL1869	15	4	3	2			24	63	0.667
MSC148-A	11	8	5				24	46	0.750
ATL NEWLEAF	11	10	1	1	1		24	46	0.792
MSB107-1	10	11	1	2			24	42	0.792
ATLANTIC	10	9	4			1	24	42	0.917
MSE018-1	9	6	5	4			24	38	1.167
MSB057-2	8	7	3	3	1	1	23	35	1.348

* Tuber samples were collected at harvest, graded, and placed in a six-sided plywood drum and rotated ten times to produce simulated bruising. Samples were abrasive-peeled and scored on October 23, 1997.

Table is presented in descending order of average number of spots per tuber.

VARIETY	0	NUMBER OF SPOT PER TUBER 1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
NORTH CENTRAL REGIONAL TRIAL									
R. NORKOTAH	24						24	100	0.000
ND2676-10	20	2					22	91	0.091
RED NORLAND	21	3					24	88	0.125
W1151RUS	21	3					24	88	0.125
R. BURBANK	20	4					24	83	0.167
RED PONTIAC	19	5					24	79	0.208
ND2225-1R	17	5	1				23	74	0.304
MN16489	16	8					24	67	0.333
NORCHIP	16	6	1				23	70	0.348
SNOWDEN	17	6		1			24	71	0.375
MSB073-2	16	6	1	1			24	67	0.458
MN16180	14	5	3	1			23	61	0.609
ND3828-15	10	9	2				21	48	0.619
MN16966	11	11	1	1			24	46	0.667
MSB076-2	8	10	6				24	33	0.917
MSB106-7	8	10	5	1			24	33	0.958
W1348RUS	9	8	6			1	24	38	1.042
ATLANTIC	7	9	5	1	1	1	24	29	1.292
W1313	0	5	8	6	4	1	24	0	2.500
YELLOW FLESH & EUROPEAN TRIAL									
DALI	23	1					24	96	0.042
LATONA	23	1					24	96	0.042
YUKON GOLD	23	1					24	96	0.042
MSD029-3Y	21	3					24	88	0.125
MSE226-4Y	22	1	1				24	92	0.125
OBELIX	22	1	1				24	92	0.125
MSE222-5Y	20	4					24	83	0.167
IS. SUNSET	20	4					24	83	0.167
MICHIGOLD	20	4					24	83	0.167
MSE048-2Y	18	5	1				24	75	0.292
MSA097-1Y	13	11					24	54	0.458
MSE149-5Y	16	5	1	2			24	67	0.542
SAGINAW GOLD	15	6	2	1			24	63	0.542
MSC120-1Y	13	7	3				23	57	0.565
MATILDA	8	13	1				22	36	0.682
SNOWDEN	12	7	5				24	50	0.708
MSD040-4RY	8	10	4	2			24	33	1.000
MSU BREEDING LINES 2 X 23 TRIAL									
MSB094-1	20						20	100	0.000
MSA110-2	19	1					20	95	0.050
MSB027-1RUS	18	2					20	90	0.100
MSF090-1	18	2					20	90	0.100
MSG209-1	18	2					20	90	0.100
MSF373-A	18	2					20	90	0.100
MSE033-1RD	17	3					20	85	0.150
ND860-2	17	3					20	85	0.150
MSG141-3	15	4					19	79	0.211
MSG124-8P	14	4					18	78	0.222
YUKON GOLD	14	4					18	78	0.222
MSG077-7Y	17	2		1			20	85	0.250
MSG119-1RD	15	3	1				19	79	0.263
MSB054-4	16	2	2				20	80	0.300

VARIETY	0	NUMBER OF SPOT PER TUBER 1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
MSG010-11	13	6					19	68	0.316
MSG104-6	13	7					20	65	0.350
MSG007-1	12	8					20	60	0.400
MSG080-1	13	6	1				20	65	0.400
MSG012-1RD	13	4	2				19	68	0.421
MSG296-3	12	7	1				20	60	0.450
ONAWAY	14	3	2	1			20	70	0.500
MSG050-2	13	2		1	1		17	76	0.529
MSG236-1	11	5	3				19	58	0.579
P84-12-7	11	5	2	1			19	58	0.632
MSG227-2	10	8	1	1			20	50	0.650
MSE215-12	8	9	2				19	42	0.684
SNOWDEN	10	6	2	1			19	53	0.684
MSG049-7	10	6	4				20	50	0.700
MSA105-1	10	6	3	1			20	50	0.750
MSG083-1RD	10	7	1	2			20	50	0.750
MSG274-3	8	8	2	1			19	42	0.789
MSG287-4	8	7	4	1			20	40	0.900
MSF321-5	6	8	5				19	32	0.947
MSG135-12	5	12	1	2			20	25	1.000
P84-9-8	7	7	4	2			20	35	1.050
MSF313-3	8	4	4	4			20	40	1.200
MSG163-1	6	10	1	1	1	1	20	30	1.200
MSE226-5	5	8	4	3			20	25	1.250
ATLANTIC	8	3	4	5			20	40	1.300
MSF327-G	7	4	5	1	2		19	37	1.316
MSG139-1	3	8	7	1	1		20	15	1.450
MSG245-2	3	9	5	2	1		20	15	1.450
MSG261-3	5	9	3	3	3		23	22	1.565
MSG301-9	3	8	4	3	1	1	20	15	1.700
MSG049-4	0	8	4	1	2		15	0	1.800
MSG260-4	3	4	3	4	2		16	19	1.875
MSG297-4RD	3	6	5	3	2	1	20	15	1.900
MSG135-5	3	6	3	5	3		20	15	1.950
MSG251-10	3	7	1	6	3		20	15	1.950
MSG079-2	1	5	7	6	1		20	5	2.050
MSG295-5	3	5	5	4	2	2	21	14	2.143
ADAPTATION TRIAL									
MSE228-1	22	1	1				24	92	0.125
MSF002-1	20	4					24	83	0.167
B0984-3	21	1	2				24	88	0.208
MSE041-1	19	5					24	79	0.208
MSE026-B	19	3	1				23	83	0.217
MSE230-6	18	6					24	75	0.250
P63-1	18	6					24	75	0.250
MSF014-9	17	6					23	74	0.261
P83-6-18	16	7					23	70	0.304
MSE030-4	15	5	2				22	68	0.409
MSE230-3	13	8	1				22	59	0.455
MSF020-23	15	8		1			24	63	0.458
MSE080-4	16	5	2			1	24	67	0.583
MSF099-3	12	8	3				23	52	0.609
ONAWAY	12	8	3				23	52	0.609
MSE009-1	15	7	3	1			26	58	0.615

								PERCENT (%)	
		NUMBER OF SPOT PER TUBER					TOTAL	BRUISE	AVERAGE
VARIETY	0	1	2	3	4	5+	TUBERS	FREE	SPOTS/TUBER
MSF001-2	18	1	2	2	1		24	75	0.625
MSF165-6RY	13	5	3	2			23	57	0.739
P73-2	12	7	2	2			23	52	0.739
P32-3	10	11	2	1			24	42	0.750
MSE263-3	10	11	4				25	40	0.760
Q8-2	12	5	7				24	50	0.792
B0856-4	15	3	3	2		1	24	63	0.833
B1004-8	10	9	4		1		24	42	0.875
SNOWDEN	8	11	5				24	33	0.875
MSE263-10	10	6	6	1			23	43	0.913
MSF087-3	11	5	6		1		23	48	0.913
MSF068-5	6	14	2	2			24	25	1.000
B0915-3	7	12	2	3			24	29	1.042
MSF349-1RY	12	3	6	2	1		24	50	1.042
MSF105-10	7	11	2	3			23	30	1.043
MSE245-B	7	11	3	3			24	29	1.083
MSF019-11	8	9	5	1	1		24	33	1.083
P88-15-1	7	8	8	1			24	29	1.125
MSE234-3	12	4	4	1	2	1	24	50	1.167
MSF373-8	6	9	5	2	1	1	24	25	1.417
MSF019-2	7	4	10	2	1		24	29	1.417
MSE250-2	3	8	10	3			24	13	1.542
MSF093-5	3	11	5	4	1		24	13	1.542
MSE213-2	5	6	11	1	2		25	20	1.560
MSF015-1	2	10	8	3	1		24	8	1.625
MSF100-1	3	8	4	9			24	13	1.792
MSE011-10	4	5	7	5	2		23	17	1.826
MSE246-5	5	5	5	5	3	1	24	21	1.958
MSE247-2	4	3	2	5	3	7	24	17	2.875
SNACK FOOD ASSOCIATION (SFA) TRIAL									
AF1433-3	23	2					25	92	0.080
ND2676-10	24	3					27	89	0.111
NY115	20	3	2				25	80	0.280
ATLANTIC	21	7	1				29	72	0.310
ATL NEWLEAF	14	8					22	64	0.364
NY103	15	10					25	60	0.400
SNOWDEN	16	7	2				25	64	0.440
B0564-8	14	9	1	1			25	56	0.560
BCO894-2	11	11	2	1			25	44	0.720
ATX85404-8	11	10	4				25	44	0.720

Table 8B **1997 BLACKSPOT BRUISE SUSCEPTIBILITY TEST**

B. CHECK BRUISE SAMPLES**

VARIETY	NUMBER OF SPOT PER TUBER 0	1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
DATE OF HARVEST: LONG-LATE									
MSE202-3RUS	24						24	100	0.000
JS111-28	24						24	100	0.000
R. BURBANK	24						24	100	0.000
RB NEWLEAF	24						24	100	0.000
SHEPODY	24						24	100	0.000
A7961-1	23	1					24	96	0.042
A8495-1	23	1					24	96	0.042
P88-13-4	23	1					24	96	0.042
MSB106-7	22	1					23	96	0.043
UMATILLA RUS.	23	2					25	92	0.080
A84118-3	22	2					24	92	0.083
CENTURY RUSSET	21	3					24	88	0.125
DATE OF HARVEST: ROUND WHITES-LATE									
MSB107-1	24						24	100	0.000
MSC103-2	24						24	100	0.000
MSB040-3	23	1					24	96	0.042
MSE018-1	23	1					24	96	0.042
MSE228-11	23	1					24	96	0.042
FL1869	23	1					24	96	0.042
MSNT-1	23	1					24	96	0.042
NY101	23	1					24	96	0.042
NY103	23	1					24	96	0.042
ONAWAY	23	1					24	96	0.042
REBA	23	1					24	96	0.042
MSE228-9	23	2					25	92	0.080
MSA091-1	22	2					24	92	0.083
FL1879	22	2					24	92	0.083
MSB073-2	21	3					24	88	0.125
MSB076-2	22	1		1			24	92	0.167
SNOWDEN	20	4					24	83	0.167
MSC148-A	20	3	1				24	83	0.208
FL1833	19	3	1				23	83	0.217
PIKE	15	4	1				20	75	0.300
MSE221-1	16	8					24	67	0.333
FL1831	19	2	3				24	79	0.333
ATL NEWLEAF	17	4	2	1			24	71	0.458
MSB057-2	14	9	1				24	58	0.458
ATLANTIC	13	7	2				22	59	0.500

** Tuber samples were collected at harvest, graded, and held until evaluation.
Samples were abrasive-peeled and scored on October 23, 1997.

VARIETY	NUMBER OF SPOT PER TUBER 0	1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
NORTH CENTRAL REGIONAL TRIAL									
R. NORKOTAH	24						24	100	0.000
MSB073-2	24						24	100	0.000
RED NORLAND	24						24	100	0.000
RED PONTIAC	23	1					24	96	0.042
NORCHIP	23	1					24	96	0.042
ND2676-10	23	1					24	96	0.042
R. BURBANK	23	1					24	96	0.042
SNOWDEN	22	2					24	92	0.083
MN16180	22	2					24	92	0.083
W1151RUS	22	2					24	92	0.083
ND2225-1R	20	4					24	83	0.167
ND3828-15	20	4					24	83	0.167
MN16966	19	4					23	83	0.174
MSB106-7	20	3	1				24	83	0.208
W1313	19	5					24	79	0.208
MN16489	19	3	1				23	83	0.217
W1348RUS	17	6	1				24	71	0.333
MSB076-2	16	8					24	67	0.333
ATLANTIC	8	13	1	1	1		24	33	0.917
YELLOW FLESH & EUROPEAN TRIAL									
MSD029-3Y	24						24	100	0.000
DALI	23						23	100	0.000
MSE230-6	24						24	100	0.000
LATONA	24						24	100	0.000
MSE048-2Y	23	1					24	96	0.042
MSE226-4Y	23	1					24	96	0.042
MICHIGOLD	23	1					24	96	0.042
OBELIX	23	1					24	96	0.042
MSE149-5Y	22	2					24	92	0.083
SAGINAW GOLD	22	2					24	92	0.083
SNOWDEN	22	2					24	92	0.083
MSA097-1Y	22	1	1				24	92	0.125
MSE222-5Y	22	1	1				24	92	0.125
IS. SUNSET	21	3					24	88	0.125
MSC120-1Y	18	6					24	75	0.250
MSD040-4RY	17	5		1			23	74	0.348
MATILDA	12	10					22	55	0.455
MSU BREEDING LINES 2 X 23 TRIAL									
MSA110-2	20						20	100	0.000
MSG301-9	19						19	100	0.000
MSG012-1RD	20						20	100	0.000
MSF373-A	20						20	100	0.000
MSG050-2	18						18	100	0.000
MSF090-1	20						20	100	0.000
P84-12-7	19	1					20	95	0.050
MSG119-1RD	19	1					20	95	0.050
P84-9-8	19	1					20	95	0.050
MSG163-1	19	1					20	95	0.050
MSB027-1RUS	19	1					20	95	0.050
MSG010-11	19	1					20	95	0.050
SNOWDEN	19	1					20	95	0.050
MSG077-7Y	19	1					20	95	0.050

VARIETY	0	NUMBER OF SPOT PER TUBER 1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
YUKON GOLD	17	1					18	94	0.056
MSG236-1	23	2					25	92	0.080
ONAWAY	18	2					20	90	0.100
MSG135-12	18	2					20	90	0.100
MSF321-5	18	2					20	90	0.100
MSG083-1RD	18	2					20	90	0.100
MSG227-2	18	2					20	90	0.100
MSG287-4	18	2					20	90	0.100
MSG141-3	17	2					19	89	0.105
MSB094-1	16	2					18	89	0.111
MSF313-3	16	2					18	89	0.111
MSA105-1	18	1	1				20	90	0.150
MSG209-1	17	3					20	85	0.150
ND860-2	17	3					20	85	0.150
MSG139-1	17	3					20	85	0.150
MSG104-6	17	3					20	85	0.150
MSE215-12	16	3					19	84	0.158
MSG007-1	16	4					20	80	0.200
MSB054-4	17	2	1				20	85	0.200
MSE033-1RD	17	2	1				20	85	0.200
MSF327-G	16	4					20	80	0.200
MSG079-2	16	4					20	80	0.200
MSG296-3	16	4					20	80	0.200
ATLANTIC	16	4					20	80	0.200
MSG080-1	15	5					20	75	0.250
MSE226-5	16	6					22	73	0.273
MSG261-3	14	6					20	70	0.300
MSG049-7	16	3		1			20	80	0.300
MSG245-2	12	7					19	63	0.368
MSG260-4	15	3	1	1			20	75	0.400
MSG049-4	12	7	1				20	60	0.450
MSG297-4RD	12	7		1			20	60	0.500
MSG135-5	13	5		2			20	65	0.550
MSG251-10	9	6	4		1		20	45	0.900
MSG295-5	7	9	1	1		1	19	37	1.000
ADAPTATION TRIAL									
B0984-3	24						24	100	0.000
B1004-8	24						24	100	0.000
MSE009-1	24						24	100	0.000
MSE041-1	24						24	100	0.000
MSE228-1	24						24	100	0.000
MSE230-3	23						23	100	0.000
MSE250-2	24						24	100	0.000
MSF002-1	24						24	100	0.000
MSF014-9	24						24	100	0.000
MSF019-2	24						24	100	0.000
MSF099-3	24						24	100	0.000
MSF165-6RY	24						24	100	0.000
MSE026-B	23	1					24	96	0.042
MSE234-3	23	1					24	96	0.042
MSE245-B	23	1					24	96	0.042
MSF001-2	23	1					24	96	0.042
MSF020-23	23	1					24	96	0.042
MSF349-1RY	23	1					24	96	0.042

VARIETY	NUMBER OF SPOT PER TUBER 0	1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
P63-1	23	1					24	96	0.042
P83-6-18	23	1					24	96	0.042
SNOWDEN	23	1					24	96	0.042
MSE213-2	22	2					24	92	0.083
MSE263-3	22	2					24	92	0.083
MSF087-3	22	2					24	92	0.083
B0856-4	21	3					24	88	0.125
MSF068-5	22	1	1				24	92	0.125
MSF194-3	21	3					24	88	0.125
ONAWAY	21	3					24	88	0.125
MSE263-10	20	4					24	83	0.167
MSF100-1	19	4					23	83	0.174
MSE080-4	20	3	1				24	83	0.208
MSF019-11	19	5					24	79	0.208
MSE030-4	20	4	1				25	80	0.240
P73-2	18	6					24	75	0.250
MSF105-10	17	7					24	71	0.292
MSF373-8	17	7					24	71	0.292
P32-3	20	2	1	1			24	83	0.292
B0915-3	17	6	1				24	71	0.333
MSF015-1	17	6	1				24	71	0.333
MSF093-5	13	4	1				18	72	0.333
P88-15-1	18	4	2				24	75	0.333
MSE011-10	15	7	1				23	65	0.391
MSE247-2	16	4	1	2			23	70	0.522
MSE246-5	14	7	1	2			24	58	0.625
Q8-2	13	7	4				24	54	0.625
SNACK FOOD ASSOCIATION (SFA) TRIAL									
NY115	23	2					25	92	0.080
ATL NEWLEAF	23	1	1				25	92	0.120
NY103	21	4					25	84	0.160
ND2676-10	20	5					25	80	0.200
AF1433-3	20	4		1			25	80	0.280
ATLANTIC	17	8					25	68	0.320
SNOWDEN	17	8					25	68	0.320
B0564-8	20	5	2				27	74	0.333
ATX85404-8	12	11	2				25	48	0.600
BCO894-2	11	9	6				26	42	0.808

Table 9: 1997 Results from MSU Late Blight Variety Trial (1)

Resistant (2)	Moderately Resistant		Reduced Susceptibility			Susceptible (3)
AWN86514-2	A080432-1	Lily	A84118-3	MSB027-1Rus	MSF105-10	Atlantic
B0288-17	A082611-7	Matilda	Allegany	MSB040-3	MSF165-6RY	Century Russet
B0692-4	A084275-3	MSE230-6	Alpha	MSB076-2	MSF373-8	Onaway
B0718-3	B0749-2F	MSE246-5	B0811-13	MSB107-1	MSG007-1	R. Norkotah
B0767-2	B1004-8	MSG139-1	B0856-4	MSC103-2	MSG050-2	R. Burbank
Bertita	C0083008-1	MSG163-1	B0915-3	MSC120-1Y	MSG135-5	Shepody
Bzura	Dorita	Nordonna	Dali	MSE009-1	MSG297-4RD	Yukon Gold
MSG274-3	Elba	Obelix	Desiree	MSE018-1	ND2676-10	Norchip
	Greta	Ontario	FL1879	MSE222-5Y	Pike	
	Hindenburg	Pimpernel	Hampton	MSE263-10	R. Norland	
	Is. Sunshine	Robijn	Is. Sunset	MSF001-2	Russian Blue	
	Krantz	Stobrawa	MN16489	MSF015-1	Snowden	
	Latona	Zarevo	MSA091-1	MSF019-11		
	Libertas					

(1) 33 days after inoculation with US-8 genotype of *P. infestans*

(2) RAUDPC < 0.15 = Resistant; 0.16 - 0.30 = Mod. Resistant; 0.31 - 0.45 = Reduced Susc.; > 0.45 = Susceptible

(3) Only named cultivars are listed

Table 10. Results from the Fusarium dry rot tuber susceptibility test.

Low Tuber Infection

Clone	Avg. Width	Avg. Depth[1]
B1004-8	3.6	2.3
Snowden	9.5	3.1
MSF105-10	9.3	4.4
MSG236-1	3.4	4.5
FL1833	13.8	4.6
MSE030-4	9.0	4.8
MSF194-3	8.1	5.1
MSA091-1	13.1	5.6
P32-3	10.9	5.7
Shepody	17.4	5.8
MSF068-5	13.0	5.8
MSG080-1	11.0	5.9
MN16966	9.7	5.9
NY101	12.5	6.0
MSF087-3	12.5	6.1
MSNT-1	9.7	6.2
B0915-3	8.9	6.3
NY103	14.7	6.4
MSF002-1	26.9	6.5
MSE263-10	12.0	6.7
MSE080-4	13.8	7.0
MSF373-8	10.4	7.1
ND3828-15	14.4	7.2
Latona	15.2	7.3
P83-6-18	11.9	7.3
MSE263-3	17.5	7.3
MSE246-5	14.1	7.4
MSE026-B	17.5	7.4
MSF349-1	17.0	7.5
MSF020-23	14.2	7.5
MSF019-2	14.1	7.7
MSE228-9	15.9	7.7
MSF327-6	4.7	7.8
MSA097-1Y	15.5	7.9
NYP63-1	18.4	7.9

Moderate Tuber Infection

Clone	Avg. Width	Avg. Depth	Clone	Avg. Width	Avg. Depth
MSF100-1	15.7	8.0	MSC120-1Y	20.2	10.6
MN16489	13.7	8.1	MSG012-1RD	7.8	10.7
MSF093-5	19.6	8.3	Norchip	9.4	10.9
MSG104-6	12.1	8.3	A7961-1	22.1	11.0
MSB073-2	14.4	8.3	MSG301-9	9.0	11.2
MSE222-5Y	12.0	8.4	MSE213-2	23.0	11.3
MSE234-3	17.1	8.5	Red Norland	7.9	11.3
MSC148-A	22.8	8.5	W1313	4.9	11.5
MSE247-2	23.8	8.5	MSG083-1RD	23.8	11.6
MSG049-7	16.3	8.5	Michigold	14.1	11.6
P84-9-8	9.2	8.6	MSG049-4	9.6	11.6
W1151RUS	23.8	8.6	MSG135-5	6.9	11.7
MSE230-3	14.7	8.7	MSC103-2	47.6	11.8
MSE018-1	14.7	8.7	MSG163-1	9.6	11.8
MSE009-1	14.6	8.9	P88-15-1	17.4	12.1
MSE221-1	14.1	9.0	W1834RUS	7.4	12.1
MSF015-1	18.3	9.0	MSE202-3RUS	16.2	12.1
MSB057-2	15.9	9.1	P84-12-7	23.2	12.3
Russet Burbank	10.8	9.1	Saginaw Gold	25.3	12.3
A8495-1	16.4	9.2	MSF019-11	16.3	12.5
MSG260-4	7.0	9.2	MSE149-5Y	18.4	12.7
MSF099-3	16.2	9.3	FL1831	24.3	12.8
MSF001-2	14.5	9.3	ND2225-1R	18.9	12.8
MSG077-7Y	5.7	9.3	MSG007-1	9.8	13.0
NY87-Reba	15.8	9.4	NYP73-2	18.8	13.1
Matilda	14.2	9.5	Century R.	17.6	13.1
FL1879	13.5	9.5	MSE245-B	16.9	13.1
ND2676-10	18.1	9.5	MSG135-12	8.9	13.2
Pike	22.2	9.6	MSB106-7	31.9	13.3
Is. Sunset	21.4	9.7	MSF373-A	12.6	13.6
Yukon Gold	5.3	9.9	MSE033-1RD	8.0	13.6
MSB076-2	21.2	10.0	MSD029-3Y	22.6	14.1
MSF165-6RY	18.8	10.0	ATL Newleaf	26.3	14.1
MSB094-1	7.6	10.1	Onaway	10.7	14.4
MSF321-5	6.3	10.1	MSG119-1RD	11.0	14.6
P88-13-4	17.4	10.2	Red Pontiac	15.4	14.7
MSE011-10	20.5	10.2	RB Newleaf	20.4	14.7
FL1869	16.4	10.2	MSE230-6	9.0	14.8
MSG209-1	35.7	10.4	MSG139-1	7.3	14.9
A84118-3	10.2	10.4	MSG297-4RD	8.5	15.3
Dali	13.3	10.5	MSG295-5	6.1	15.4

High Tuber Infection

Clone	Avg. Width	Avg. Depth
MSB027-1R	16.9	16.2
MSF014-9	30.4	16.4
MSF313-3	11.5	16.4
MSE228-1	42.1	17.1
MSG245-2	14.1	17.6
MSE226-5	29.6	17.6
MSB054-4	12.5	17.7
B0984-3	12.6	17.8
MSG287-4	9.2	18.0
MSG251-10	13.3	18.1
MSE250-2	25.3	18.3
MSG274-3	32.0	18.4
MSE041-1	25.3	18.5
MN16180	14.4	18.6
MSG079-2	14.8	18.6
MSB040-3	36.5	18.6
MSF090-1	9.0	19.0
Atlantic	9.6	19.1
MSG227-2	10.3	19.4
MSA105-1	10.5	19.5
MSE226-4Y	25.9	19.8
MSE215-12	12.9	20.1
B0856-4	34.2	20.5
MSB107-1	37.8	20.7
Obelix	34.1	20.7
MSG050-2	10.0	20.9
MSG261-3	17.5	20.9
MSA110-2	12.6	21.0
A082611-7	20.0	21.1
ND860-2	13.4	21.7
MSE048-2Y	58.8	21.7
MSG296-3	17.7	23.7
MSE228-11	35.9	23.7
MSG141-3	17.5	26.0
MSG010-11	27.8	33.8
MSG124-8P	36.9	37.7

[1] width and depth measured in mm.

Funding ___Federal Grant___

1997 On-Farm Potato Variety Trials

Dr. Dick Chase, Dr. Dave Douches, Don Smucker (Montcalm), Paul Marks (Monroe), Lyndon Kelley (St. Joseph), Dave Glenn (Presque Isle) and Jim Isleib (Alger)

Introduction:

On-farm potato variety trials were conducted on 12 farms in 1997, 4 evaluating fresh market entries, 5 evaluating processing entries, 1 evaluating yellow flesh seedlings, 1 in the Upper Peninsula and the SFA Chip Trial. The fresh market trial cooperators were Hansen Farms, Inc. (Montcalm), Terry Groulx (Bay), Mike Julian Farm (Presque Isle) and Smith Bros. Farm (Monroe). The processing trial cooperators were Crooks Farms/V&G Farms (St. Joseph), Fertile Valley Farms (Allegan), Walther Farms (Tuscola), Sandyland Farms (Montcalm) and W.J. Lennard and Sons, Inc. (Monroe). The U.P. variety plot was located at DeBacker Potato, Inc. (Marquette), a yellow-flesh variety trial at Fedak Farms (Bay) and the SFA Chip Trial at V&G Farms (Montcalm).

Procedure:

There were 12 entries in the processing trials including five from the MSU potato breeding program. The ten entries in the freshpack trial included seven from MSU. For each trial location, 25 pounds of seed were provided for planting in single rows. During the growing season, emergence, growth and maturity data were collected. At harvest, a yield check was made for each entry from a uniform sized plot area. Size distribution, specific gravity, internal defects and processing quality were determined from samples collected at harvest. For chip processing entries, samples for sugar analysis were prepared at MSU and readings were determined at Techmark, Inc. using a Dual Channel YS12700 select instrument.

A. Freshpack Trial Results:

Table 1 provides the overall average from three locations. Data from the Bay County location are not included. In general, yields were very good with seven entries exceeding 300 cwt/A of marketable potatoes. Following are notations for each entry:

NY101— A 1986 selection from a New York cross between Steuben x Norwis with a pale yellow flesh. In previous years, this seedling has had excellent yield. It has medium-late maturity, large tubers with medium-low specific gravity and good scab resistance, similar to Superior. It has shallow eyes and a netted skin. Internal defects are minimal, tubers are generally very round and eating quality is good.

MSB107-1 — A 1989 selection from an MSU cross between LaBelle and MS702-80. Tubers are large, round-oblong with medium specific gravity and intermediate scab resistance. Maturity is medium-late and showed no internal defects. External defects were growth cracks, some greening and surface scab. It exceeded 600 cwt/A at the Presque Isle location.

NY103 — A 1986 selection from a cross between Steuben x (Neotbr x tbr). It has mid season maturity and tubers have excellent general appearance, smooth skin and shallow eyes. It has also been evaluated for chip processing, however, specific gravity generally is below the desired 1.080 level. In many Michigan trials, it has had a high yield of very bright tubers, minimal internal defects and may be released as a variety later in 1998.

MSC103-2 — A 1990 selection from an MSU cross between Eramosa x Nooksack. Maturity is late and scab tolerance is intermediate. At the Presque Isle location, 79% of the potatoes were over 3¼", however, the average for three locations was 30%. Internal defects were minimal and some surface scab was noted at two locations.

MSB040-3 — A 1989 selection from open pollinated Steuben. This entry has been dropped.

MSB106-7 — A 1989 selection from an MSU cross between LaBelle x Lemhi Russet. This entry has been dropped.

MSE228-9 — A 1992 selection from an MSU cross between Russet Nugget and Spartan Pearl. Maturity is mid season and scab tolerance is high. Tubers have a heavy netting and traces of surface scab were noted. It had early and vigorous emergence.

Onaway — Check variety, however, yields and quality were generally below normal.

MSE228-11 — A 1992 selection from an MSU cross between Russet Nugget and Spartan Pearl. Maturity is mid-season and scab tolerance is intermediate. Specific gravity was highest in the trial, however, tuber size is smaller than MSE228-9 and skin is smooth.

MSB057-2 — A 1989 selection from a cross between Onaway and Nooksack. This seedling has been dropped.

B. Processing Trial Results:

Table 2 contains the overall average from the five locations. Eight entries were classified as chipping varieties and four were evaluated for frozen processing. Average yields among locations ranged from 286 to 397 cwt/A of U.S. No. 1's and MSE018-1 was one of the top two yielders at four locations. Following are notations for each entry:

MSE018-1 — A 1992 selection from an MSU cross between Gemchip and W877. Maturity is late and scab tolerance is intermediate. Specific gravity ranged from 1.079 to 1.088. Tubers are generally large with very minimal internal defects. Surface scab was noted at one location.

Snowden — Serves as the later maturing check variety.

Atlantic — Serves as the earlier maturing check variety.

MSA091-1 — A 1988 selection from an MSU cross between MS702-80 x Norchip. Maturity is mid season and scab tolerance is high. Yields ranged from 337 to 430 cwt/A of No. 1's. Tuber sizing was fairly uniform with an average of 16% over 3¼". Vascular discoloration was noted at three locations and off-type shapes were noted at two locations. Plant vigor was rated above average during the growing season.

MSB076-2 — A 1989 selection from an MSU cross between MS716-15 x Lemhi Russet. Maturity is late; it has a large, upright plant and scab tolerance is high. Specific gravity is high and tuber shape is oval. Internal defects are nearly nil and tuber size is fairly uniform in the mid size range. Marketable yields ranged from 301 to 448 cwt/A. Some brown center has been noted in the chips.

MSB073-2 — A 1989 selection from an MSU cross between MS716-15 x Superior. Maturity is mid season and scab tolerance is high. Yields were intermediate ranging from 258-368 cwt/A. It was also noted that this seedling is sensitive to post emergence metribuzin.

Atlantic NewLeaf from NatureMark. Plants were noted to have a darker foliage color and more blossoming. Yields were below Atlantic.

MSC148-A — A 1990 selection from an MSU cross between MS700-70 x Ontario. This seedling will be dropped.

Shepody — Yields were good with a high percentage of potatoes over 3¼". Yields ranged from 277 to 469 cwt/A. Considerable scab was noted at one location and hollow heart and vascular discoloration were also recorded.

Russet Burbank — Serves as a check variety for frozen processing. Internal defects were minimal and pick outs were mostly off-type potatoes.

A7961-1 — A selection from USDA-Aberdeen. Previous yields of blocky to long russeted tubers have usually been above average. Maturity is mid to late.

JS111-28 — An entry from J.R. Simplot Co. Tubers have good appearance and a high scab tolerance. It is a somaclonal derivative of Lemhi Russet.

Table 3 summarizes the sugar analysis for sucrose and glucose and the percentage of chips by weight with acceptable color, undesirable color and external and internal defects. Chip samples were processed from a 25 tuber sample within 24 hours following harvest and the scores for the acceptable chips for all samples were 1.0-1.5 on the SFA 1-5 scale. In terms of external defects, stem end discoloration was noted in many samples. External and internal defect values are likely higher than would be detected in a commercial sampling. Two slices from each tuber center are used in the fryer and every tuber is cut the same from the apical end through the stem end so any stem end discoloration will readily appear.

The most frequent internal defect was vascular discoloration and it appeared to be fairly prevalent in 1997. This defect is scored if the discoloration in the vascular ring is deeper than one-half inch from the stem end and is severely discolored. Snowden and MSC148-A had the best scores overall.

C. <u>U.P. Potato Variety Trial</u>

Jim Isleib, Alger County Extension Director, coordinated the trial located on the Jeff DeBacker Farm in Marquette County. Varieties were planted in a randomized complete block design with four replications. Seed was planted at 12 inch spacing in 30 inch rows on May 27 and harvested October 1. The plot was not irrigated.

Table 4 provides the yield, size distribution, specific gravity and quality data. MSC103-2, NY101 and JS111-28 all exceeded 400 cwt/A of U.S. No.1 potatoes. Overall yields were very good and Russet Norkotah, MSC103-2, JS111-28 and Shepody all produced greater than 30% of tubers over 3¼ inches or 12 ounces. A7961 had the greatest incidence of hollow heart. Slight surface scab was noted for MSC103-2, Snowden and Shepody and growth crack was evident in MSB106-7.

D. <u>Yellow Flesh Trial</u>

Seven seedlings were evaluated in a yellow flesh trial on the Fedak Farm in Linwood (Bay County). Six entries were from the MSU potato breeding program. NY101, MSA097-1Y and MSE149-5Y all exceeded 300 cwt/A of U.S. No.1 potatoes (Table 5). NY101 was the top yielder with 490 cwt/A. Internal defects were nil and MSA097-1Y and MSE048-2Y were unique in that tuber size except for B size were all in the 2-3¼ inch range.

E. <u>SFA Chip Trial</u>

The SFA Chip Trial was located at V&G Farms in Montcalm County. Michigan is one of seven locations of the Trial in the U.S. The other locations are California, Florida, Maine, Pennsylvania, Red River Valley and Washington. Table 6 summarizes the data for the Michigan location. Atlantic NewLeaf is the only entry which is not a part of the national trial. Specific gravity values for most entries were below the desired 1.080. Yields were generally very good and hollow heart was greatest in ATX85404-8, Snowden and Atlantic. BO564-8 and BC0894-2 size distribution were very uniform in the 2-3¼ inch range.

Chip quality was best in BCO894-2 with no defects recorded. NY115 also showed very low defects. NY103 and ATX85404-8 showed the greatest defects of undesirable color, dark cores and stem end discoloration. Vascular discoloration was noted in several entries.

Table 1. 1997 Freshpack Potato Variety Trials

Overall Average - 3 Locations

	Yield (cwt/A)		Percent Size Distribution					
Entry	No. 1	Total	No. 1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.
NY101	473	537	88	9	63	25	3	1.073
MSB107-1	422	484	84	9	63	21	7	1.082
NY103	343	399	85	14	72	13	1	1.074
MSC103-2	341	391	86	11	56	30	3	1.076
MSB040-3	340	406	84	12	80	4	4	1.077
MSB106-7	331	412	79	15	60	19	6	1.070
MSE228-9	303	337	89	9	73	16	2	1.082
Onaway	296	396	74	18	60	13	9	1.068
MSE228-11	279	405	67	31	64	3	2	1.087
MSB057-2	248	335	71	27	59	12	2	1.081

Table 2. 1997 MPIC/MSU Processing Potato Trial

Overall Average - 5 Locations

A. Chip Processing

Entry	Yield (cwt/A) No. 1	Yield (cwt/A) Total	Percent Size Distribution No. 1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.
[1/]MSE018-1	506	551	92	7	64	28	1	1.084
Snowden	399	443	91	8	82	9	1	1.085
Atlantic	396	439	90	9	72	18	2	1.083
MSA091-1	386	446	87	8	71	16	5	1.084
MSB076-2	377	431	88	9	81	7	3	1.087
[1/]MSB073-2	317	379	84	15	83	1	1	1.085
[2/]NL-Atlantic	291	342	85	11	74	11	4	1.081
MSC148-A	277	338	81	18	73	8	2	[1/]1.075

B. Frozen Processing

Entry	Yield (cwt/A) No. 1	Yield (cwt/A) Total	Percent Size Distribution No. 1	<4 oz.	4-10 oz.	>10 oz.	Pick Outs	S.G.
Shepody	351	421	84	6	43	41	10	1.076
[1/]Russet Burbank	330	451	73	11	53	20	15	1.080
A7961-1	274	338	81	13	52	29	6	1.079
JS111-28	273	363	77	17	57	20	7	1.080

[1/]Four locations.

[2/]Three locations.

Table 3. 1997 MPIC/MSU Processing Trial

Average Internal and Chip Quality Data

	Sugar Analysis		Percent			
	Sucrose	Glucose	Acc.	Und. Color	Ext.	Int.
Atlantic	0.465	0.003	60	3	16	21
NL-Atlantic[1/]	0.534	0.003	59	3	18	20
Snowden	0.618	0.003	81	1	8	8
MSB073-2	0.962	0.004	67	1	13	18
MSB076-2	0.663	0.005	62	2	14	21
MSA091-1	0.613	0.003	64	0	24	12
MSC148-A[2/]	0.533	0.004	79	1	9	12
MSE018-1	0.735	0.005	66	3	12	19

[1/]Three locations.

[2/]Four locations.

Table 4. 1997 Potato Variety Trial

Jeff DeBacker Farm — Marquette County

	Yield (cwt/A)		Percent Size Distribution						
Entry	No. 1	Total	No. 1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.	Comments
MSC103-2	476	507	93	6	56	37	1	1.070	1/40 HH, sl. surf. scab
NY101	444	476	93	6	89	4	1	1.066	1/40 IBS, 1/40 BC
JS111-28	400	460	87	8	52	35	5	1.083	1/40 HH, 1/40 IBS, 1/40 BC
Snowden	384	419	92	7	83	9	1	1.085	3/40 VD, sl. surf. scab
Shepody	379	425	89	7	57	32	3	1.075	1/40 IBS, sl. surf. scab
A7961-1	377	416	91	9	65	26	0	1.086	8/40 HH, 2/40 BC
MSB106-7	348	377	92	7	65	28	0	1.073	1/40 HH, 10/40 growth crack
R. Norkotah	314	361	87	11	48	39	1	1.070	1/40 HH, 2/40 VD, 1/40 BC
R. Burbank	301	379	79	18	64	15	2	1.082	13/40 VD, 2/40 BC
AVERAGE	380	424	90					1.077	

Planted: May 27, 1997

Harvest: October 1, 1997

Table 5. Yellow Flesh Trial

Fedak Farm
Linwood, MI

	Yield (cwt/A)		Percent Size Distribution						
Entry	No. 1	Total	No. 1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.	Comments*
NY101	490	513	95	5	95	0	0	1.074	0/5 clean heavy net round-oblong
MSA097-1Y	343	351	98	2	98	0	0	1.082	0/5 clean heavy net round
MSE149-5Y	312	345	90	10	73	17	0	1.070	0/5 clean sl. net round-slightly flattened
MSE048-2Y	254	260	98	2	98	0	0	1.081	0/5 clean netted round
MSC120-1Y	231	273	85	15	72	13	0	1.077	0/5 clean netted round-oblong
Julianna Rose	220	279	79	18	79	0	3	1.088	1/5 vas. dis. med. net oblong
MSD029-3Y	197	271	72	20	72	0	8	1.073	0/5 clean med. net
AVERAGE	292	327	88					1.078	

*5 large tubers cut for internal defects.

Planted: May 20, 1997

Harvested: September 16, 1997

Table 6. 1997 SFA Chip Trial

V & G Farms

	Yield (cwt/A) U.S. #1	Yield (cwt/A) Total	Percent Size Distribution U.S. #1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.	Internal Quality HH	VD	IBS	BC	Total Cut
ATX85404-8	600	655	92	1	62	30	3	1.081	9	0	0	0	25
B0564-8	460	508	90	1	83	7	1	1.074	0	4	0	0	25
NY103	416	455	91	1	74	17	2	1.070	3	2	0	0	25
Snowden	366	425	86	2	74	12	1	1.087	7	8	0	0	25
Atlantic	364	403	90	1	57	33	5	1.080	7	0	1	0	25
NL Atlantic	352	386	91	1	66	25	2	1.079	2	3	2	0	25
BC0894-2	347	430	81	3	76	5	0	1.069	0	1	0	0	25
NY115	321	347	92	1	67	25	1	1.070	0	1	0	0	25
AF1433-4	309	349	88	2	78	11	1	1.072	1	3	0	0	25
ND2676-10	291	383	76	4	72	4	2	1.070	0	2	0	0	25
AVERAGE	383	434	88					1.075					

Planted: May 12, 1997 Harvested: October 8, 1997

Internal and Chip Quality Data

	Sugar Analysis Sucrose Rating	Glucose Percent	Agtron	SFA Score	Percent Acc.	Und. color	Ext.	Int.	Comments
Snowden	0.813	0.003	52	3	78	0	13	9	VD, SED
Atlantic	0.621	0.003	51	3	70	0	14	16	SED, VD, HH
NL Atlantic	0.617	0.003	53	3	65	0	26	9	SED, VD
ATX85404-8	0.757	0.005	51	3	43	6	23	28	Dark cores, SED
ND2676-10	0.823	0.003	57	2	73	0	13	13	SED, VD
B0564-8	0.260	0.005	51	3	80	0	14	6	IBS, VD
BC0894-2	0.684	0.005	54	3	100	0	0	0	Clean
AF1433-4	0.727	0.003	54	3	82	6	4	8	VD
NY103	0.961	0.007	52	3	43	19	8	30	Dark cores, VD
NY115	0.439	0.002	56	2	90	0	5	5	VD

Funding MPIC/Industry

Evaluation of Pre-planting Applied Seed Piece Treatments for Potato Late Blight Control

W.W. Kirk, B.A. Niemira, B.J. Kitchen, and J.M. Stein
Room 35 Plant Biology Building, Department of Botany and Plant Pathology
Michigan State University, East Lansing, MI 48824

INTRODUCTION

Potato late blight (*Phytophthora infestans*) is the most important potato pathogen in Michigan. For three years in succession, successful epidemics have been established at the Michigan State University Experimental Research Farm, Bath, MI. Control of potato late blight is traditionally achieved by crop protection strategies that rely almost exclusively on applications of foliar fungicides. Potato late blight is essentially a seed-borne disease. Other seed-borne pathogens of potatoes, such as *Fusarium* spp. and black scurf (*Rhizoctonia solani*) can be effectively controlled by the pre-planting application of seed-piece treatments. Trials in controlled environments and in the field were carried out to establish the efficacy of fungicides applied as pre-planting seed-piece treatments in the control seed-borne potato late blight. Seed treatments applied to plants generated from true seed generally persist after the plant has emerged and developed and can prevent establishment of disease, thus protecting the plant from early disease exposure. The immature stems and leaves may be exposed to late blight from infected seed pieces or from foliar infection after emergence. Experiments were set up to establish the persistence and efficacy of pre-planting applied potato seed-piece treatments applied to developing sprouts. The following report outlines the efficacy of several products tested as pre-planting applied seed-piece treatments for the control of potato late blight.

METHODS

Potatoes(cv. Snowden)harvested from a crop in Michigan with no record of foliar or tuber late blight were selected for freedom from disease and uniformity of size. The tubers were stored at 40°F in the dark for 80, 100 and 120 days (controlled environment experiments run 1 - 3 respectively) after harvest then transferred to 68°F, (14 h photo-period) to break dormancy. Prior to storage the tubers were sterilized by washing in distilled water, soaking for 2 hours in 2% Clorox solution and then dried and stored until used. The number of leaf initials at the time of seed treatment application was established by counting the number of leaf initials under a dissecting microscope (n = 20 sprouts). The tubers for the field experiments were pre-cut 7 days prior to inoculation. Seed treatments were applied 24 h after inoculation. Seed tubers and pieces were planted 48 - 72 h after the seed treatment application.

Two concurrent experiments were conducted during each run of the controlled environment experiments and the field experiment. The tuber inoculation study examined the effect of seed treatments applied pre-planting to sprouted seed. In this study, early infection events caused by late blight were examined in plants from tubers inoculated with late blight before planting. The foliar inoculation study examined the effect of seed treatments applied pre-planting to non-infected tubers. In this study, foliar late blight was examined in plants inoculated with late blight after emergence.

The controlled environment experiments were carried out in specially constructed temperature and humidity-controlled environment chambers. The chambers (120 ft^3, 3.4 m^3) were situated within green houses and covered with 1mm transparent polyethylethene. Natural light was supplemented by high-pressure sodium lamps, 400w 14-10 day-night. Relative humidity was maintained at greater than 90% by timer controlled humidifiers (Hermidifier model 500). Temperature typically ranged between 60 and 75°F.Ten replicate plants per treatment were used for each of the three runs and also in both of the concurrent experiments.

The field experiment was planted at the Michigan State University Muck Soils Experimental Station, Bath, MI on 1 June into five-row by 5 plant plots (34-inch row spacing) replicated four times in a randomized complete block design. Plots were irrigated as needed with sprinklers and were hilled immediately after emergence. No fungicides were applied to either of the field experiments. Weeds were controlled by hilling and with one application of Dual 8E (2 pt/A on 10 Jun), two applications of Basagran (2 pt/A on 20 Jun and 10 Jul) and one application of Poast (1.5 pt/A on 28 Jul). Insects were controlled with applications of Admire 2F (20 fl oz/A at planting), Sevin 80S (1.25 lb on 1 and 25 Jul), Thiodan 3EC (2.33 pt/A on 4 and 26 Aug) and Pounce 3.2EC (8 oz/A on 18 Jul).

Application of seed treatments(controlled environment and field experiments).
The seed treatments were applied when sprouts had broken dormancy. The sprouts already had about 15 leaves initiated at the time of application (15.1 ± 0.45, $n = 20$). The number of internodes between the base of the sprout and the first leaf appeared above ground was about eight. The amount of fungicide required to treat the seed tubers was calculated from manufacturer recommended seed application rates, e.g. for dust (D) formulations. As no seed application rates are recommended for treatments formulated as foliar fungicides, seed application rates were adapted from effective foliar application rates with a tuber seed-piece model. The model uses surface area estimates, % product a.i., application rate, seed size and shape to calculate the amount of product required to cover whole and cut seed pieces (Table 1, Figure 4). The amount of product required was calculated and applied as a liquid to the seed pieces. The seed treatments were applied with a CO_2 powered boom delivering 2 pt/t (80 p.s.i.) and using one XR11003VS nozzle per 1 m wide spray application table. The application rates are shown on tables 2 - 5. The liquid application was applied at 2 pt/ton (2 l/tonne). Tubers were dried before planting.

The seed treatments
Established seed treatment fungicides such as Tops 5 5D (thiophanate-methyl, Gustaffson), novel products e.g. Maxim (fludioxinil, Novartis), development products such as LS130 D and LS132 D (thiophanate-methyl + mancozeb + cymoxanil, Gustaffson) and products not formulated as seed treatments e.g. Acrobat MZ 69WP (dimethomorph + mancozeb, American Cyanamid), Cymoxanil 50WP and Curzate 72WP (cymoxanil, cymoxanil + mancozeb, Griffin/Dupont), Quadris (azoxystrobin, Zeneca) and fluazinam (fluazinam, ISK Biosciences) were applied to whole seed (controlled environments) and cut seed (field experiments). A full list and application rates of the chemicals are included in Tables 2 - 5. An additional treatment, Myconate (formononetin, NPT) was included in the field trial as application of this product has shown that potato plants have demonstrated decreased susceptibility to other diseases.

Inoculation procedures
Seed-borne late blight (controlled environment and field experiments)
Late blight inoculations with performed with a zoospore suspension of *P. infestans* US8 (insensitive to metalaxyl, A2 mating type) genotype (10^3 conidia/ml) from cultures grown on rye agar plates. Tubers were inoculated with about 0.1 ml of the zoospore suspension injected to a depth of 2.0 mm below the periderm and 1.0 cm from the main apical sprout. The wound was covered with a smear of petroleum jelly. After 24 hours, seed treatments were applied.

Foliar late blight (controlled environment and field experiments).
After the plants were about 6 - 7" (15 cm) tall with about 10 main stem leaves appeared and in the rapid expansion phase, the plants in the chambers were inoculated with 1000 ml of the above described zoospore suspension, delivered as an aerosol. In the field experiment all the rows were inoculated (100 ml/25-foot row) with the above described aerosol zoospore suspension on 30 July.

Data collection
Emergence was rated in concurrent experiments both in the controlled environments and in the field. Vigor was rated for the field experiment (foliar inoculation experiment only). The number of leaves per main stem and the number of stems per plant were counted in the controlled environment experiments to evaluate phytotoxicity or development regulation as a result of the seed treatments. Vigor was estimated by multiplying stem number, by a score for general appearance and plant height. The number was expressed relative to the score for the untreated plot in each replicate.

Plots (field) and replicate plants (controlled environments) were rated visually for percentage foliar area affected by late blight and the average amount of disease calculated over the disease progress period.

In the foliar inoculation controlled environment experiment the ratio of infected to non-infected leaves was calculated with respect to the position of the leaf on the main stem. The number of leaves with infections was evaluated at each main stem leaf position above the soil surface and the ratio of infected to non-infected leaves was calculated for each treatment. The first leaf above the soil was counted as leaf one. A leaf was considered infected if it had one or more late blight lesions on any of the leaflets or the petiole. The stem that was apically dominant (i.e. had most main stem leaves) was selected for the evaluation on each of ten separate plants.

The data were analyzed by two-way analysis of variance and means compared at $p = 0.05$ level of statistical significance by a multiple range comparison of means (Tukey, SigmaStat) .

RESULTS

Controlled environment experiments

Tuber inoculation experiments

In all three runs of this experiment, the number of emerged plants that developed from inoculated seed-pieces did not exceed 50%, regardless of the seed treatment (Table 2). Some of the treatments had fewer plants emerge than the untreated check plots. There were no clear differences in emergence between treatments. Of the plants that did emerge, some developed late blight lesions on the leaves and/or the stems (Table 2). The numbers of infected plants were low, e.g. one diseased plant of three emerged (33%), of ten seed pieces planted (30%).

Foliar inoculation experiments

General plant development

The number of leaves per main stem tended to be reduced by some of the seed treatments (Table 3). There was an indication that some of the fungicides applied as pre-planting seed treatments e.g. propamocarb (applied alone) and fluazinam reduced stem and leaf number.

Disease development

Overall disease development and the number of stems with disease was reduced by the application of pre-planting applied seed-piece treatments (Table 3). The variation and ranking between the treatments was inconsistent across the three runs of the experiment and the amount of disease that developed in the third run was lower than in runs 1 and 2. The most effective treatments appeared to be those that included cymoxanil in the formulation. The treatments that included dimethomorph in the formulation were inconsistent but generally the combination products such as Acrobat MZ 69WP gave better overall disease control, reducing the number of stems infected. The formulations that included propamocarb were generally inconsistent, giving lower levels of overall disease control. Thiophanate-methyl and fludioxinil clearly reduced development in comparison with the check plants and often gave adequate disease control

The number of leaves with infections was evaluated at each main stem leaf position above the soil surface and the ratio of infected to non-infected leaves was calculated for each treatment (Figures 2 - 4). The first run of the experiment clearly indicated that generally the lower leaves on the main stem had a lower ratio of infected leaves for the leaves in positions 1 to about 6. The ratio of infected leaves between treatments was similar to the untreated plots above leaf position 6. Some treatments, e.g. cymoxanil-based seed fungicides maintained a low ratio of infected leaves up to leaf position 14 (Figure 2). The dimethomorph-based treatments were less effective than the cymoxanil-based treatments but more effective than the propamocarb-based treatments in experiments 1 and 3 (Figures 2 and 4). However, the Acrobat MZ 69WP treatment in experiment 2 and the Tattoo C 6.25SC treatment were similar to the cymoxanil and Curzate M8 treatments in experiment 2 (Figure 3).

Both Tops-based treatments and Maxim also had low ratios of infected leaves from about leaf positions1 - 5 (run 1), 1 - 4 (run 2) and 1 - 3 (run 3). The results from experiments 1 - 3 indicated that azoxystrobin and fluazinam also reduced the ratio of infected leaves on the lower portion of the main stem. In experiment 3, the novel cymoxanil-based treatments LS130 and LS132 both had low ratios of infected leaves up to leaf position 5.

The general trend of the ratio, regardless of treatment, indicated that at leaf positions above 10 the ratio of infected leaves was reduced (Figure 2). The results were similar in runs 2 and 3 of the experiment (Figure 3 and 4). The results generally reflected the overall disease measured (Table 3).

Field Experiments

Tuber inoculation experiments

The number of emerged plants that developed from inoculated seed-pieces did not exceed 33%, regardless of the seed treatment (Table 4). Only the Tattoo C 6.25SC treated plants had significantly ($p = 0.05$) more plants emerged than the untreated check. Some of the treatments had fewer plants emerge than the untreated check plots. There were no clear differences in emergence between the other treatments. Of the plants that did emerge, none developed late blight lesions on the leaves and/or the stems.

Foliar inoculation experiments

General plant development

Curzate M8 72WP applied as a seed treatment at 0.05lb/cwt had significantly ($p = 0.05$) fewer plants emerge in comparison with the untreated plots and many of the formulated seed treatments both 21 and 32 days after planting (Table 5). There were clear differences in relative vigor 21 and 32 days after planting. The least vigorous treatments were the Tattoo C 6.25 SC, Curzate M8 and Dithane 75DF (Table 5). The most vigorous treatments were Maxim, the thiophanate-methyl-based treatments and dimethomorph-based treatments (Table 5).

Disease development

The average amount of disease over the period after inoculation was measured as the relative area under the disease progress curve (raudpc maximum = 100). There was no reduction in the amount of disease or the progress of the disease between treatments and all treatments were 100% infected within 30 days after inoculation (Table 5).

Discussion

Fungicides formulated with active ingredients previously thought to be inactive against late blight such as thiophanate-methyl and fludioxinil clearly reduced development in comparison with the check plants and often gave better disease control than products formulated with active ingredients known to be effective against late blight.

Seed treatments are considered to be useful for the control of traditional seed-borne diseases such as *R. solani* (black scurf) and *Fusarium* spp.(dry rot). In this series of experiments, the role of chemical protection of the developing potato sprout was examined. In the first set of experiments, seed tubers were inoculated to simulate late blight *(P. infestans)* infected seed. The mechanism of seed infection was not the subject of this study. Rather, the objective was to investigate the potential efficacy of pre-planting applied seed and seed-piece treatments against the development of late blight on emerging sprouts. There exists a fine balance between the pathogen and the host in this relationship. The pathogen relies on establishing a moderate level of sprout infection to initiate the seasonal epidemic above ground. Severe infection of the sprout results in premature sprout death and non-emergence. The first two controlled environment experiments described it was established that seed treatments have little effect on the fate of the sprout. No plants emerged in the third experiment. The application of seed treatments to infected seed had no effect on emergence and did not prevent disease developing on some of the emerged sprouts. The use of seed treatments to prevent the establishment of disease from already infected seed is therefore not justified.

It is recommended to both and seed and commercial growers that seed health and quality is of paramount importance in potato crop production. Although at present it is not possible to be completely certain that a potato seed lot is 100% free of late blight, it is prudent to plant seed that meets the seed certification standards. The application of appropriate seed treatments to already healthy seed may seem unnecessary. The second set of experiments in this study were intended to evaluate whether seed treatments applied to potato seed and seed pieces could protect the crop from exposure to late blight while the plants were young, shortly after emergence. The inoculation of the emerged stems that had developed from fungicide-treated sprouts may establish whether seed treatments confer some duration of protection to the developing stems.

The controlled environment experiments showed reduction in overall disease on the leaves and stems after inoculation with late blight indicated that the seed treatments conferred some duration of protection to the developing leaves and stems. The duration of protection on the lower leaves was not estimated. It was clear, however, that not all the leaves were protected from late blight. The leaves that had a reduced ratio of infection were at the base of the main stem and may have been exposed to the seed treatments at the time of application. The leaves that emerge above ground were initiated but would have been less than 0.5 cm in length at the time of treatment. It is possible that the fungicides applied accumulate on tuber structures and crevices e.g. developing sprouts where they are likely to be stored, dispersed and taken up (if systemic) by the developing leaf, stolon and root primordia. Studies with fungicide-amended rye agar growth media have shown that both thiophanate-methyl (Tops) and fludioxinil (Maxim) at high concentrations can suppress the growth of late blight (US8 less effectively than US1). Redistribution of the seed treatment products may result in effective dose accumulations on the developing leaves and internodes. The mechanism of sprout protection by fungicides in potatoes has not been extensively studied.

The efficacy of some of the products tested in this study is clear. The development of products for late blight control is currently focused on products to prevent the transmission of the disease at seed cutting (Lambert et al. 1998). These products have systemic and non-systemic fungicide components. The LS130 D and LS132 D development products are such formulations. Both products, in this study, have shown that they can suppress late blight development in recently emerged plants in controlled environments. Further work is required to establish a strategy to use these products most effectively. Potato seed and seed-piece products are optimal formulations which do not compromise crop vigor at the expense of disease control. The precise timing of application of seed treatments in relation to seed cutting, sprout development and timing of planting requires further study.

Table 1. The amount of seed-piece product adhering to individual seed pieces of different shape and size. The assumptions are explained in the text.

Properties of potato seed piece		Diameter (cm)	Application rate of product lb dust/cwt	Product Concentration mg ai/l H2O (ppm /seed piece)		
type	shape			0.5% ai	1% ai	5% ai
Whole	Sphere	4.00	0.50	1.89	3.79	18.94
		5.00	0.50	2.27	4.55	22.73
		6.00	0.50	2.84	5.68	28.41
Cut once	Hemisphere	4.00	0.50	0.95	1.89	9.47
		5.00	0.50	1.14	2.27	11.36
		6.00	0.50	1.42	2.84	14.20
Cut twice	Wedge	4.00	0.50	0.47	0.95	4.73
		5.00	0.50	0.57	1.14	5.68
		6.00	0.50	0.71	1.42	7.10
Whole	Sphere	4.00	1.00	3.79	7.58	37.88
		5.00	1.00	4.55	9.09	45.45
		6.00	1.00	5.68	11.36	56.82
Cut once	Hemisphere	4.00	1.00	1.89	3.79	18.94
		5.00	1.00	2.27	4.55	22.73
		6.00	1.00	2.84	5.68	28.41
Cut twice	Wedge	4.00	1.00	0.95	1.89	9.47
		5.00	1.00	1.14	2.27	11.36
		6.00	1.00	1.42	2.84	14.20

Table 2. Control of potato late blight with pre-planting applied fungicide seed piece treatments, 1997.
The final percentage of emerged potato plants which received pre-planting applied fungicide treatments and were inoculated 24 hours prior to the application of the seed treatments. Controlled environment experiments.

Seed treatment	Application rate (pints or lbs/cwt)		Final percent emergence			Percent of emerged plants with foliar late blight lesions			
			run 1 26 dap	run 2 24 dap	run 3 24 dap	run 1		run 2	
						leaves	stems	leaves	stems
Untreated			50a	20a	20a	80	0	20	0
Maxim 0.5D	0.5	lb	10a	20a	20a	0	0	0	0
Tops 5 5D	0.5	lb	0 b	20a	40a			0	0
Cymoxanil 50WP	0.0075	lb	0 b	0 b	20a	0	0		
Dimethomorph 50WP	0.004	lb	40a	20a	20a	50	0	0	0
Propamocarb 8.5SC	0.014	pt	40a	20a	20a	50	0	20	0
Fluazinam 5SC	0.005	pt	0 b	20a	40a			0	0
Quadris WDG	0.0125	lb	20a	40a	20a	0	0	0	0
Dithane 75DF	0.05	lb	30a	40a	20a	33	0	0	0
Acrobat MZ 69WP	0.22	lb	40a	20a		100	25	0	0
Tattoo C 6.25SC	0.04	pt	30a	20a		67	0	0	0
Curzate M8 72WP	0.05	lb	20a	20a		100	50	0	0
Tops MZ 8.5D	1.0	lb			20a				
LS132 D	0.5	lb			0 b				
LS130 D	0.5	lb			0 b				

no disease was observed on emerged plants in run 3.

Table 3. Control of potato late blight with pre-planting applied fungicide seed piece treatments, 1997.
The final percentage of emerged potato plants which received pre-planting applied fungicide treatments and foliar inoculated 14 days after emergence. Controlled environment experiments.

Seed treatment	Application rate (pints or lbs/cwt)		Leaf number per main stem			Stem number per plant			% stems with infections			% overall disease		
			run 1	run 2	run 3	run 1	run 2	run 3	run 1	run 2	run 3	run 1	run 2	run 3
Untreated			16.0ab	14.6ab	15.2ab	2.6	3.4ab	3.6	47.3	53.3 b	66.7 b	19.0	15.0 d	9.6 d
Maxim 0.5D	0.5	lb	16.3a	14.8ab	15.0a	2.8	2.6abc	2.8	9.2	23.3ab	6.7a	3.8	3.4ab	4.6 c
Tops 5 5D	0.5	lb	17.3a	16.4a	16.2 b	2.2	2.2 bc	2.6	15.0	10.0a	13.3a	2.2	2.6ab	2.0ab
Cymoxanil 50WP	0.0075	lb	14.1 b	14.4 b	15.0a	2.2	2.4 bc	3.0	20.0	16.7ab	21.7a	4.4	7.0 c	4.6 c
Dimethomorph 50WP	0.004	lb	16.8a	14.8ab	16.6 b	2.6	2.2 bc	2.6	18.3	0a	16.7a	15.0	2.2a	2.6ab
Propamocarb 8.5SC	0.014	pt	16.3a	13.4 b	14.4a	1.9	2.0 c	2.6	33.3	0a	0a	16.6	3.2ab	2.6abc
Fluazinam 5SC	0.005	pt	18.0a	14.4ab	14.4a	1.9	2.4 bc	2.6	5.0	0a	6.7a	3.8	1.6a	1.8ab
Quadris WDG	0.0125	lb	16.4a	14.8ab	15.6ab	1.9	3.0ab	3.0	22.5	20.0ab	20.0a	14.3	3.0ab	1.8ab
Dithane 75DF	0.05	lb	18.0a	13.8 b	14.6a	2.3	3.8a	3.6	23.3	38.3ab	36.7ab	18.8	9.0 c	3.4 bc
Acrobat MZ 69WP	0.22	lb	17.1a	15.4ab		2.6	3.2ab		6.7	16.7ab		1.3	2.6ab	
Tattoo C 6.25SC	0.04	pt	17.1a	16.0a		2.5	2.8abc		48.3	0a		21.7	1.6a	
Curzate M8 72WP	0.05	lb	18.0a	14.6ab	15.2ab	1.9	2.2 bc	3.0	5.0	0a	21.7a	3.8	2.2a	2.2ab
Tops MZ 8.5D	1.0	lb			16.6 b			3.2			9.0a			1.8ab
LS132 D	0.5	lb			16.8 b			2.8			20.0a			2.0ab
LS130 D	0.5	lb			15.6ab			2.6			6.7a			1.2a
SEM (P = 0.05)			0.42	0.44	0.39	0.29	0.28	0.32	9.83	7.88	8.61	5.03	9.08	0.42

no disease was observed on emerged plants in run 3.

Table 4. Control of potato late blight with pre-planting applied fungicide seed piece treatments, field experiment 1997. The percentage of emerged potato plants in plots which received pre-planting applied fungicide treatments. The potato seed-pieces were inoculated 24 hours prior to the application of the seed treatments.

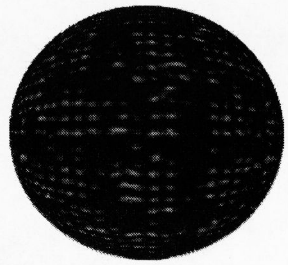
Seed treatment	Rate of application pints or lbs/cwt		Final percent emergence 32 days after planting
Untreated			12 bc
Myconate 15D	0.02	lb	9 c
Maxim 0.5D	0.5	lb	9 c
Tops 5 5D	0.5	lb	7 c
Tops MZ 8.5D	1.0	lb	13 bc
LS132 D	0.5	lb	13 bc
LS130 D	0.5	lb	12 bc
LS130 D	0.75	lb	10 bc
Cymoxanil 50WP	0.0075	lb	11 bc
Dimethomorph 50WP	0.004	lb	28ab
Propamocarb 8.5SC	0.014	pt	28ab
Fluazinam 5SC	0.005	pt	23abc
Fluazinam 5SC	0.025	pt	22abc
Fluazinam 5SC	0.05	pt	19abc
Quadris WDG	0.0125	lb	20abc
Quadris WDG	0.125	lb	6 c
Dithane 75DF	0.05	lb	9 c
Acrobat MZ 69WP	0.22	lb	12 bc
Tattoo C 6.25SC	0.04	pt	33a
Curzate M8 72WP	0.05	lb	10 bc

Table 5. Control of potato late blight with pre-planting applied fungicide seed piece treatments, field experiment 1997.

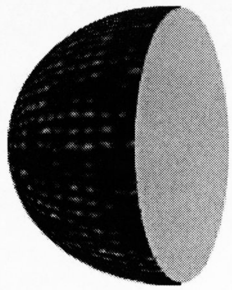
Seed treatment	Application rate		Percent emergence days afer planting		Relative vigor index Stem number x vigor estimate (relative to untreated plots)		Relative area under disease progress curve max=100
			21 days	32 days	21 days	32 days	
Untreated			89a	91a	100abcd	100abc	43.7
Myconate 15D	0.02	lb	85ab	92a	90abcde	87abc	40.1
Maxim 0.5D	0.5	lb	94a	94a	115a	111a	45.0
Tops 5 5D	0.5	lb	93a	94a	109ab	98abc	41.7
Tops MZ 8.5D	1.0	lb	92a	92a	101ab	89abc	41.9
LS132 D	0.5	lb	86ab	91a	84abcde	84abc	41.6
LS130 D	0.5	lb	90a	94a	96abcd	97abc	42.1
LS130 D	0.75	lb	86ab	91a	81 bcde	94abc	46.0
Cymoxanil 50WP	0.0075	lb	87ab	89ab	69 cde	68 cd	41.9
Dimethomorph 50WP	0.004	lb	88ab	93a	100abcd	106a	43.7
Propamocarb 8.5SC	0.014	pt	86ab	92a	91abcd	99abc	47.1
Fluazinam 5SC	0.005	pt	90a	92a	99abcd	99abc	44.9
Fluazinam 5SC	0.025	pt	79ab	87ab	76 bcde	80abcd	42.0
Fluazinam 5SC	0.05	pt	89a	91a	74 cde	81abcd	42.5
Quadris WDG	0.0125	lb	76ab	86ab	70 cde	78abcd	40.6
Quadris WDG	0.125	lb	86ab	85ab	83abcde	84abc	39.0
Dithane 75DF	0.05	lb	65 bc	80ab	62 ef	71 bcd	40.5
Acrobat MZ 69WP	0.22	lb	89a	89ab	90 bcde	103ab	44.5
Tattoo C 6.25SC	0.04	pt	74ab	79ab	66 def	68 cd	42.1
Curzate M8 72WP	0.05	lb	44 bc	72 b	35 f	51 d	39.9
sem (p = 0.05)							20.39 (nsd)

Figure 1. The surface area of potato tubers can be calculated using these formulae. The formulae assume that the seed tuber is spherical and that there are no depressions, lumps or other structures on the surface that would influence the estimate of the area.

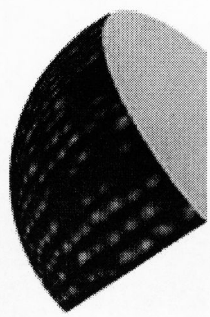
Whole seed
Surface area = $4\pi r^2$



Seed cut once
surface area = $(4\pi r^2)/2 + \pi r^2$



Seed cut twice
surface area = $(4\pi r^2)/4 + \pi r^2$



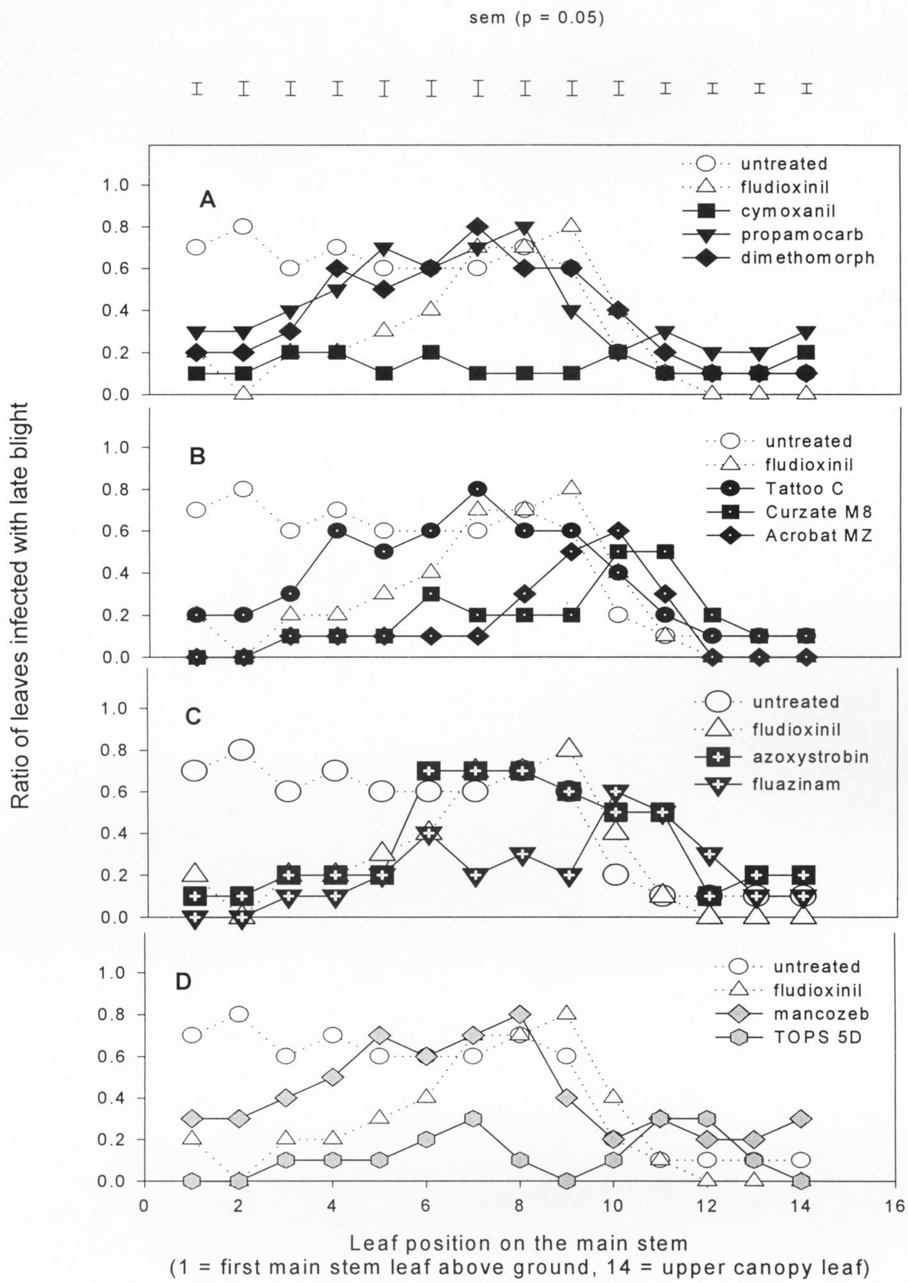


Figure 2. The effect of pre-planting applied potato tuber seed-piece treatments on the ratio of leaves infected with late blight (presence of lesion(s)) in relation to leaf position on the main stem after inoculation when the plants were ca. 15 cm tall (experiment 1). The treatments are shown in the legends. In all four figures, untreated plots and fludioxinil are included for reference. 1A, components of systemic fungicides; 1B, systemic fungicides; 1C, novel chemistries; 1D, protectant traditional fungicides

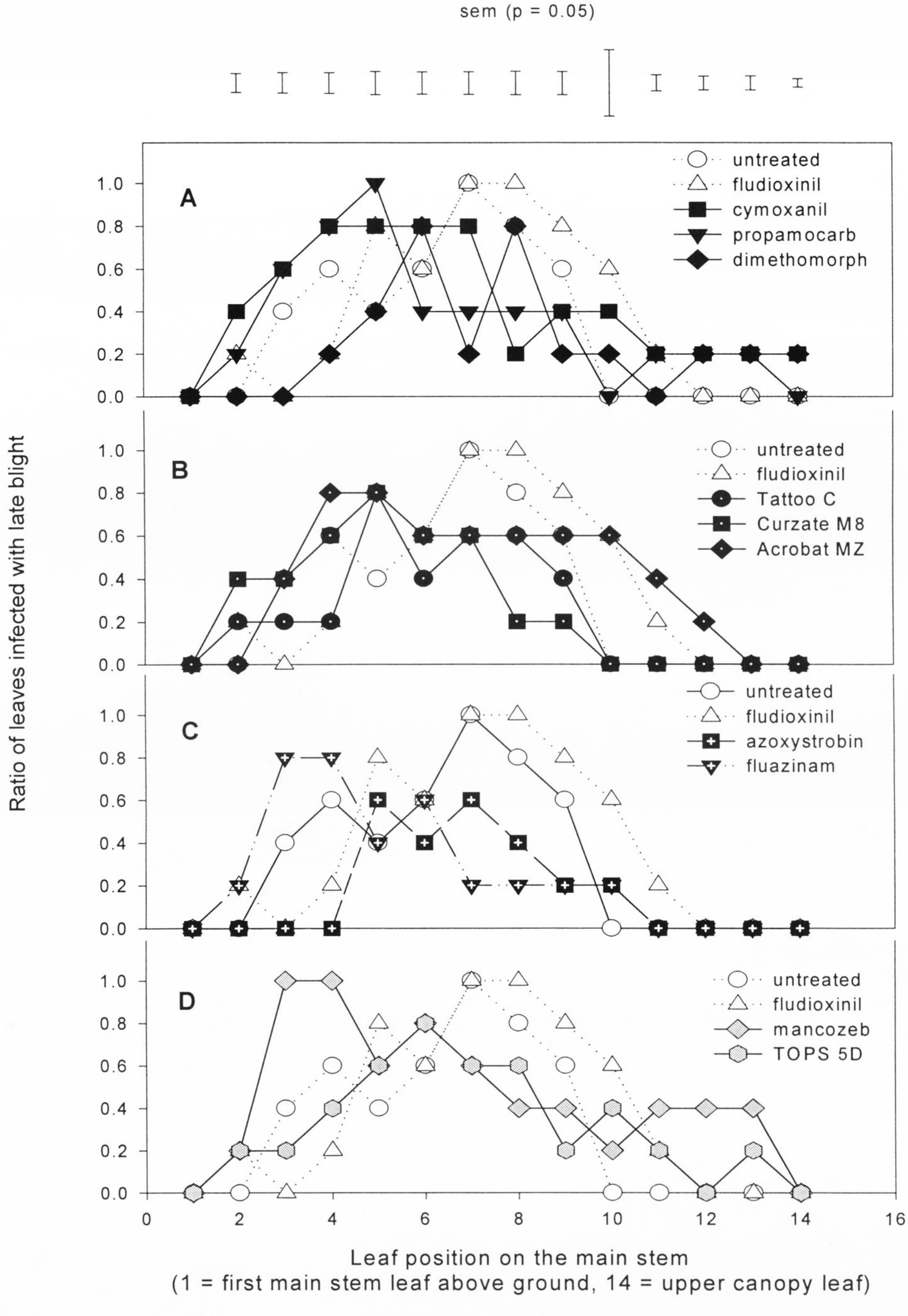


Figure 3. The effect of pre-planting applied potato tuber seed-piece treatments on the ratio of leaves infected with late blight (presence of lesion(s)) in relation to leaf position on the main stem after inoculation when the plants were ca. 15 cm tall (experiment 2). The treatments are shown in the legends. In all four figures, untreated plots and fludioxinil are included for reference. 1A, components of systemic fungicides; 1B, systemic fungicides; 1C, novel chemistries; 1D, protectant traditional fungicides

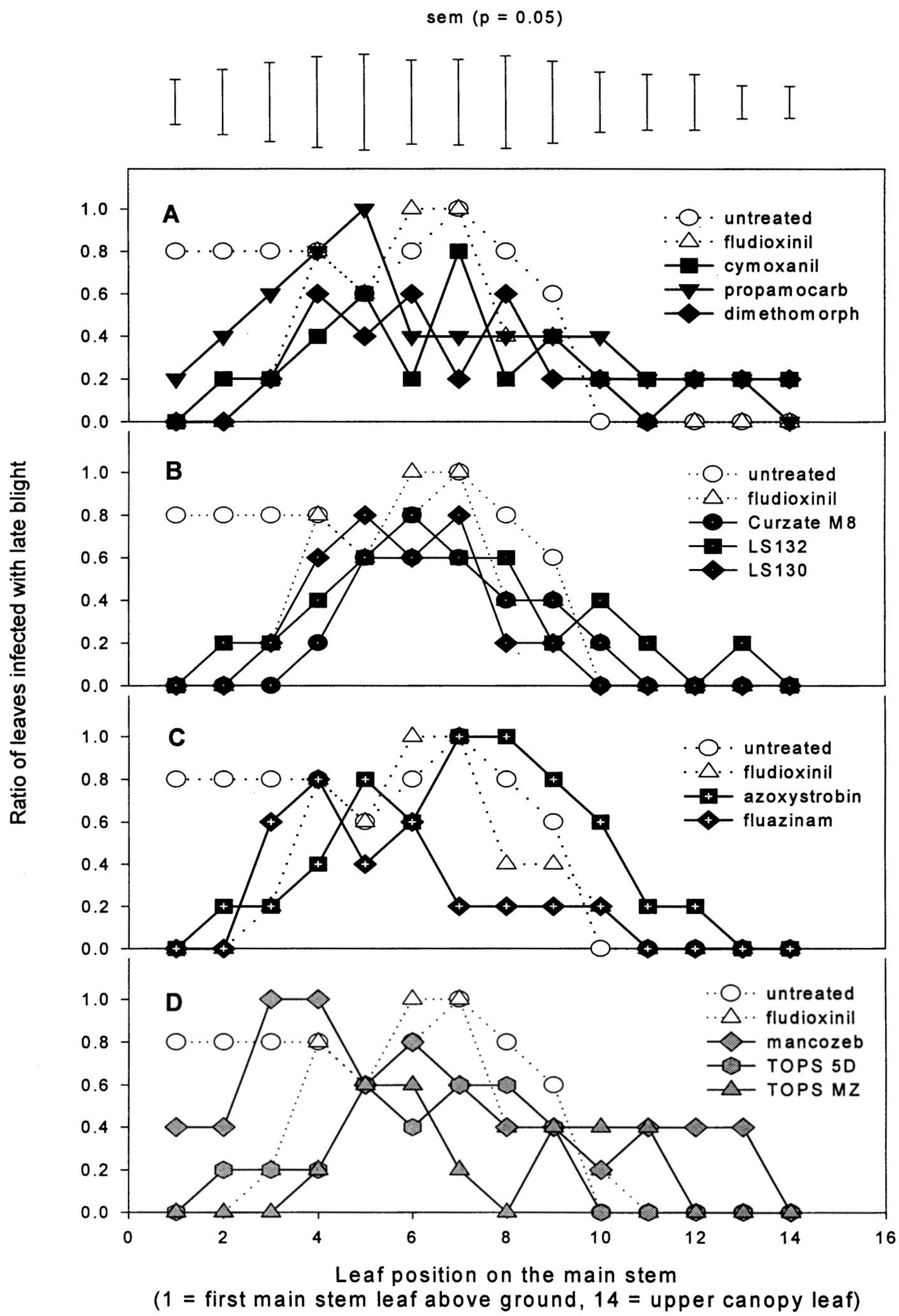


Figure 4. The effect of pre-planting applied potato tuber seed-piece treatments on the ratio of leaves infected with late blight (presence of lesion(s)) in relation to leaf position on the main stem after inoculation when the plants wereca. 15 cm tall (experiment 3). The treatments are shown in the legends. In all four figures, untreated plots and fludioxinil are included for reference. 1A, components of systemic fungicides; 1B, systemic fungicides including LS130 and LS132, novel systemic fungicides from Gustafsson; 1C, novel chemistries; 1D, protectant traditional fungicides

Funding: MPIC

NITRATE-N AND NITROGEN PARTITIONING IN POTATOES UNDER DIFFERENT FERTILIZER MANAGEMENT

M. L. Vitosh, J. T. Ritchie, B. Basso and S. Stornaiuolo
Department of Crop and Soil Sciences, Michigan State University

Quantitatively understanding responses to nitrogen (N) nutrition in potatoes is important for two reasons. One is the diminishing response in terms of yield to increasing rates of N supply; this poses the question of finding the economic optimum rate of supply. The second and recently acknowledged reason is losses of N to the environment posing the question of the ecologically optimum rate of N supply. Neither the economic optimum rate, nor the ecological optimum rate is constant.

Soil and plant chemical analysis are common management tools that can improve fertilizer use efficiency and crop yields. Soil analysis can identify preplant nutrient availabilities, fertilizer requirements, soil pH and salt problems. Plant analysis are used to determine the cause of poor plant growth and effectiveness of preplant fertilizer applications. Increasingly, they are being used to help manage the crop's nutritional status during growth to achieve high yields and quality, particularly for a high cash value and intensively managed crops like potatoes (*Solanum tuberosum* L.). Efficient nutrient management becomes more important when the potential environmental impact of a nutrient is also considered. Accurate sampling techniques, analytical methods and interpretations based on research results are required for any diagnostic test to be effective.

The objectives of this study were: (a) to quantify the Nitrate-N fraction and total N in potatoes to achieve a better understanding of N partitioning in the different organs of the plant, (b) to relate these properties to yield and (c) to use them as indicators of the N availability.

METHODOLOGY

The experiment was conducted using a randomized complete block design with five treatments (0, 60, 120, 180 and 240 lbs N/Acre) with four replications. Each plot was 10 rows wide. Six rows were available for plant sampling. The variety used was Snowden. On July 1, 10, 15, 22, 29, August 4, 19 and September 18, four whole plants were harvested, including tubers for dry and fresh weight biomass. The plant samples were fractionated into: lower stems (0-3 inches above ground level), upper stem, leaves, stolon and tubers. On July 1, 10, 15, 22, 29 and August 4, soil and petiole samples were taken. All these fractioned samples were oven-dried at 105 F and finely ground; Nitrate-N was extracted with a KCl (2M) solution. The extract was then analyzed with Automated Flow Injection Ion Analyzer (Lachat Instrument - Quikchem method N.10-107-04-1-A, Federal Environmental Protection Agency, Methods for chemical analysis of water and waste) and total N was determined with C/N analyzer (Carlo Erba Instruments). Leaf chlorophyll readings were also made at the same time petiole samples were collected. Approximately 120 readings were made in each plot with a hand held Minolta SPAD 502 chlorophyll meter. These readings were later correlated with the corresponding petiole nitrate content. Yields were harvested in

September from two rows 50 feet long. Tubers were graded into three categories, oversize (>3 ¼"), A's (2-3¼") and B's (<2"). Specific gravity was also measured.

RESULTS

<u>Plant and Soil Analysis:</u>

The potato crop has a large demand for soil nutrients. As shown in Figure 1 the biomass accumulation increased with increasing N applications. There were no significant differences in biomass between the 120 lbs/Acre and 180 lbs/Acre applications. The 240 lbs/Acre treatment shows that excessive supply of N can alter the physiological balance of the plant, and the vegetative growth may be stimulated at the expense of the reproductive growth and the formation of commercially important storage organs (Figure 2).

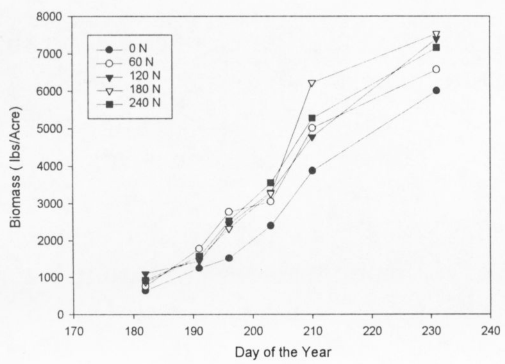


Figure 1. Total biomass - dry weight basis.

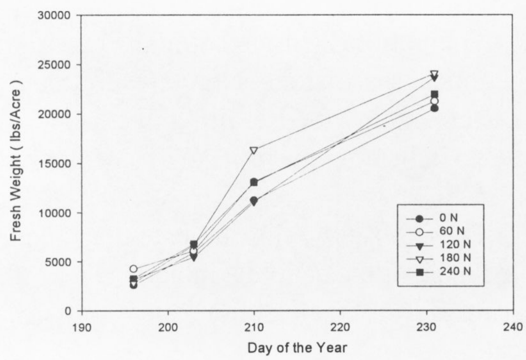


Figure 2: Total biomass - fresh weight basis.

The soil nitrate analysis over the season (Figure 3) reflects the nutrient availability as affected by the different treatments. The sandy soil in which potatoes are grown is highly susceptible to nitrate leaching which can be consistent with the higher rate of N fertilizer applied. Nitrogen demand during vegetative growth is high. Uptake is rapid and the N stored in the plant tissues is translocated to the tubers later in the season.

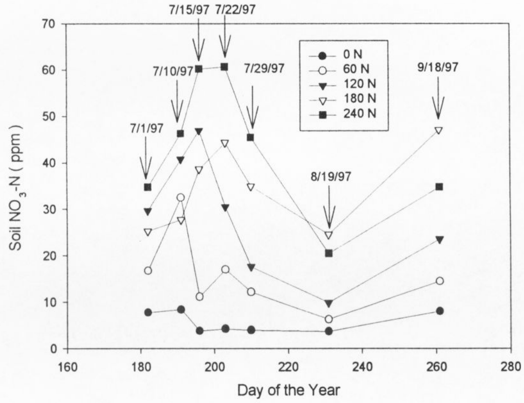


Figure 3. Soil Nitrate-N (0-10 inches).

Nutrient concentrations in the plant change with plant age. Nitrate-N and total N concentrations decrease with time in all the organs as depicted in Figures 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.

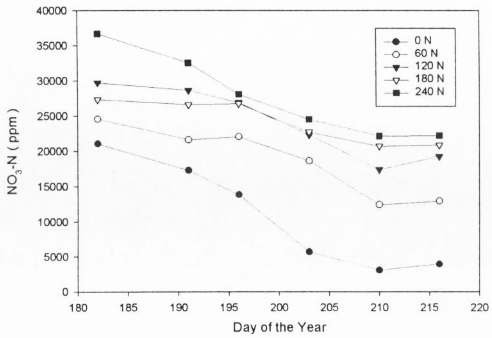


Figure 4. Petiole - Nitrate-N (ppm).

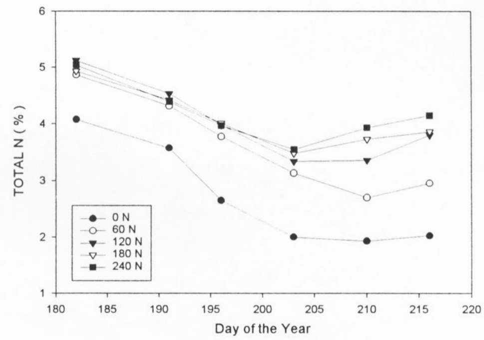


Figure 5. Petiole-Total N (%).

The petioles (Figures 4 and 5) were the most sensitive to the different rate of N fertilizer application all season long. Nitrate-N concentrations were directly related to total N applied. Higher levels were maintained with three sidedress N high rates compared to the non-sidedressed treatments indicating that uptake of sidedressed N occurred rapidly and remained in the plant tissue.

These observations indicate that sidedressed N can be used to correct N deficiencies when detected making the petiole Nitrate-N test a valuable in-season monitoring tool. The petiole Nitrate-N test is able to pick deficiencies, but it can also be used to identify excessive N fertilizer applications.

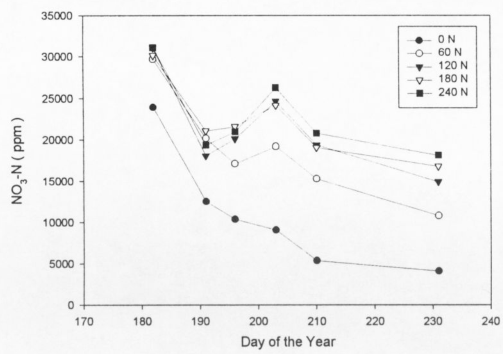


Figure 6. Top stem - Nitrate-N (ppm).

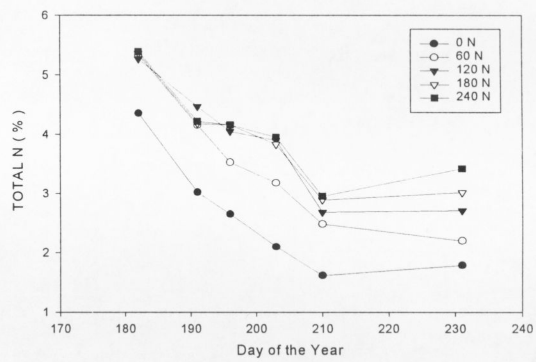
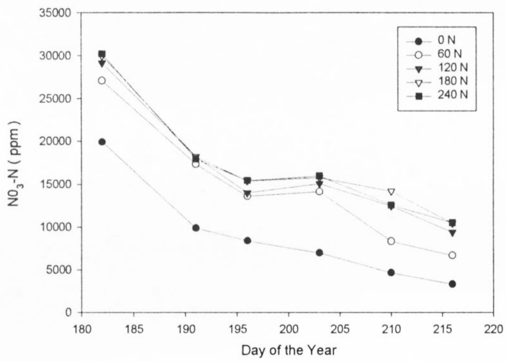


Figure 7. Top Stem - Total N (%).

The concentration of Nitrate-N and total N in the top stem (Figures 6 and 7) of the plant was not as sensitive as the petiole's but reflected the change in the nutritional status of the plant.



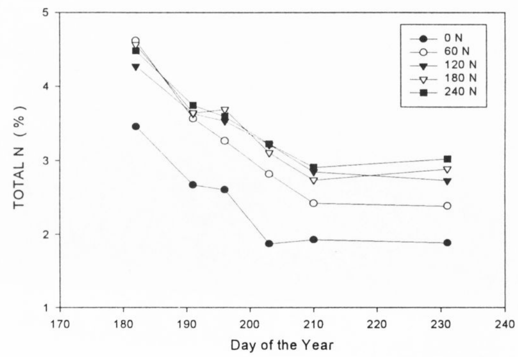
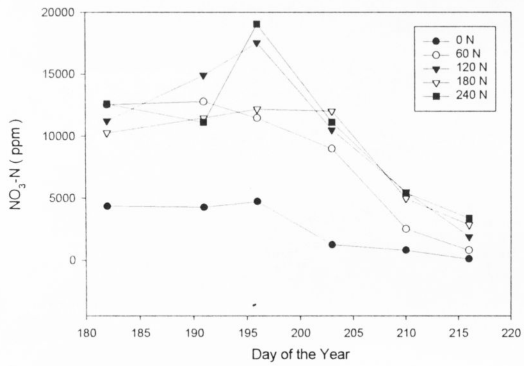


Figure 8. Lower stems - Nitrate N (ppm).

Figure 9. Lower stems - Total N (%).

The concentration of Nitrate-N and total N is even less sensitive in the lower part of the stem (Figures 8 and 9).



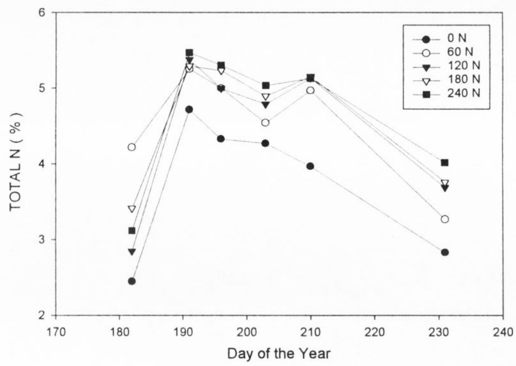


Figure 10. Leaves - Nitrate-N (ppm).

Figure 11. Leaves - Total N (%).

The concentration of Nitrate-N and total N in the leaf tissue (Figures 10 and 11) indicates clearly the effect of the sidedressing on the nutrient balance in the plant. The higher application rates were more sensitive to leaf response while the control showed only small changes as we expected.

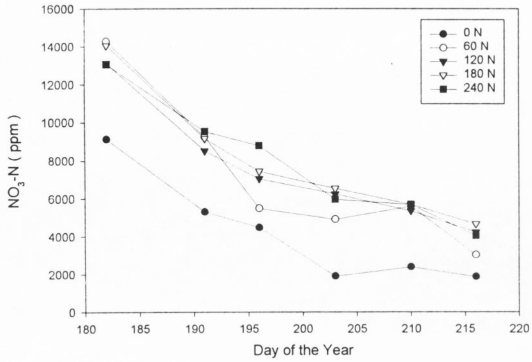


Figure 12. Stolon - Nitrate-N (ppm).

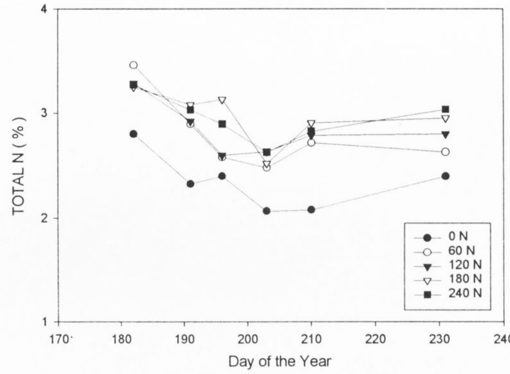


Figure 13. Stolon - Total N (%).

Nitrate-N and N concentrations in the stolon (Figure 12 and 13) and in the tuber (Figures 14 and 15) do not show significant response to the fertilizer applications compared to the control.

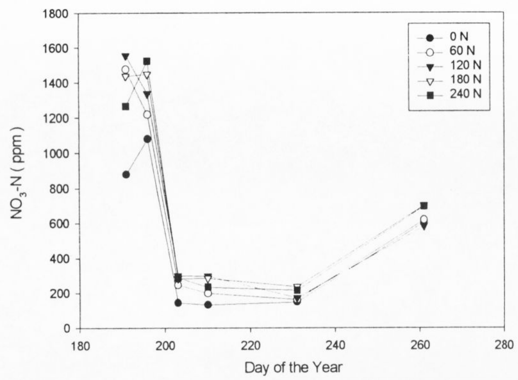


Figure 14. Tubers - Nitrate-N (ppm).

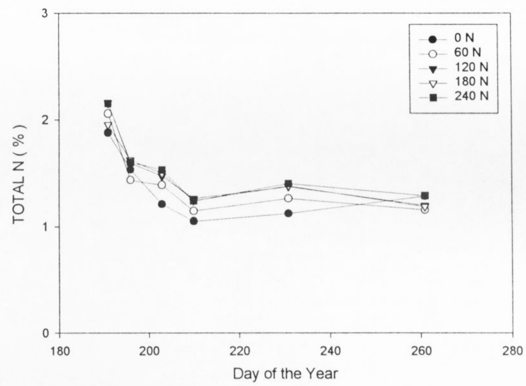


Figure 15. Tubers - Total N (%).

Yield, Tuber Size and Specific Gravity:

Yield, tuber size and specific gravity are reported in Table 1. U.S.#1 yields, total yield, yield of A's, yield of oversize and percent oversize were all maximized by 120 lb of N/A. Percent U.S.#1 and percent B's were optimum with 60 lb N/A.

Table 1. Snowden tuber yield, size distribution, specific gravity and nitrogen economic returns for the nitrogen experiment - 1997.

N Rate	Total	U.S.#1	Percent of the Total US#1	A's	OV	B's	Sp. Gr.	Gross Margin ($)[2]
0	190.4 c[1]	185.9 c	92.5 b	90.3	2.2 c	7.4 a	1.090 a	$1,142.40
60	263.8 ab	252.1 ab	94.3 a	90.3	4.1 bc	5.7 b	1.067 b	$1,569.60
120	288.8 a	266.9 a	94.8 a	87.8	7.1 a	5.2 b	1.063 b	$1,706.40
180	254.7 b	236.2 b	94.5 a	87.7	6.8 ab	5.5 b	1.067 b	$1,488.60
240	278.3 ab	258.8 ab	94.6 a	88.3	6.5 ab	5.4 b	1.065 b	$1,617.00

[1] Any mean followed by the a different letter within a column is significantly different based on the Duncan's Multiple Range test ($p \leq 0.05$).

[2] Gross margin = Gross returns - N fertilizer variable costs (based on $6.00/cwt for U.S.#1 potatoes and $0.22/lb for N fertilizer).

Chlorophyll Meter Readings:

Figure16 shows the correlation between chlorophyll content of potato leaves and nitrate N in potato petioles. Both values are expressed as a percent of the maximum value in each replication.

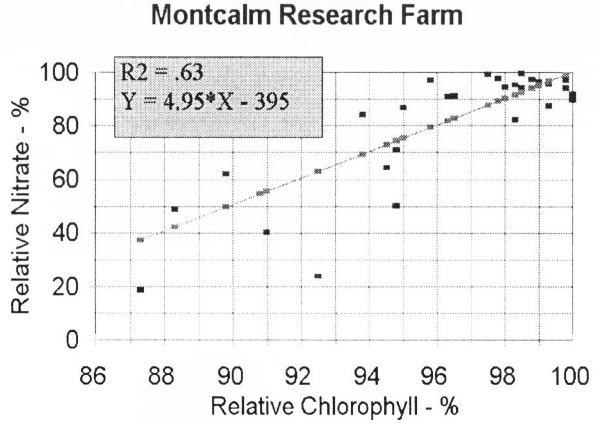


Figure 16. Nitrate - Chlorophyll Correlation.

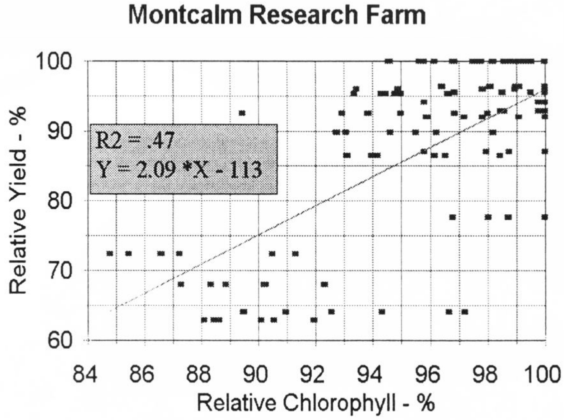


Figure 17. Yield - Chlorophyll Correlation

The correlation coefficient R^2 was 0.63 indicating a fair correlation. Figure 17, shows the correlation between relative chlorophyll content and yield of potatoes. The correlation coefficient R^2 was 0.47 again indicating a fair correlation. The data, however show a clear seperation between deficient leaves and reduced yields. A relative chlorophyll content of 94 percent clearly seperates the high yielding plots from low yielding plots. We believe that the chlorophyll meter can be a very useful tool for determing the N status of the potato plant when used in conjunction with a reference plot

which contains adequate N. This plot can be easily established by adding 60-80 lb extra N to a small plot area.

CONCLUSION

The response of the potato plant to the available N supply is an important determinant for accurate N fertilizer recommendations. Development of recommendations according to dry matter production and N uptake during each crop growth stage has the potential of increasing the fertilizer use efficiency and may also increase the final tuber yield within the climatic, disease and variety limitations. Our data indicate that petiole Nitrate-N content is a sensitive indicator of the N status of differentially fertilized potatoes. Changes in petiole Nitrate-N concentration reflect expected differences in N status. Cautious interpretation may be necessary, Nitrate-N in the potato plant tissue is in a dynamic state. At any given time the Nitrate-N concentration in the petiole reflects the growth stage of the plant and the availability of soil N, particularly Nitrate. Plant tissue samples must be taken properly and carefully to be useful in evaluating the nutritional status of the crop.

These guidelines for petiole nitrate and leaf chlorophyll should be useful in management strategies which maximize use of previous crop residues, organic amendments and soil reserves as N sources. In such a system, at-planting N fertilizer applications would be reduced and supplemental N application should be applied when deemed necessary with petiole testing or leaf chlorophyll monitoring.

Funding: MDA

NITROGEN STEWARDSHIP PRACTICES TO REDUCE NITRATE LEACHING AND SUSTAIN PROFITABILITY IN AN IRRIGATED POTATO PRODUCTION SYSTEM

Principal Investigator:	M. L. Vitosh	Professor, Crop and Soil Sciences, MSU
MSU Cooperators:	E. A. Paul	Professor, Crop and Soil Sciences
	R. R. Harwood	Professor and Sustainable Ag. Chair
	D. R. Smucker	County Extension Director, Montcalm Extension

PROJECT INTENT:

A collaborative effort by MSU crop and soil specialists, Michigan Department of Agriculture (MDA), Michigan Potato Industry Commission (MPIC), and Michigan State University Extension Service (MSUE) was initiated in 1995 to demonstrate how on-farm N stewardship practices could influence farm profitability and nitrate leaching to groundwater. We proposed to (a) establish N stewardship plots on potato farms and evaluate petiole sap nitrate testing as a tool for adjusting mid-season N fertilization, (b) install lysimeters to intensively monitor on-farm N leaching losses as affected by N practices and crop rotation for three consecutive years and (c) identify peak leaching periods and quantify nitrate losses to groundwater in relation to rainfall and irrigation.

PROTOCOL

INSTALLATION OF LYSIMETERS

In 1995, three types of undisturbed soil drainage lysimeters were installed on three irrigated potato farms in Montcalm County. Lysimeter types were: (a) zero-tension 6-ft long, semicircular troughs of 12 inch diameter, (b) low-tension quartz soil water samplers and (c) medium-tension soil solution access tubes (SSAT). These types were selected to evaluate the precision of measurements and reduce the effects of variability due to channeled flow. At each site, lysimeters were laid out into eight separate workstations, four located inside and four outside the N stewardship plot. Each workstation consisting of one trough, one quartz, and one 3-ft long SSAT located at a depth of 3 feet were installed perpendicular to the rows. The 6-foot long troughs extended across two potato rows. These lysimeters were installed in April, before field preparation time to enable farmers to plant potatoes over the lysimeters. After the crop emerged, three additional SSAT's were installed, two at 12-inch depth and one at 18-inch depth in the row between plants, to monitor soil solution nitrate levels in the root zone. Three other sites were selected to evaluate reduced N fertilizer rates but did not include lysimeters.

In 1996, seven different irrigated potato fields were selected to demonstrate nitrogen stewardship practices. This time the N stewardship plots were much larger, extending the entire length of the field. Trough and quartz lysimeters were not installed in the 1996 plots. Instead, six sets of SSAT's were installed at each location (three sets inside and three outside of the stewardship area). Each SSAT was installed in the potato row at depths of 12, 24 and 36 inches.

In 1997, eight irrigated potato fields were selected to demonstrate nitrogen stewardship practices. The N stewardship plots extended the entire length of the field. The potato crop was monitored for petiole nitrate content and leaf chlorophyll content. Eight sets of SSAT's were installed at four sites. Four sets were established inside and four outside of the N stewardship area. All SSAT's were installed in the potato row at depths of 12, 24 and 36 inches.

In another collaborative effort, MSU scientists, MPIC and MSUE have established a large drainage lysimeter facility at the Montcalm Research Farm. This facility provides direct measurements of nitrate leaching amounts for a potato-corn production system. This project was initiated in 1987 at the Montcalm Research Farm with the relatively long-term objectives of monitoring nitrate leaching as influenced by nitrogen fertilizer management. Data collected from these lysimeters and other research plots are being used to test and improve a computer simulation model, SUBSTOR which predicts not only crop growth and yield but also the important soil processes affecting nitrate leaching. This research will be used to establish the credibility of the model which will be used to predict long-term leaching from the Montcalm site and other locations in Michigan.

ESTABLISHMENT OF N STEWARDSHIP PLOTS

In 1997, N stewardship plots were established in eight fields to serve as a reference point for determining the N status of the entire field. The stewardship plots were narrow strips extending the entire length of the field. The width of each strip varied from 6 to 24 rows depending on the equipment available for applying fertilizer and harvesting. Each stewardship plot received a reduced N fertilizer rate, about 60-120 lb/acre less N than the conventional rate applied to the rest of the field. The differential N rates were applied either at first cultivation or at hilling.

RESIDUAL SOIL NITRATE AND SOIL SOLUTION NITRATE TESTING

Soil samples were taken to a depth of 3 feet, in 1 foot increments, prior to planting and after harvest to evaluate the initial and final residual soil nitrate levels. Soil solution samples were collected from each SSAT on a weekly basis starting July 1 and ending July 29. All samples were analyzed for nitrate N using an auto-analyzer.

WEEKLY PETIOLE SAP TESTING AND LEAF CHLOROPHYLL READINGS

Weekly potato petiole sap testing commenced on July 1 and ceased on August 12. Four composite samples of petioles were taken from inside the N stewardship plot and four from the farmers field outside the area. The test results were faxed to the growers on the same day of the analysis by the Montcalm Extension Service. The results were used to assess N status of potatoes and adjust mid-season N fertilizer applications. Additionally, the sap testing service was available to other interested potato growers.

Leaf chlorophyll readings were also made at the same time petiole samples were collected. Approximately 120 readings were made in each plot with a hand held Minolta SPAD 502 chlorophyll meter. These readings were later correlated with the corresponding petiole nitrate content.

POTATO HARVEST

In 1997, potatoes were harvested in September and October with the farmers equipment. Four to twelve rows, 800 to 2000 feet long, were harvested and loaded into trucks which were weighed at the nearest certified scale. Samples of tubers from each plot were graded according to size and analyzed for specific gravity. For the round variety, Snowden, U.S. #1 grade included all tubers greater than 2 inches in diameter. Tubers smaller than 2 inches were graded as B's. Tubers greater than 3.25 inches were classified as premium oversized. For Russet Burbank, tubers under 4 oz. were graded as B's. Those weighing over 10 oz. were classified as premium oversized. Tuber yields from inside and outside the N stewardship plots were compared.

RESULTS AND DISCUSSION

Rates and times of N fertilizer application for 1997 are presented in Table 1. Nitrogen rates varied from a low of 160 lb/acre to a high of 280 lb/acre. The number of applications varied from three to seven times. The varieties grown were Snowden and Shepody.

POTATO YIELD

Potato yield data from the seven of the eight N stewardship plots are presented in Table 2. Site 5 was not harvested. We are unable to calculate statistical differences for each site because the strips were not replicated. However, we did do a statistical analysis for N rates over all sites. At each site we harvested one truck load from each strip. Harvest strips varied from four to 12 rows wide and 800 to 3890 feet long. Truck loads varied from 2 to 14 tons of fresh weight tubers.

Sites 4, 7 and 8 tended to show an increase in U.S.#1 and total yields due to the extra N while sites 1, 2, 3 and 6 tended to yield better with less N. The overall analysis showed no significant differences for any of the variables measured ($p \leq 0.10$). Shepody had the largest percentage of premium oversize tubers. Sites 6 and 8 were allowed to grow late into the season, resulting in a longer than normal bulking period. This variety is usually harvested for the early processing market.

Specific gravity of tubers decreased slightly but not significantly with the higher N rates. Gross margins, calculated as the gross price times yield minus the fertilizer N costs, favored the higher N rates by $87/acre. Differences between high and low N rates varied from a loss of $115 per acre for site 6 to a gain of $395 per acre for site 7. A price of $6.60/cwt for potatoes and $0.22/lb of N fertilizer was used in the analysis. Yields at site 7 were low due to early-die disease complex. The extra N at this site tended to keep the plants alive longer resulting in a larger yield.

Table 3 shows a combined analysis for the last three years. A statistical analysis of the data shows that there were differences between years but not between the two N rates. For the 20 locations, there was only a 6 cwt/acre difference in total yield (396-390) and a gross margin difference of only $26/acre between the two N rates.

This data strongly supports the N stewardship practice of reducing N fertilizer use on potatoes. In general, there were differences by year and site but when the data were averaged over the three years (1995-1997), the extra 73 lb of N/acre (266-193) did not significantly increase yields. The use of farm equipment to harvest large plots has several advantages over small plot harvesting and can be used to draw meaningful conclusions about N fertilizer rates as long as we are willing to combine data over locations and years.

SAP NITRATE TEST AND LEAF CHLOROPHYLL READINGS

Weekly petiole sap nitrate tests from inside and outside the stewardship plots are published in the Appendix and summarized in Tables 4 and 5. Only six sites were included in the analysis due to a sampling problem at two sites (sites 6 and 7). Petiole nitrate levels declined slightly during the growing season as expected but all composite values were above the critical levels throughout the season. The high N rates gave the highest petiole nitrate levels as expected Only site 4 exhibited significantly lower petiole nitrate with reduced N fertilizer.

Leaf chlorophyll readings were also made each week when petioles were sampled for nitrate. Previous research has shown that leaf chlorophyll is closely correlated with N content of the leaf. Most scientists have shown that it is best to present the data as a percent of the high N treatment. Chlorophyll SPAD readings for 1997 ranged from 39-45. Relative chlorophyll readings (percentage based on the highest SPAD reading in each trial) ranged from 94 to 98 percent. Preliminary data developed at the Montcalm Research Farm and MSU Agronomy Farm in 1997 indicates that any value above 95 percent is adequate for maximum production. Relative values in August were the only ones to fall below the 95 percent adequacy level. This occurred for both the high and low N rates.

From these data, we conclude that the chlorophyll meter has great potential for use as a diagnostic tool in evaluating the N status of the potato crop.

SOIL WATER ANALYSIS

The zero-tension trough lysimeters installed in the spring of 1995 were abandoned in 1996 due to very little drainage water and high variability in the volume of water collected from each trough. We attribute this variability due to the capillary rise of water above the trough and to preferential flow through the soil profile around the trough lysimeters.

The 1997 weekly soil solution nitrate N concentrations from the medium-tension SSAT lysimeters are presented in Table 6 for five locations for the month of July. In general, there was a decline in nitrate concentrations during the season at most locations. Site number 5, however had relatively high nitrate levels in the soil solution throughout the growing season. Soil solution nitrate decreased with depth at the first two sampling dates but was equally distributed throughout the profile after the first two weeks. Soil solution nitrate levels in 1997 were considerable lower than in 1996 where levels exceeded 100 ppm at the 12 inch depth for the high N plots for most of the growing season. The implications of excess N in the profile whenever excess rain occurs could easily leach this N from the profile. **Growers need to be conscious of the N uptake pattern of potatoes and apply N more timely to meet the daily demands of the crop. Growers appeared to do a better job of managing N in 1997 than 1996. There appears to be considerable variability between access tubes, dates and locations which makes it difficult to establish a critical soil solution nitrate N level for optimum plant growth in the field using the SSAT's.**

PREPLANT AND POST-HARVEST RESIDUAL SOIL NITRATE

Soil nitrate data for the nitrogen stewardship plots are shown in Tables 7, 8 and 9. The initial soil samples prior to establishing the 1997 studies are reported in Table 7. Very little nitrate N was found in the 3-foot profile at all sites (less than 12 lb per acre 3-feet). The post-harvest data are shown in Table 8. The average for six of the sites was 65.3 lb/acre-3 feet for the low N plots compared to 96.7 lb/acre-3 feet in the high N plots. The high N treatments left significantly more nitrate ($p \leq 0.05$) in the profile at all sites except site 4.

Table 9 shows the data summarized for 16 sites over three years. In 1997, the amount of nitrate remaining in the soil profile after harvest was more than double the amount found in the previous two years even though more N fertilizer was applied in those years. The high N profile showed an average of slightly more than 20 lb per acre than the low N profiles.

From these data we conclude that potato growers are leaving approximately 40-60 lb of nitrate in the soil profile at harvest time. In dry years, the amount is expected to be greater than in wet years where greater amounts will be leached from the profile before harvest. The amount of N left in sandy soils after harvest is difficult to recover because forage crops have very little opportunity to grow late in the season. This makes it very important that growers match their fertilizer N applications to crop uptake as close as possible to prevent nitrate contamination of groundwater.

EFFECTS OF IRRIGATION AND RAINFALL

Table 10 shows calculated excess water based on the MSU Scheduler computer program. Excess rainfall during the growing season (June 20 through September 10) ranged from a low of 23 percent to a high of 58 percent or about 2-6 inches of leached rainfall. Excess irrigation water ranged from 10 to 51 percent. On average, about 25-45 percent of the incoming water (rain + irrigation) was lost from these sites in 1997. At first glance these numbers appear to be large and alarming, but when we looked at the water balance in the irrigation scheduling program, we see that just a few untimely rains can create a significant amount of leaching. The amounts of water lost due to irrigation are really very small averaging less than 1 inch for the 8 sites. The amount of excess water due to rainfall was much greater, ranging from 1.9 to 6.2 inches. There is nothing the grower can do about the untimely rains except to anticipate when the rain will come and reduce or eliminate irrigating prior to the rain. This practice will allow for more water to be stored in the soil profile and thereby reduce the amount of nitrate that is leached.

RECOVERY OF APPLIED NITROGEN FERTILIZER

Some calculations were made in Table 11 to estimate the amount of N fertilizer recovered by the potato crop and to estimate the potential loss of N from the N stewardship plots. The data are summarized over 20 locations for 1995-97. The percent N recovery from the low N plots was 67 percent of that applied. The amount recovered in the high N plots was 49 percent. More than 50 percent of the N in these plots was unaccounted for by crop removal. **These findings are very significant and emphasize the importance of managing N fertilizer properly. The reduced N plots lowered yields by only 6 cwt per acre but improved N recovery by nearly 30 percent.**

SUBSTOR POTATO MODEL SIMULATION STUDY

Considerable time was spent collecting and inputting weather data for each of the 1996 sites into the SUBSTOR potato simulation model, version 2.0. The model appears to be very sensitive to water input and as a result does not estimate yields accurately. More time is needed to study and validate the model. The model appears to be giving good realistic information on drainage and runoff. If the yields can be properly estimated, then we will be able to obtain realistic values on crop removal and the amount of N leached from our plots. We plan to continue working on this model throughout the winter months so that we can give potato growers a more realistic estimate of their N losses to groundwater. Ten years of drainage and N leaching data have now been collected from the large lysimeters at the Montcalm Research Farm. This data will be very valuable in validating the SUBSTOR potato model and predicting N losses from growers fields.

CONCLUSIONS

Since this project was initiated in April 1995, we have made excellent progress toward achieving our objectives. With a combination of N stewardship plots, sap nitrate testing, and on-farm lysimeters, we have been able to demonstrate that N stewardship practices are effective in: (a) maintaining potato yields and profitability; (b) reducing soil nitrate N residual levels at harvest and (c) lowering nitrate N concentration of drainage water compared to conventional N practices.

In addition, our weekly petiole sap nitrate testing program has gained acceptance as a practical tool for in-season N management of potatoes and the use of the Minolta chlorophyll meter appears promising for evaluating the N status of the potato crop. We have made excellent progress in calibrating this instrument with petiole nitrate content. In 1998 we plan to make more extensive use of this tool in the field to quickly determine the N status of the crop.

Potato growers are leaving approximately 40-60 lbs of nitrate in the soil profile at harvest time. In dry years, the amount will be greater than in wet years where more water is leached from the profile before harvest. The amount of N left in sandy soils after a late harvest of potatoes is difficult to recover because forage crops have very little chance to grow. This makes it very important that growers match their fertilizer N applications to crop uptake as close as possible to prevent nitrate contamination of groundwater.

With regards to irrigation scheduling, there is little or nothing irrigators can do about the untimely rains except to anticipate when the rain will come and reduce or eliminate irrigating prior to the rain. This will allow for more water to be stored in the soil profile and thereby reduce the amount that is leached.

N recovery was found to be significantly improved by reducing the amount of N fertilizer that most growers use by 60 to 80 lbs per acre. These findings emphasize the importance of managing N fertilizer properly. The three-year average showed that the reduced N plots lowered yields by only 6 cwt per acre but improved N recovery by nearly 30 percent.

Trough lysimeters do not appear to be suitable for evaluating nitrate N losses from potato fields. The use of soil solution access tubes (SSAT) is a practical way to follow nitrate movement in soils but inherent soil variability and preferential water flow are causing a great deal of variability in the values obtained. This variability will make it very difficult to establish critical nitrate levels in the root zone for optimum plant growth.

In summary our data suggest that there is environmental justification to reducing the current N application rates on potatoes and that N stewardship practices can be utilized effectively for this purpose.

Table 1. Nitrogen fertilizer application rates for nitrogen stewardship plots - 1997.

Site No	Treatment	---------- lb N per Acre ----------								
1	**Date applied**	**Preplant**	**5/28**	**7/2**	**7/7**	**7/22**	**Foliar**			**Total**
Snowden	Inside	21	62	72	--	46	4			205
	Outside	21	62	72	68	46	4			273
2	**Date applied**	**Preplant**	**5/22**	**6/27**	**7/4**					**Total**
Snowden	Inside	--	47	90	30					167
	Outside	--	47	90	90					227
3	**Date applied**	**Preplant**	**5/20**	**5/23**	**6/15**	**6/25**				**Total**
Snowden	Inside	--	60	60	--	120				240
	Outside	--	60	60	60	160				280
4	**Date applied**	**Preplant**	**5/7**	**6/4**	**6/14**	**6/18**	**8/1**			**Total**
Shepody	Inside	--	50	60	45	36	21			212
	Outside	--	50	60	45	75	21			251
5	**Date applied**	**Preplant**	**5/31**	**7/3**	**8/2**					**Total**
Snowden	Inside	--	55	105	--					160
	Outside	--	55	105	45					205
6	**Date applied**	**Preplant**	**5/22**	**6/25**	**7/15**	**8/1**	**8/10**			**Total**
Shepody	Inside	--	55	50	--	30	20			155
	Outside	--	55	50	30	30	20			185
7	**Date applied**	**Preplant**	**5/22**	**6/4**	**6/26**	**7/7**				**Total**
Snowden	Inside		52	19	76	--				147
	Outside		52	19	76	58				205
8	**Date applied**	**Preplant**	**5/5**	**5/20**	**6/24**	**8/4**				**Total**
Shepody	Inside	--	46	91	--	46				183
	Outside	--	46	91	92	46				275

Table 2. Tuber yield, size distribution, specific gravity and nitrogen economic returns for the nitrogen stewardship plots - 1997.

Site No.	Variety	N Rate	US#1	Total	Percent of the Total US#1	B's	A's	OV	Sp Gr	Gross Margin ($)[1]
1	Snowden	205	384	431	89.0	11.0	85.2	3.8	1.087	$2,258.90
		273	375	435	87.0	14.1	83.0	3.0	1.079	$2,189.94
2	Snowden	167	359	378	94.6	5.4	85.6	9.0	1.082	$2,117.26
		227	345	367	94.1	5.9	87.7	6.4	1.080	$2,020.06
3	Snowden	240	371	391	94.9	5.1	86.7	8.2	1.082	$2,173.20
		280	346	363	95.5	4.6	83.8	11.7	1.079	$2,014.40
4	Shepody	213	346	362	95.4	4.6	85.2	10.2	1.077	$2,029.14
		251	414	429	96.5	3.6	82.7	13.8	1.073	$2,428.78
5	Snowden	---	Not		----	----	----	----	-----	---
		---	Harvested		----	----	----	----	-----	---
6	Shepody	155	402	411	99.0	2.1	62.0	36.0	1.079	$2,377.90
		185	384	402	95.5	4.5	70.3	25.2	1.079	$2,263.30
7	Snowden	147	228	287	76.7	23.3	75.9	0.8	1.083	$1,335.66
		205	296	353	83.7	16.3	82.0	1.7	1.084	$1,730.90
8	Shepody	183	337	350	96.4	3.8	49.4	46.8	1.070	$1,981.74
		275	383	395	97.2	2.8	41.9	55.3	1.073	$2,237.50
Overall Means[2]	**Low N**	187	347	373	92.3	7.9	75.7	16.4	1.080	$2,039.11
	High N	243	363	392	92.9	7.4	76.0	16.7	1.078	$2,126.41

[1] Gross margin = Gross returns - N fertilizer variable costs (based on $6.00/cwt for US#1 potatoes and $0.22/lb for N fertilizer).

[2] None of the values were found to be significantly different from each other ($p \leq 0.10$).

Table 3. Tuber yield, size distribution, specific gravity and nitrogen economic returns for the nitrogen stewardship plots - Summary 1995-97 for 20 locations.

Year	Average N rate (lb/acre)	US#1	Total	Percent of the Total US#1	B's	A's	OV	Sp Gr	Gross Margin ($)[1]
		Overall means[2]							
1995	238	321c	371c	87c	12a	77b	10	1.074c	$1,873.64c
1996	236	402a	428a	93a	5c	83a	11	1.083a	$2,360.08a
1997	215	349b	378b	92b	8b	78b	14	1.079b	$2,046.70b
N Rate		Overall means							
Low N	193	354	390	90	9	80	10	1.079	$2081.54
High N	266	361	396	91	8	79	13	1.078	$2107.48

[1] Gross margin = Gross returns - N fertilizer variable costs (based on $6.00/cwt for US#1 potatoes and $0.22/lb for N fertilizer).

[2] Means followed by the same letter within a block are not significantly different as determined by the Duncans Multiple Range Test ($P \leq 0.05$)

Table 4. Effect of N fertilizer rate and sampling date on petiole nitrate and leaf chlorophyll content averaged over six nitrogen stewardship plots - 1997.

N Rate	Petiole and Leaf Sampling Date 7/1	7/8	7/15	7/22	7/29	8/5	8/12	Mean
	Petiole nitrate (ppm)							
Low N	1489	1361	1262	1346	971	1180	1085	1263
High N	1460	1418	1365	1411	1036	1719	1202	1400
Mean	1475	1389	1310	1379	1004	1449	1138	
	Chlorophyll SPAD Reading							
Low N	44	40	40	39	39	39	39	40
High N	45	40	41	40	39	40	41	41
Mean	44	40	40	39	39	39	40	
	Relative Chlorophyll Reading (%)							
Low N	97	97	97	95	95	93	95	96
High N	98	96	97	98	96	94	94	96
Mean	98	96	97	96	96	93	95	

Table 5. Effect of N fertilizer rate on average seasonal petiole nitrate levels and leaf chlorophyll readings for eight nitrogen stewardship plots - 1997.

N Rate	Site Number								
	1	2	3	4	5	6	7	8	Mean
	----------------------Petiole nitrate (ppm)-------------------------								
Low N	1303	1294	1471	946	1258	---	---	1683	1326
High N	1262	1315	1529	1348	1375	---	---	2122	1477
Mean	1283	1304	1500	1147	1317	---	---	1902	
	--------------Chlorophyll SPAD Reading-------------------------								
Low N	43	41	43	36	40	---	---	39	40
High N	43	42	43	39	40	---	---	38	41
Mean	43	42	43	38	40	---	---	39	
	--------------Relative Chlorophyll Reading (%)----------------								
Low N	96	96	96	90	96	---	---	96	95
High N	96	98	97	97	96	---	---	94	97
Mean	96	97	97	94	96	---	---	95	

Table 6. Nitrate-nitrogen content of water from soil solution access tubes (SSAT) sampled weekly at five locations, three sample depths and two nitrogen rates.

		Date				
Site No.	**N Rate**	**7/1**	**7/7**	**7/15**	**7/21**	**7/28**
		Nitrate-Nitrogen (ppm)				
1	205	34.0	19.4	10.6	12.9	15.6
	273	24.2	10.2	5.0	5.2	5.3
2	167	40.4	26.0	16.0	19.9	7.5
	227	19.9	16.9	8.1	8.9	--
3	240	18.2	61.2	39.0	25.2	25.1
	280	31.1	16.3	6.7	6.3	5.6
5	160	32.6	42.0	22.4	23.1	46.1
	205	46.1	44.1	27.5	22.1	--
7	147	38.3	32.8	15.4	7.1	6.1
	205	25.9	22.9	10.0	14.2	10.6
Overall Treatment Means[1]						
Treatment	Low N	33.3a	33.7a	19.4abc	17.2abc	14.5bc
	High N	29.5ab	23.0abc	11.7c	12.0c	13.9bc
Overall Depth Means[1]						
Depth	12"	51.1a	39.1ab	21.0cd	18.2cd	11.9cd
	24"	26.2bcd	28.5bc	15.7cd	13.1cd	16.8cd
	36"	15.1cd	16.1cd	11.3d	13.8cd	13.5cd
Overall Date Means[1]						
	Date	31.2a	28.1a	15.7b	14.8b	14.2b

[1] Means followed by the same letter within a block are not significantly different as determined by the Duncans Multiple Range Test ($P \leq 0.05$).

Table 7. Preplant soil nitrate-nitrogen levels for seven nitrogen stewardship plots - 1997.

Site Number	---- Sample Depth (inches) ----			Total
	0 - 12"	12 - 24"	24 - 36"	
	----- lb of Nitrate-Nitrogen per Acre -----			
1	8.2	0.5	1.1	**9.9**
2	4.2	1.4	6.5	**12.0**
3	nd[2]	nd	nd	**0.0**
4	3.2	1.5	3.2	**7.9**
5	1.3	0.2	0.1	**4.0**
7	nd	nd	0.3	**0.3**
8	5.9	2.4	1.7	**10.0**

[1] Means followed by the same letter within a block are not significantly different as determined by the Duncans Multiple Range Test ($P \leq 0.05$).
[2] nd = not detected

Table 8. Post-harvest soil nitrate-nitrogen levels as affected by nitrogen fertilizer rate and profile depth for six nitrogen stewardship plots - 1997.

Site Number	N Rate -lb/A-	---- Sample Depth (inches) ----			Total
		0 - 12"	12 - 24"	24 - 36"	
		----- lb of Nitrate-Nitrogen per Acre -------			
1	205	62.9	38.3	13.4	**114.5 b**
	273	48.6	39.8	13.2	**101.6 c**
2	167	37.7	23.3	11.3	**72.3 f**
	227	37.5	31.6	9.6	**78.8 e**
3	240	55.8	31.6	17.0	**104.4 c**
	280	142.5	79.5	40.2	**262.2 a**
4	212	10.2	1.7	4.2	**16.2 i**
	251	9.1	2.8	3.6	**15.5 i**
5	160	22.3	24.6	20.2	**67.1 g**
	205	26.0	35.4	33.1	**94.5 d**
8	183	9.0	5.4	2.7	**17.1 i**
	275	19.8	4.0	4.1	**27.8 h**
Low N	**195**	**33.0 b**	**20.8 c**	**11.5 e**	**65.3 a**
High N	**252**	**47.3 a**	**32.2 b**	**17.3 d**	**96.7 b**

[1] Means followed by the same letter within a block are not significantly different as determined by the Duncans Multiple Range Test ($P \leq 0.05$).

Table 9. Post-harvest soil nitrate-nitrogen levels as affected by nitrogen rate and profile depth for the nitrogen stewardship plots - Summary 1995-97 for 16 sites.

Site Years	Average N Rate -lb/A-	---- Sample Depth (inches) ----			Total
		0 - 12"	12 - 24"	24 - 36"	
		----- lb of Nitrate Nitrogen per Acre -------			
1995	264	17.4 bc	10.4 bc	8.9 c	**36.9 b**
1996	239	12.1 bc	10.8 bc	13.2 bc	**36.1 b**
1997	224	40.1 a	26.5 ab	14.4 bc	**81.0 a**
Treatment		------------ **Overall means** --------------			
Low N	208	20.2 ab	12.4 b	9.9 b	**42.5 a**
High N	276	27.0 a	20.8 ab	15.8 ab	**63.6 b**

[1] Means followed by the same letter within a block are not significantly different as determined by the Duncans Multiple Range Test ($p \leq 0.05$).

Table 10. Seasonal rainfall and irrigation amounts with calculated excesses based on a water balance from an irrigation scheduling program for the eight nitrogen stewardship plots.

Site No.	Rain	Irrigation	Total Precip[1]	Excess Rain	Excess Irrigation	Excess water	Excess Rain	Excess Irrigation	Excess Water
	-------------------inches/season*-----------------						-------percent-------		
1	10.3	3.6	13.9	4.04	0.46	4.5	39	13	32
2	10.8	4.27	15.07	6.23	056	6.79	58	13	45
3	7.55	6.20	13.75	2.96	1.02	3.98	39	16	29
4	9.31	4.55	13.86	4.29	1.21	5.50	46	27	40
5	7.40	5.85	13.25	4.41	1.63	6.04	23	51	29
6	8.08	3.20	11.28	1.87	1.17	3.04	31	10	25
7	7.25	2.85	10.10	2.26	0.29	2.55	31	10	25
8	8.05	4.20	12.25	2.62	1.61	4.23	33	38	35
Average	8.59	4.34	12.93	3.59	0.99	4.58	38	21	32

[1] June 20 through September 10, 1997.

Table 11. Estimated recovery of applied N by potatoes as affected by two nitrogen fertilizer rates - Summary 1995-97 for 20 locations.

	N Rate (lb N/A)	Total Yield (cwt/A)	N Recovered[1] (lb N/A)	N Unrecovered (lb N/A)	Recovery[2] (%)
Low N	193	390	129	64	67
High N	266	396	131	135	49

[1] N Recovered = Total yield x 0.33 lb N/cwt.

[2] N Recovery = (N recovered/N applied)*100.

Funding: MPIC

EFFECTS OF NITROGEN FERTILIZER MANAGEMENT ON NITRATE LEACHING

J. T. Ritchie, M. L. Vitosh, B. Basso and S. Stornaiuolo

Department of Crop and Soil Sciences, Michigan State University

This study represents a continuing effort to evaluate the impact of contrasting nitrogen strategies on nitrate leaching and crop yield. Increasing public awareness of nitrate contamination of groundwater has caused the agriculturalists to focus their attention on nitrogen recommendations and management strategies. The problem of nitrate contamination of groundwater in Michigan is pervasive. High nitrate concentration in groundwater are found in three regions in Michigan, the northwest, central and southwest (figure 1). All three areas are dominated by sandy soils and require supplemental irrigation for most crops. The use of large, permanently installed drainage lysimeters at the Montcalm Research Farm allows the direct measurement of nitrate leaching for contrasting nitrogen management strategies. This study is providing direct evidence of the impact of fertilizer management of potential groundwater contamination and the results of long term management decisions. As scrutiny of agricultural practices increase, this type of information becomes important for establishing leaching amounts from conventional fertilizer management as well as for possible conservative lower input systems.

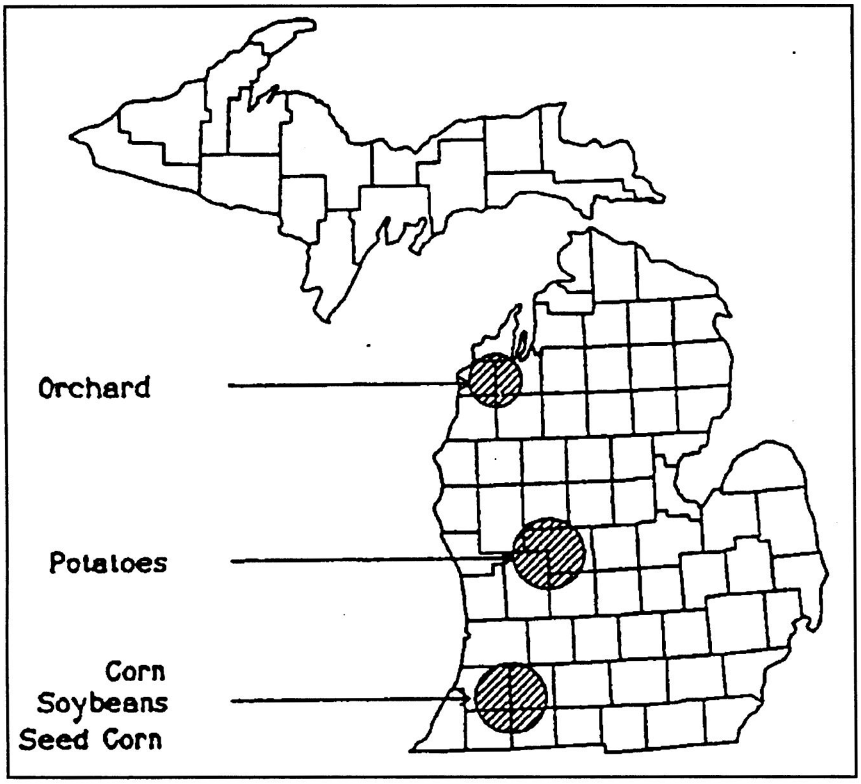


Figure 1. Map of Michigan showing the areas where high nitrate concentrations have been measured in ground water samples.

METHODOLOGY

The lysimeters used in this study are steel, box shape containers that are 48" wide, 68" long and 72" deep (figure 2).

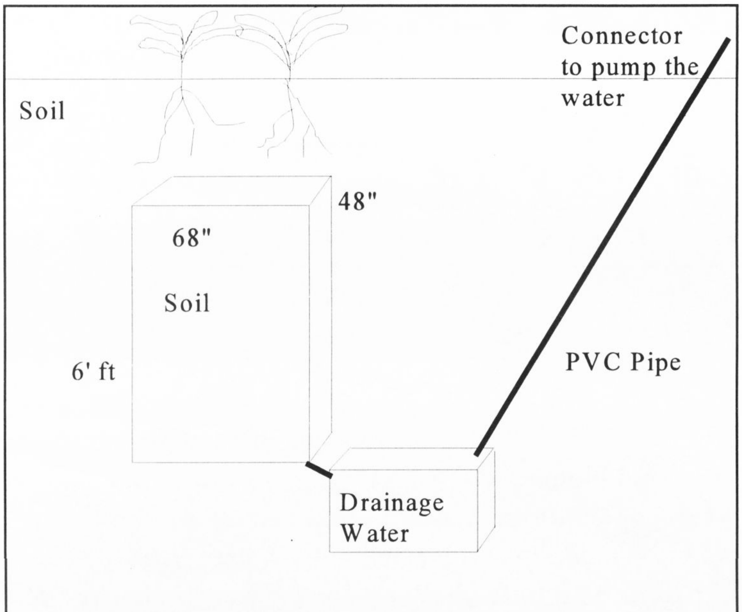


Figure 2. Diagram of the lysimeters.

The boxes have open tops and are installed so that their tops are about 15" below the soil surface, allowing for normal tillage operations. The bottoms of the lysimeters are closed except for a small opening through which the drainage water is channeled into a closed container. The volume of outflow is manually measured and samples of the outflow are analyzed for nitrates.

The lysimeters are separated into two treatments, a reduced input N fertilizer treatment and a higher than recommended management treatment. Each year since 1988 the plot receiving the lower treatment have received more than half the N fertilizer of the higher plot. Corn was planted in 1997 following as part of the rotation with potatoes. Both plots were planted with Pioneer hybrid on May 15, 1997, at which time a starter fertilizer containing 45 lbs of N was applied to both treatments. The corn was planted with 30" row spacing and 6" seed spacing yielding a plant population of approximately 30,900 plants/acre. Side dress nitrogen was applied at a rate of 75 lbs/ac on the reduced N plot and 175 lbs/ac on the high plot on June 25. Soil and plants were sampled for nitrates and total nitrogen on three occasions during the season for each N treatment.. Yields were measured on carefully controlled area directly over the top of each lysimeter and from 2 randomly chosen areas outside the direct area but near the lysimeters. The corn was hand harvested on November 7. Irrigation was supplied with the schedule used by the Montcalm Farm system using the regular sprinkler system.

RESULTS

The yield and the biomass for the two treatments are shown in table 1.

	Reduced Nitrogen Management	High Nitrogen Management
YIELDS (bu/acre)	152	156
BIOMASS (lbs/acre)	16470	18730
Grain N (%)	1.52	1.78

Table 1. Harvest data

The two treatments did not show significant differences throughout the season, although the measured biomass was slightly larger for the High Nitrogen Management treatment. The corn was sampled for biomass and nitrogen uptake during the season on three occasion. The plants were separated in leaves, stem, lower stem (first 6 inches) and ear, and then analyzed for total nitrogen and nitrate. Previous studies shown that corn plants tend to accumulated excess nitrogen as nitrate (NO_3^-) in the lower stem. The results of the analysis confirm what it has been found in the literature (Figure 3 and 4).

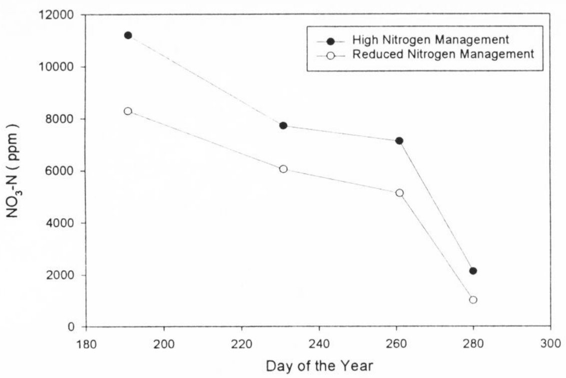


Figure 3. Nitrate in the lower stem

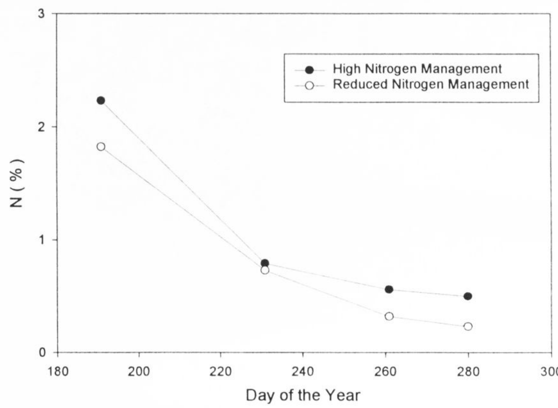
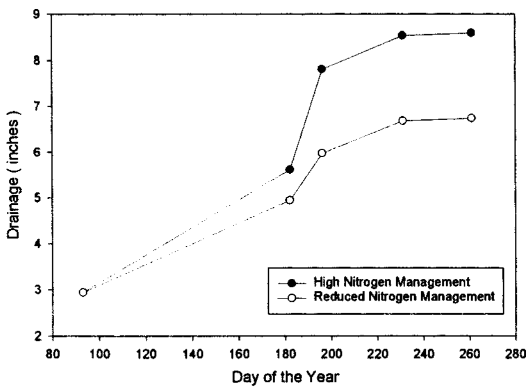


Figure 4. Total Nitrogen in the lower stem

Cumulative drainage for 1997 for the two treatments is shown in figure 5. Drainage was similar for both treatments till July 4, when one rain event caused the cumulative drainage to be higher for the higher treatment.



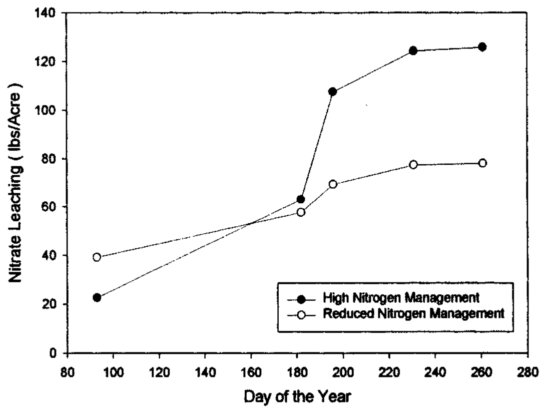
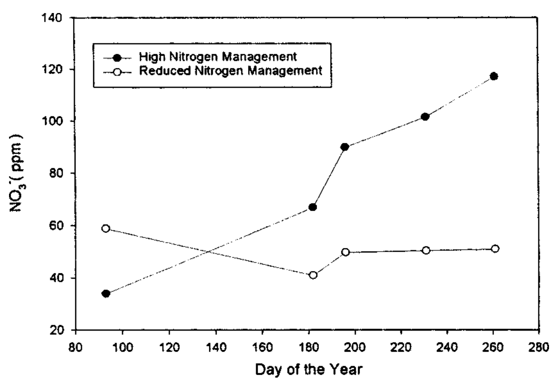


Figure 5 Amount of drainage for the two treatments

Figure 6 Nitrate-N leaching for the two treatments

The nitrate leaching, as depicted in figure 6, was considerably higher for the high nitrogen treatment, even though the reduced nitrogen management started with an higher amount of leaching at the beginning of the year. The concentration of nitrate in the drainage samples was quite different for the two treatments (figure 7).The highest concentration was found in the high nitrogen treatment at the end of the season. The reduced nitrogen treatment was uniform throughout the year. Figure 8 depicts the amount of nitrate leached in the drainage water. The reduced nitrogen treatment leached less because of the lower amount of fertilizer applied and the lower drainage observed.



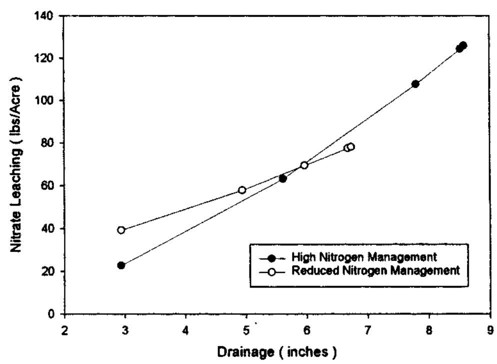


Figure 7 Nitrate Concentration in the drainage water

Figure 8 Amount of leaching for the drained water

Year	Crop Type	Fertilizer Applied (lbs/acre)		N Uptake By The Crop (lbs/acre)		NO_3^--N Leached (lbs/acre)		N Appl. - N Uptake (lbs/acre)		Yield cwt/ac bu/ac (corn)	
		RNM	HNM	RNM	HNM	RNM	HNM	RNM	HNM	RNM	HNM
1988	Potato	110	200	80	81	58	73	30	119	233	219
1989	Corn	130	200	100	106	200	215	30	94	154	158
1990	Potato	110	193	68	102	110	160	42	91	198	277
1991	Potato	125	200	51	79	74	84	74	121	148	214
1992	Corn	90	230	93	80	56	117	-3	150	143	119
1993	Potato	158	196	46	68	23	40	112	128	134	184
1994	Potato	107	196	111	133	52	57	-4	63	323	359
1995	Corn	148	260	101	100	75	97	47	160	155	149
1996	Potato	160	260	152	128	73	102	-8	132	441	345
1997	Corn	120	220	99	105	77	124	21	115	152	156
AVERAGE		**126**	**215**	**88**	**108**	**80**	**107**	**34**	**117**	-	-

Table 2 Annual N balance for the lysimeter plots for the 1988-1996. Montcalm Research Farm.

The long term results of the treatments since 1988 are provided in table 2. The average annual fertilizer input for the 10 year period was 89 lbs/acre more for the higher treatment, while the N removed by the harvest has averaged only 10 lbs/acre per year more for the higher N treatment. The leaching has averaged 27 lbs/acre per year for the higher treatment, a difference that is almost identical to the 1996 results. The nitrogen fertilizer added minus the nitrogen harvested by the potatoes and the corn has averaged 81 lbs/acre per year more for the higher treatment. This average difference is the amount available for leaching or for changes in concentration of N within the soil. For the higher treatment there has been a net of 107 lbs/acre added to the soil in the ten year period, while the reduced nitrogen management only added a net of 26 lbs/acre to the soil. Yields are given to indicate the years when yields were low due to pest or weather problems. Corn yields have been consistently good but potato yields have varied from 134 cwt/ac to 441 cwt/ac/ In low yielding years, leaching increases because of lack of uptake.

CONCLUSION

The two lysimeter system at the Montcalm Research Station appears to be providing accurate assessment of the leaching losses that come from producing irrigated potatoes rotated with other crops on a sandy soil as influenced by fertilizer management. The results indicate that most of the fertilizer N added that is not removed by the harvest crop results in leaching loss, although the soil N content does change some with the management. The results also indicate that there is no absolutely best N management practices that will maximize yields with minimum leaching because of the uncertainty of the amount of N removed by a crop, partly as related to the weather uncertainty. The actual needs of the nitrogen for the crops depend on the general fertility level of the soil before fertilizer addition and the previous cropping and manuring practices.
The corn yields were above average indicating that it is possible to obtain high efficiency with conservative management practices without sacrificing profitability.

EFFECT OF AMISORB^R ON YIELD OF POTATO

Darryl D. Warncke
Department of Crop and Soil Sciences
Michigan State University

A study was established on a McBride sandy loam to evaluate the effect of AmiSorb^R on the yield of potato. AmiSorb^R is a polyaspartate being marketed as a material that will enhance nutrient uptake by plant roots. In this study AmiSorb was applied at 2, 4 and 6 quarts per acre in comparison with a check. All treatments were replicated 4 times. When the potatoes (cv Snowden) were planted on May 27 the seed pieces were left uncovered. The AmiSorb was mixed was a starter amount of fertilizer (10-34-0) diluted with water and applied over the seed pieces with a sprinkling can. The seed pieces were then covered.

The potatoes were harvested in September after the vines had died down and then were graded. The yield data is presented in Table 1. Total tuber yield and yield of marketable tubers was increased with 4 and 6 quarts per acre, but these were not statistically significantly different from the check yields. Specific gravity was not affected by any of the treatments.

Table 1. Yield of potatoes (Snowden) grown in a McBride sandy loam in relation to the application of AmiSorb^R.

Amount Applied	Yield				Specific Gravity
	Total	US#1	<2 inch	Cull	
Quarts/A	- - - lb/50 row ft. - - -				
0	76.9	64.8	11.0	1.1 a	1.078
2	75.7	65.0	10.4	0.5 b	1.077
4	80.5	68.8	11.2	0.6 b	1.077
6	80.2	68.1	11.5	0.7 ab	1.077
	ns	ns	ns		ns
CV (%)	10.1	12.4	14.8	55.6	0.12

[R]AmiSorb is a registered product of Amilar International Inc.
Michigan State University Montcalm Research Farm.

Funding MPIC

Postharvest Suppression of Fusarium Dry Rot and Other Storage Diseases of Potato Tubers by Application of Bioactive Fungal Inoculum during Plant Growth

Brendan A. Niemira, William W. Kirk, Gene R. Safir and Raymond Hammerschmidt
Department of Botany and Plant Pathology
Michigan State University, East Lansing, MI 48824

Project goals

1. Determine if the use of a commercial arbuscular mycorrhizal fungal (AMF) inoculum will result in the production of potato tubers that are differentially resistant to storage rots caused by *Fusarium sambucinum, Phytophthora infestans* and *P. erythroseptica*.
2. Determine if commercial AMF inoculum alters the resistance of potato foliage to *P. infestans*.
3. Determine if chemical stimulation of indigenous AMF alters yield and or storage disease resistance in resultant tubers.

Project status and results

Colonization of a host plant with arbuscular mycorrhizal fungi (AMF) is known to reduce the severity of damage to plant roots caused by pathogenic nematodes and fungi. Newsham et al. (1993) suggest that the AMF induced protection from root pathogens is the primary benefit that AMF provide, exceeding P uptake in importance. Studies of disease suppression have primarily focussed pathogens of the host plant, and there are few studies of AMF induced disease suppression in progeny tissues, often the tissues of most economic significance.

Potato (*Solanum tuberosum*) maintains a natural symbiosis with AMF. Although subterranean organs, tubers of potato are modified stem tissue, and are not colonized by AMF. Tubers are susceptible to a number of fungal pathogens which cause a variety of diseases in storage. The most important storage pathogens are those for which chemical control is less effective or non-existent. Among these are Fusarium dry rot (*Fusarium sambucinum*), pink rot *(Phythophthora erythoseptica*) and, of particular concern, late blight (*P. infestans*). With aggressive metalaxyl-resistant strains of *P. infestans* appearing worldwide, chemical controls are under development for this pathogen, now seen as the most significant potato disease. *P. infestans* can infect leaves, stems and tubers, killing susceptible plants within days. The aggressive US8 strain (A2 mating type) has overcome general resistance in most commercial varieties, and relatively few advanced breeding lines show promise for the development of resistant varieties in the next 3-5 years (Douches et al. 1997)

Tuber rot studies

Susceptible potato plants, cv. Atlantic were grown in mycorrhizal and non-mycorrhizal media in experimental greenhouses at Michigan State University, and in a commercial seed tuber production greenhouse (Niemira et al. 1996). After cold (4°C) storage for 5 months, these tubers were challenged with *F. sambucinum* with a mycelial plug via wounded periderm. Tubers were held at 22°C, 100% rel. humidity for 14d, conditions conducive to disease development. The tubers were then assessed for rot depth, width and a conic volume approximation of rotted tissue was calculated. Tubers from plants inoculated with AMF showed significant reductions (20-90%) in amount of tuber tissue rotted (Table 1). This increased resistance in modified stem tissue not directly colonized by AMF, demonstrated 5 months after the tubers were removed from the parent plant, suggests that AMF induce a persistent systemic resistance response.

To test the breadth of this resistance, susceptible tubers (cv. Atlantic) from mycorrhizal and non-mycorrhizal media were stored as before, and then injected with a suspension of zoospores of the aggressive US8 strain of *P. infestans*. These were held at conditions conducive to disease development (in the dark at room T (22°C), 100% relative humidity) for 7 days. These were then given a visual disease rating from 0 (no disease) to 5 (extensive physical breakdown of the tuber and/or resporulation of the pathogen). Tubers from the mycorrhizal media had notably less blighted area overall (Figure 1), and had a significantly lower average disease rating (2.1) than tubers form non-mycorrhizal media (3.0) (Figure 2). The presence of active *P. infestans* on both sets of tubers was confirmed microscopically and with a Phytophthora-specific ELISA test. This is the first demonstration of a biological treatment suppressing the post-harvest development of an aggressive modern strain of *P. infestans*.

Minitubers, produced as previously described, were tested against pink rot (*Phytophthora erythroseptica*) by placing a mycelial plug through wounded periderm. Tubers were stored under conditions conducive to disease development (as for *P. infestans*) and evaluated for disease development using a visual rating and measurements of rot penetration (as for *F. sambucinum*). There were no significant differences between tubers from plants that were inoculated with AMF and tubers from plants grown in sterile peat, i.e. treated and untreated (Table 2).

<u>Foliar susceptibility to *P. infestans* studies</u>

Susceptible potato plants, cv. Snowden, were grown in sterile and AMF inoculated peat in research greenhouses at Michigan State University, 14h/10h day/night, 22°C, 50-70% rel. humidity (n=20). The plants were fertilized once with 100ml 15-30-15 NPK, 16d after emergence. At 19d after emergence, the plants were inoculated with an aerosol suspension of US8 (A2) *P. infestans* zoospores. The plants were held at 100% rel. humidity, 22°C for 7d. Individual leaves were evaluated for # lesions and % leaf area diseased.

Inoculated and non-inoculated plants did not differ when data from the plant as a whole was combined (Table 3). On an individual leaf basis, however, differences in the positioning of late blight lesions within the entire canopy became apparent. *P. infestans* tends to occupy the upper canopy in plants grown with AMF, and tends to occupy the lower canopy in plants grown in sterile medium (Figure 3).

<u>Stimulation of indigenous AMF: effects on yield, susceptibility</u>

Potato plants, cv. Snowden, in a commercial dryland cultivation system (L. Walther and Sons, Clio, MI) were used to test the effect of chemical stimulation of indigenous AMF. These plants received one application of the AMF stimulatory chemical formononetin (product trade name: Myconate), applied as a drench to the foliage and soil 14 days after emergence. Compound was applied at concentrations of 0 (control), 25, 50 or 100 ppm, otherwise treatment (fertilization, fungicide application) was identical to commercial operations. At 8 weeks after emergence, there were no differences in the foliage appearance (color, stem number, size, leaf area). Samples of treated rows were taken (120cm) one week after burn down (14 weeks after emergence). Tubers were sorted for size and rated for severity of common scab (*Streptomyces scabies*). Size classes: "large" = greater than 2" in diameter, "small" = between 1" and 2" in diameter and "very small" = less than 1" in diameter. Harvest data shows significant differences between the treated and the untreated plants (Figure 4). Treatment with Myconate increased the total number of tubers produced by 40% (51 tubers vs. 36.5 tubers) and increased the total weight of tubers produced by 26% (10.3 lbs. vs. 8.2 lbs.). Most of the increase came in the "small" and "very small" categories. There were no differences in the scab incidence or severity. These yield effects are similar to those obtained by inoculation with AMF directly (Niemira et al. 1995)

These tubers were placed into cold storage and are scheduled to be tested for susceptibility to *F. sambucinum, P. infestans* and *P.erythroseptica* in January 1998.

Conclusions

Inoculation of potato plants with AMF results in tubers that are less susceptible to *F. sambucinum,* and *P. infestans*. Susceptibility to *P.erythroseptica* is unchanged. Growth in the presence of AMF alters the pattern of infection of *P. infestans* in the leaf canopy. Chemical stimulation of indigenous AMF in a commercial potato production field, within the framework of a normal commercial management, increases potato yield by 26%. The similarity of the yield response following chemical stimulation of indigenous AMF with the yield response following inoculation with AMF leads to the conclusion that chemical stimulation, as described, may viably replace inoculation as a means to obtain benefit from AMF associations.

These data suggest that inoculation with AMF and/or use of synthetic agrochemicals to stimulate indigenous AMF can increase yields, quality and storability of potatoes grown in Michigan. The results from these field studies indicate that this naturally bioactive component may be incorporated into a normal potato production system without significant changes in commercially accepted practice.

References

Newsham, K.K, A.H. Fitter and A.R. Watkinson. 1993. J.Ecology 83:991-1000
Douches, D.S., W.W. Kirk, K. Jastrzebski, C. Long and R. Hammerschmidt. 1997. Amer.Pot.J 74:75-86
Niemira, B.A., G.R. Safir, R. Hammerschmidt, and G.W. Bird. 1995. Agron. J. 87:942-946
Niemira, B.A., R. Hammerschmidt and G.R. Safir. 1996. Amer.Pot.J 73:509-515

Table 1. Development of dry rot (*Fusarium sambucinum*) in minitubers from plants inoculated with arbuscular mycorrhizal fungi.

Medium	Depth (mm)	Width (mm)	Volume (mm^3)
Experimental greenhouse			
- AMF	6.59	13.33	694.8
+ AMF	4.02 (60.9)*‡	9.27 (69.5)*	183.3 (26.3)*
Commercial greenhouse			
- AMF	4.69	12.06	203.4
+ AMF	2.94 (62.7)*	9.56 (79.3)*	84.8 (41.8)*

‡ Data followed in parentheses by percent of control. Data indicated by asterisk (*) are significantly (P<0.05) different from control.

Table 2. Development of pink rot (*Phytophthora erythorseptica*) in minitubers from plants inoculated with arbuscular mycorrhizal fungi.

Medium	Visual rating	Depth (mm)	Width (mm)	Volume (mm^3)
Rep. 1 - AMF	3.38	16.9	26.6	3271.9
+ AMF	3.21 (95.0)‡	15.9 (94.1)	24.3 (91.4)	2562.9 (78.3)
Rep. 2 - AMF	3.08	9.7	21.8	1265.4
+ AMF	2.60 (84.4)	12.9 (134.4)	21.7 (99.5)	1896.7 (149.9)

‡ Data followed in parentheses by percent of control. Data indicated by asterisk (*) are significantly (P<0.05) different from control.

Table 3. Development of late blight (Phytophthora infestans) in the canopies of plants grown with and without arbuscular mycorrhizal fungi.

Factor	- AMF	+ AMF
AMF root colonization (%)	0.0	28.8
# leaves per plant	11.3	11.7
Lesions per plant	3.40	4.45
Lesions per leaf	0.314	0.416
% leaf area diseased	0.350	0.547

Figure 1. Development of late blight (Phytophthora infestans) in minitubers from plants inoculated with arbuscular mycorrhizal fungi.

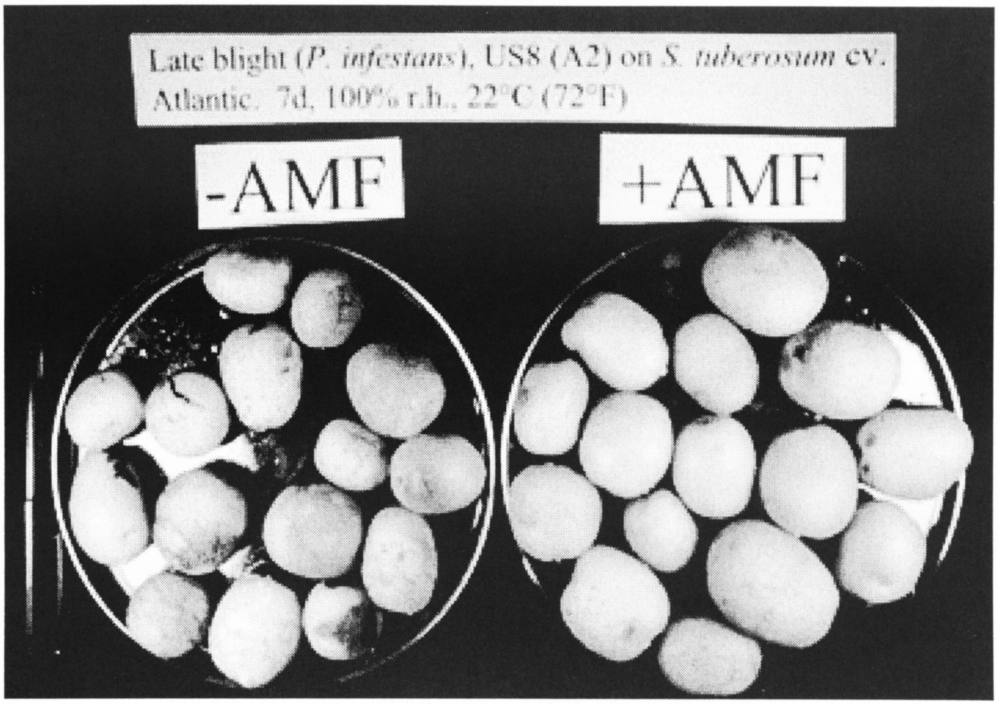


Figure 2. Quantitative assessment of late blight in minitubers from plants inoculated with arbuscular mycorrhizal fungi. (Bars indicate standard error, n=16)

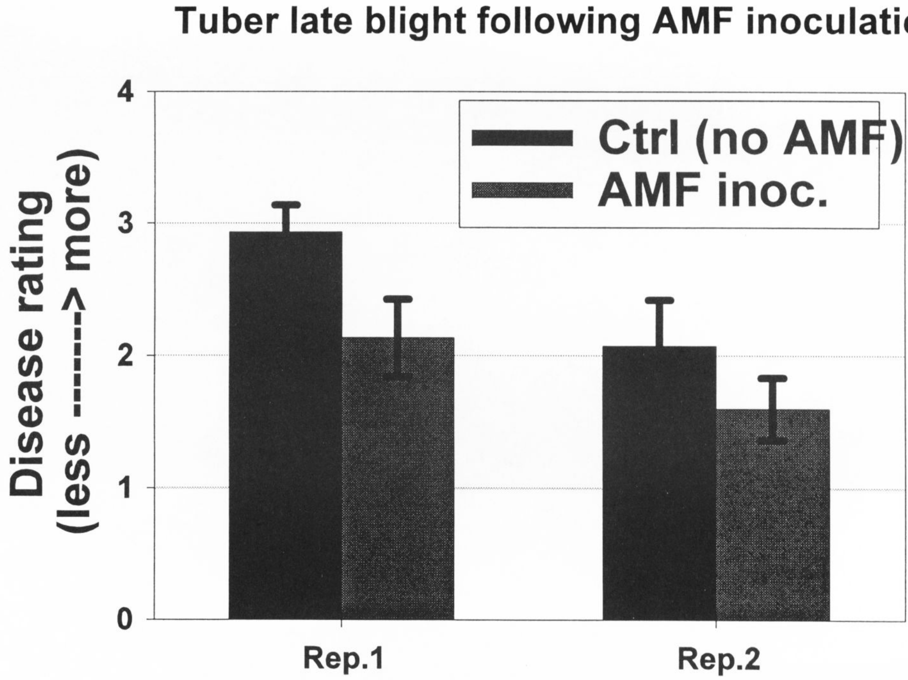
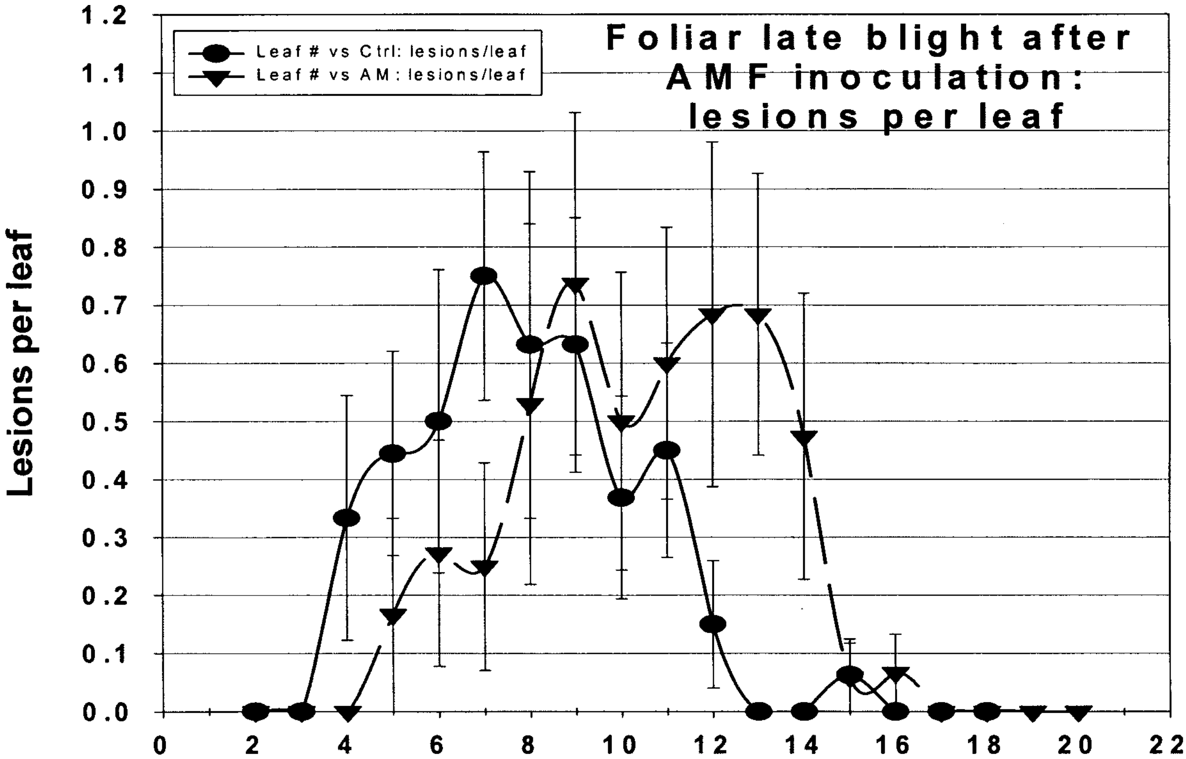


Figure 3. Foliar development of late blight (Phytophthora infestans) in canopy of plants grown with and without arbuscular mycorrhizal fungi.



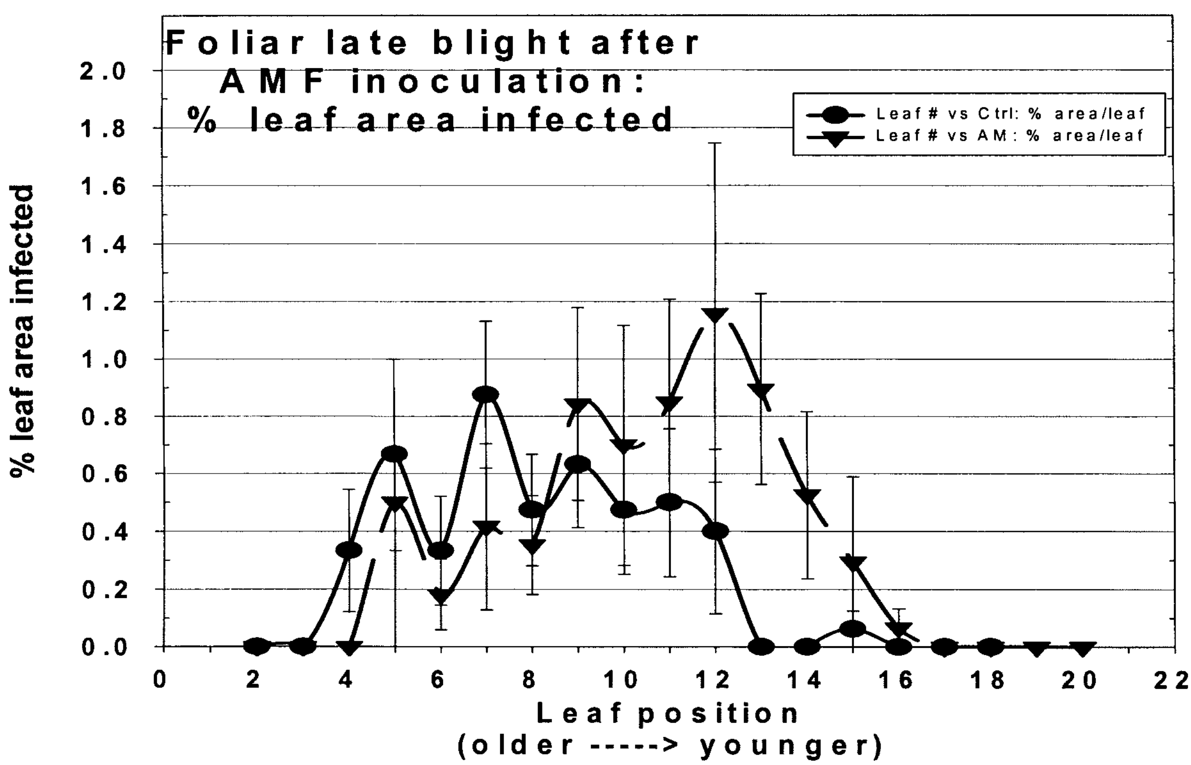
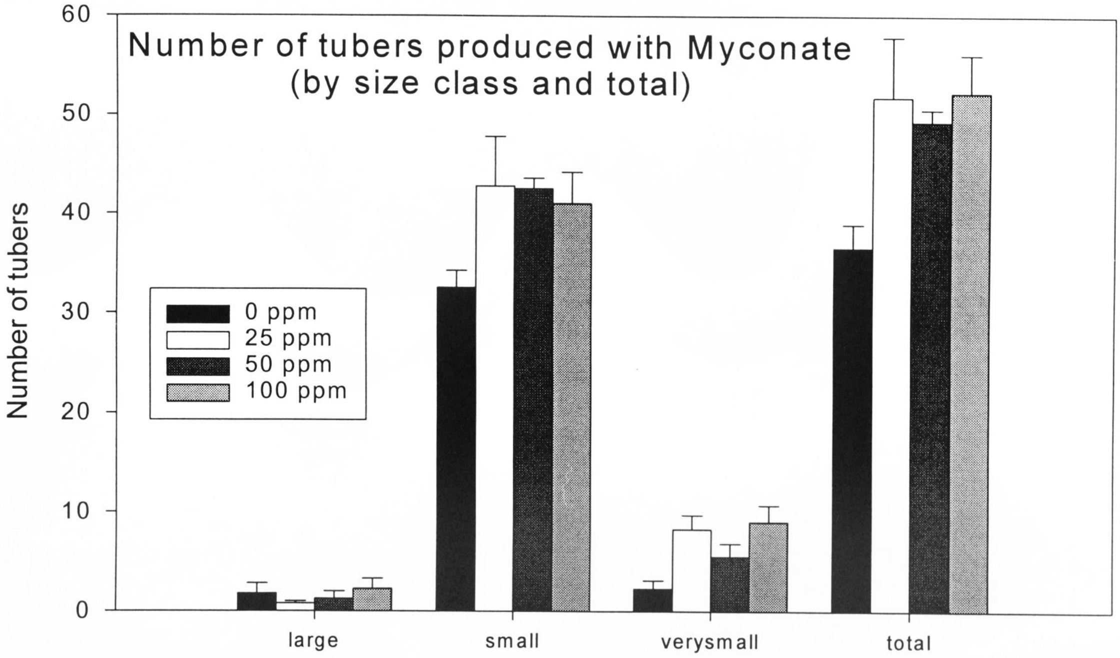
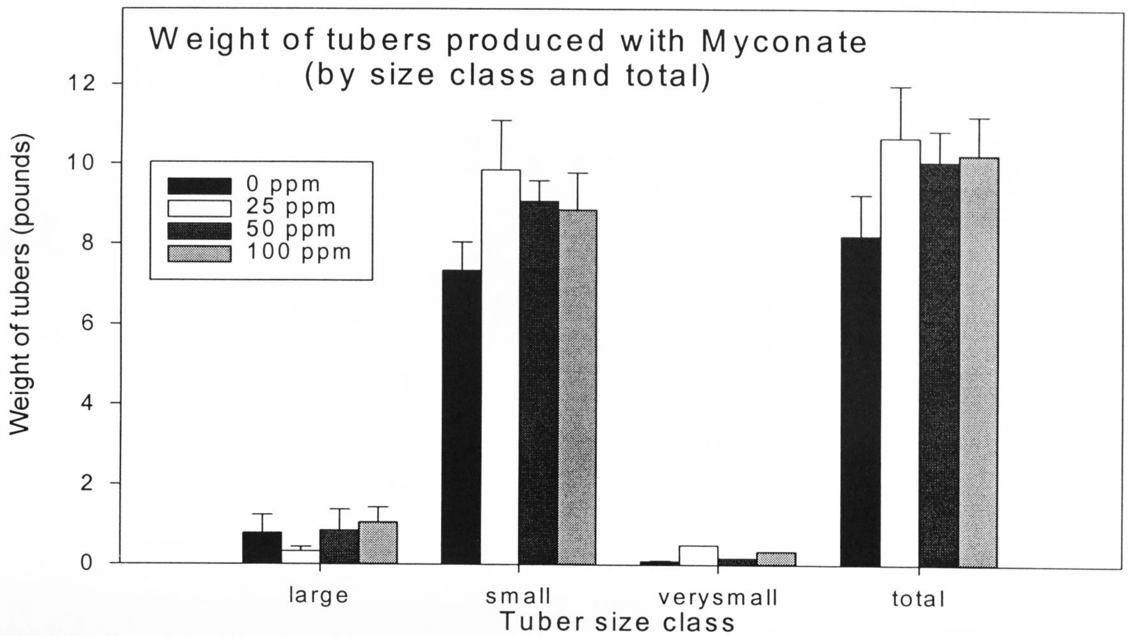


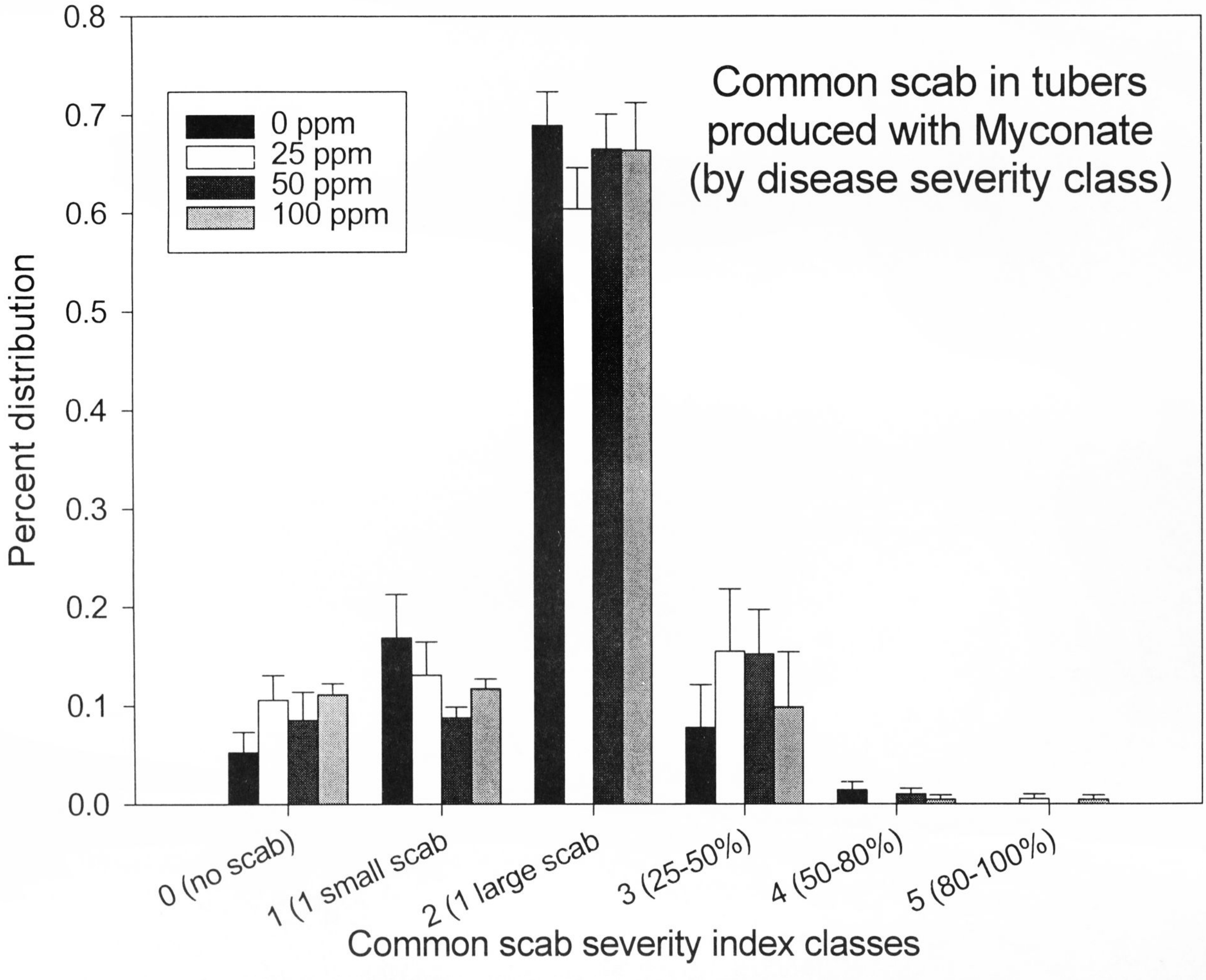
Figure 4. Yield following stimulation of indigenous arbuscular mycorrhizal fungi in a commercial potato field.





Solanum tuberosum cv. Snowden, dryland farm on sandy clay loam. One liter of AMF stimulatory solution applied as drench, 14d after emergence. Normal fungicide, fertilization for commercial potato production. Samples taken from 120cm of row, 1wk after burn down (14 wk after emergence). "Large" = greater than 2" in diameter; "Small" = between 1" and 2" in diameter; "Very small" = less than 1" in diameter. n=4, bars are standard error.

Figure 5. Development of common scab (*Streptomyces scabies*) on tubers from field plants treated with arbuscular mycorrhizal fungal stimulant chemical.



Solanum tuberosum cv. Snowden, dryland farm on sandy clay loam. One liter of AMF stimulatory solution applied as drench, 14d after emergence. Normal fungicide, fertilization for commercial potato production. Samples taken from 120cm of row, 1 wk after burn down 914 wk after emergence. n=4, bars are standard error.

Funding Fed. Grant/MPIC

Colorado Potato Beetle Management
1997 Research Report

Edward Grafius, Beth Bishop and Paul Kolarik
Department of Entomology
Michigan State University

Summary:

During 1997, we conducted research on 1) Monitoring Colorado potato beetle populations for resistance to Admire (imidacloprid), 2) the effectiveness of *Bt* transgenic potato plants as a barrier to Colorado potato beetles, and 3) the efficacy of registered and experimental insecticides for the control of Colorado potato beetle, and other potato insect pests.

Monitoring Colorado potato beetle populations for resistance to Admire (imidacloprid)

Admire (imidacloprid) was used extensively again in 1997 for the control of Colorado potato beetle. Overall, it continues to provide excellent control. However, because of such extensive use over the past three years, concerns about Colorado potato beetle developing resistance to it are increased. In 1997, we conducted laboratory assays of field-collected Colorado potato beetles to evaluate their level of susceptibility to Admire. In addition, we continued to select laboratory strains of potato beetles, originally collected from Michigan potato fields in 1995 and 1996, for resistance to Admire. Our objective was to understand Admire resistance by studying it in these laboratory strains. Last, we fed laboratory strains Admire-treated potato foliage to compare the effectiveness of Admire to susceptible and resistant potato beetles as the level of Admire decreases in the plant.

Field populations. Colorado potato beetles were collected from potato fields by MSU Extension agents, growers, crop consultants, cooperators in Wisconsin, Minnesota, and New York, and by our staff. They were brought back to our laboratory and tested for resistance, as described below. In 1997, 10 populations from Michigan potato fields were tested along with two populations from Wisconsin, and one population each from Minnesota, and Long Island, NY.

Laboratory Strains. During 1997, we maintained 3 Colorado potato beetle strains in the laboratory, two resistant strains and one susceptible strain. The first resistant strain originated from adults collected in 1995 from Bay Co. and Lapeer County ("AS" strain). The second strain originated from adults collected from a field in Montcalm County in 1996 ("MR"). Adults from both resistant strains were collected from Admire-treated potato fields. We maintained these strains in the laboratory, and selected them for resistance between generations. The susceptible strain ("UP") was collected in 1996 from an organic potato farm in Houghton County where Admire had never been used. We maintained this population in the laboratory as a susceptible population (without selecting it for resistance).

Laboratory assays. We applied a one µl drop of technical grade insecticide to the underside of the abdomen of adult Colorado potato beetles to test for resistance and determine resistance level. Mortality was checked every few days for at least 6 days after treatment. Field-collected beetles were tested in 1997 by treating individual beetles with doses of 0.1 µg Admire/beetle. This dose kills most susceptible beetles but beetles resistant to Admire survive. After treatment, beetles were classified as "alive" "affected" or "dead". "Dead" beetles were dark, exhibited no movement when prodded, and had shrunken abdomens. "Affected" beetles had extended legs, difficulty walking, were unable to right themselves when turned over on their back, and were unable to grasp the point of a pencil. "Alive" beetles walked and moved normally, and were able to do the things the "affected" beetles were not.

Results: Laboratory assays. In 7 of the 10 Michigan populations tested for resistance in 1997, most beetles were affected by Admire (Figure 1 and 2). Results were similar to those obtained with the susceptible laboratory population (UP-2). However, the remaining three populations (MI-8, MI-9, MI-10) demonstrated low levels of resistance to Admire (< 70% of beetles tested poisoned by Admire). Beetles from a field site in Minnesota (MN-1) also were resistant to Admire. These three Michigan populations, plus the Minnesota population, showed responses similar to laboratory beetles selected for resistance to Admire (MR-2, AS-2), and which are 4-5 times more resistant to Admire than susceptible beetles. More than 90% of Long Island (NY-1) beetles survived more than 10 times the discriminating dose.

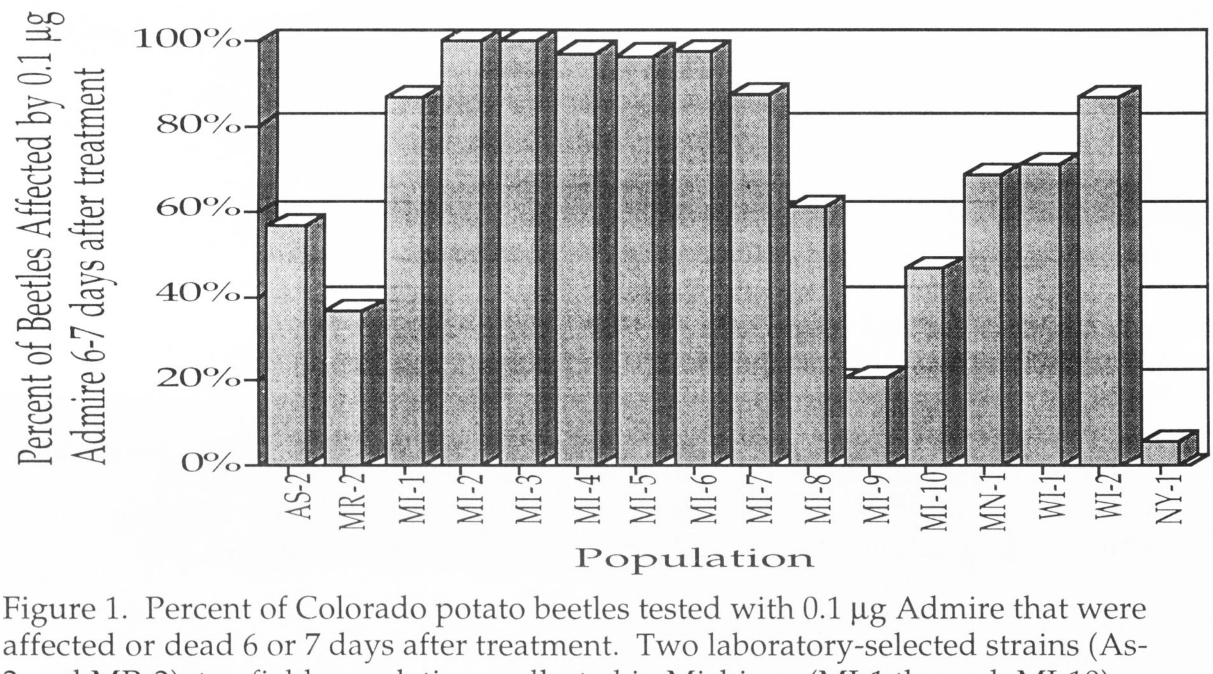


Figure 1. Percent of Colorado potato beetles tested with 0.1 µg Admire that were affected or dead 6 or 7 days after treatment. Two laboratory-selected strains (As-2 and MR-2), ten field populations collected in Michigan (MI-1 through MI-10), two field populations collected in Wisconsin (WI-1 and WI-2), and one each field population collected in Minnesota(MN-1) and Long Island, NY (LI-1) were tested.

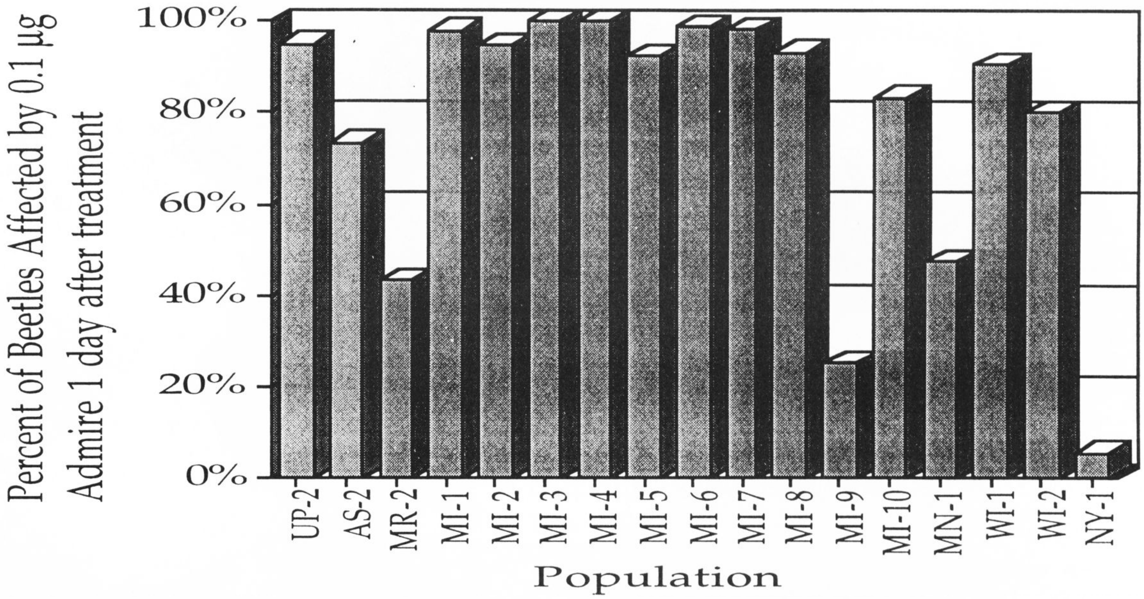


Figure 2. Percent of Colorado potato beetles tested with 0.1 µg_ Admire that were affected or dead 1 day after treatment. One susceptible laboratory population (UP-2), two resistant laboratory-selected strains (As-2 and MR-2), ten field populations collected in Michigan (MI-1 through MI-10), two field populations collected in Wisconsin (WI-1 and WI-2), and one each field population collected in Minnesota(MN-1) and Long Island, NY (LI-1) were tested.

<u>Characteristics of resistance</u>. Resistant beetles from several field populations and from both selected laboratory populations showed an unusual response to treatment with Admire: Initially the majority of beetles exhibited all symptoms of poisoning (laying on their backs with legs extended, unable to remain upright, unable to walk, uncontrolled twitching of legs) but in 3 to 7 days they recovered and resumed feeding, mating and laying eggs. Both laboratory populations that we've selected for resistance to Admire show this recovery from initial poisoning. Of the three Michigan field populations found to be resistant to Admire in 1997, two (MI-8 and MI-10) also showed this recovery (Figures 1, 2 and 3). The other resistant Michigan population was less affected one day after treatment, but showed little or no recovery (MI-9). Beetles from Long Island and from the Minnesota site also were less affected at first and had little recovery. This latter response is normally found in response to treatment with other insecticides, if the potato beetles are resistant. These two different responses to treatment with Admire may mean there are two different mechanisms responsible for resistance.

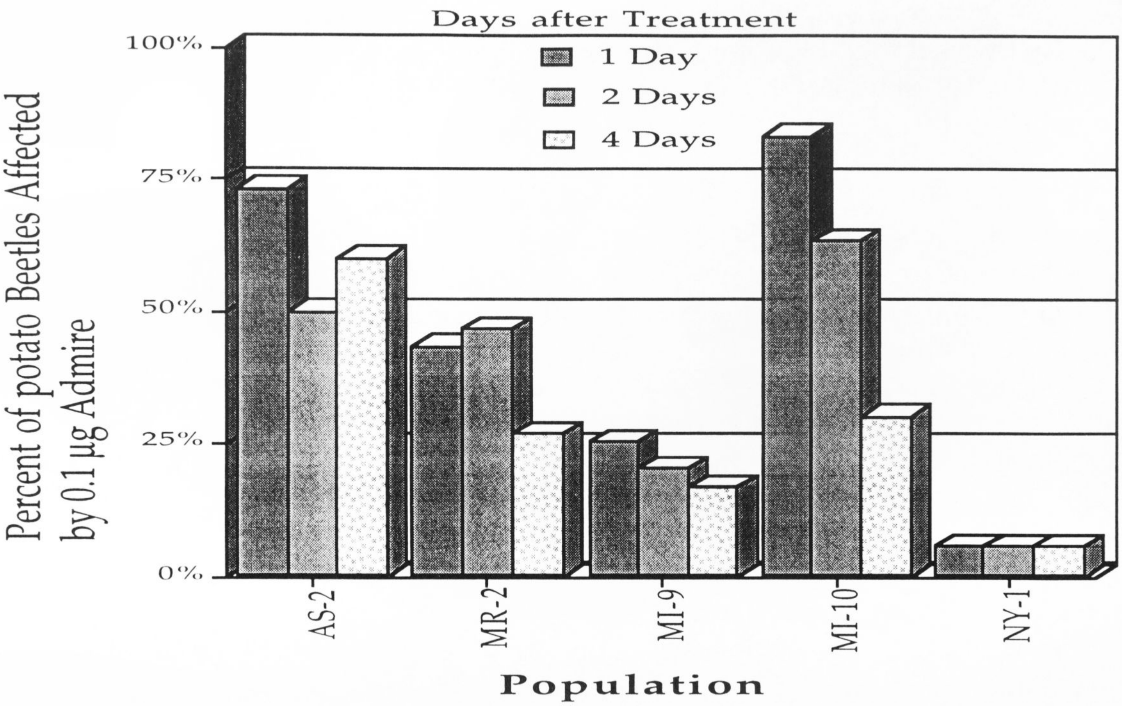


Figure 3. Recovery of Admire-resistant Colorado potato beetles from Admire poisoning. The percentage of beetles affected by 0.1 micrograms of Admire 1, 2 and 4 days after treatment is compared. Two resistant laboratory-selected strains (AS-2, MI-2), two field populations collected in Michigan (MI-9, MI-10) and one field population collected in Long Island, NY (LI-1) are shown.

Feeding Study. Low levels of resistance were found in our laboratory strains of Colorado potato beetle and in field populations. Such resistance would not necessarily lead to survival on Admire-treated plants when the level of Admire in the plant was high (i.e., early in the season). As the potato plant grows, the level of Admire in it declines, to a point where potato beetles are able to survive on it. Colorado potato beetles with low levels of resistance would be able to survive at higher levels of Admire, and thus sooner in the season, than susceptible beetles. This earlier survival may be a factor in cooler than normal years, where emergence from overwintering is attenuated.

To test this idea, potato foliage was collected, at weekly intervals, from potato plants that were treated with Admire at planting. Foliage was then fed to Colorado potato beetles in the laboratory. Three different laboratory strains were used: two strains with low levels of resistance to Admire (MR and AR), and one susceptible strain (UP) Foliage was also collected from untreated potato plants and was fed to beetles as a control. Beetles fed Admire-treated foliage were checked every few days and were classified as dead (no movement, even when pinched, elytra dark), affected (on back and shaking and/or unable to walk forward one body length in a coordinated fashion), or walking (able to walk forward normally at least one body length).

Potato foliage was collected from three potato fields in Montcalm County. The first was at the MSU Montcalm Research Farm, Entrican, MI. Potatoes were planted on 21 May, 1997. The second and third fields (Field B and Field C) were on growers' farms. Field B was planted on 4 May, 1997 and field C was planted on 23 April, 1997.

On 25 June, 1997, foliage was collected from Admire treated plants and untreated plants from the MSU Montcalm Research Farm (MRF) and fed to MR-R, AR and UP beetles (35 days after planting). On 1 July, 1997 foliage was collected from Admire-treated plants and untreated plants from the MRF (41 days after planting) and from Field B (64 days after planting). This foliage was fed to MR-R, AR and UP beetles. On 8 July, 1997 foliage was collected from Admire-treated plants and untreated plants from the MRF (48 days after planting), from Field B (71 days after planting), and from Field C (76 days after planting) This foliage was fed to MR-R, AR and UP beetles.

At each date, a lower proportion of resistant potato beetles were affected by Admire-treated foliage than susceptible beetles (Table 1 Figure 4). As the season progressed, this difference between susceptible and resistant potato beetles remained. In addition, fewer beetles were affected by Admire with each successive week. By 41 days after planting, for example, Admire-treated foliage collected from the MSU Montcalm Research Farm affected nearly half of beetles from the susceptible strain (UP 40%), but less than 20% of the resistant strains.

Table 1. Proportion of Colorado potato beetles that were dead or affected after being fed Admire-treated foliage. The MR and AS strains have been selected in the laboratory for resistance to Admire. The susceptible UP strain has never been exposed to Admire.

	Percent of potato beetles dead or affected		
Control	**25 June**	**1 July**	**8 July**
MR	0.0%	0.0%	0.0%
AR	0.0%	0.0%	0.0%
UP	0.0%	0.0%	0.0%
MRF	**35 dap**	**41 dap**	**48 dap**
MR	46.7%	16.7%	6.7%
AR	66.7%	13.3%	16.7%
UP	73.3%	40.0%	30.0%
Field B		**64 dap**	**71 dap**
MR	xxx	6.7%	0.0%
AR	xxx	0.0%	3.3%
UP	xxx	10.0%	3.0%
Field C			**76 dap**
MR	xxx	xxx	0.0%
AR	xxx	xxx	0.0%
UP	xxx	xxx	33.0%

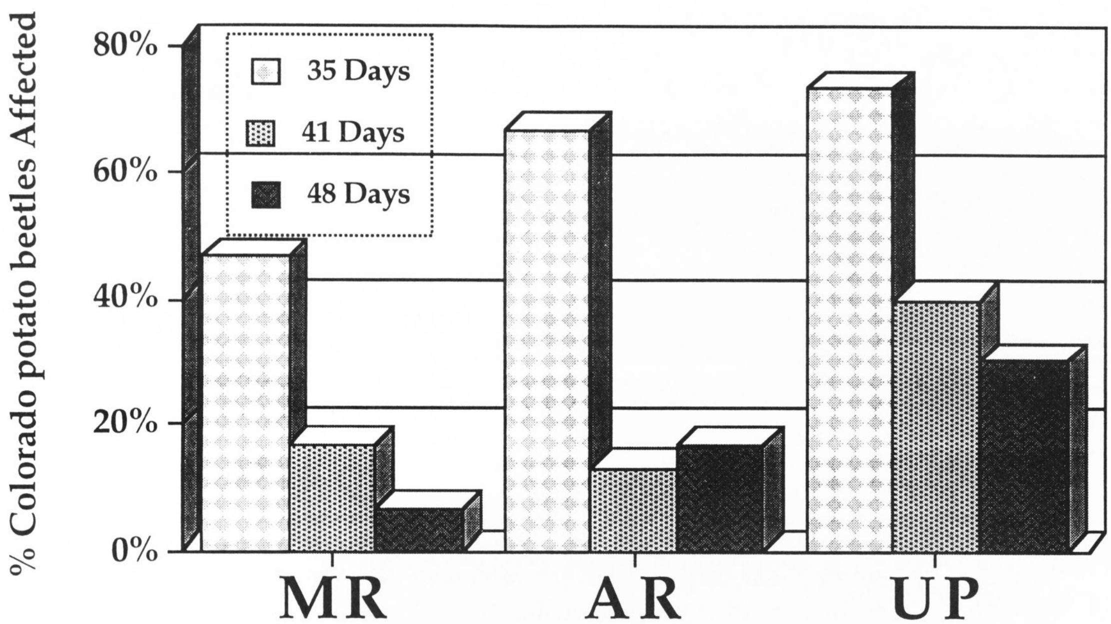


Figure 4. Percentage of Colorado potato beetles affected (poisoned or dead) when fed potato foliage that was treated with Admire at planting and collected at various intervals after planting. All Colorado potato beetles used were from laboratory-reared strains. AR and MR are Admire-resistant strains. UP is an Admire-susceptible strain.

Admire resistance management. Field populations from Michigan and Minnesota showed low levels of resistance to Admire (about 4 times more resistant than susceptible strains). These levels may be sufficient to shorten the length of control afforded by Admire when applied at planting. Even 2-3 weeks shorter control might mean survival of some late-emerging overwintered beetles. Several of the fields where we collected beetles in 1997 required treatment to control summer adults. Studies are continuing to discover how low levels of resistance and affect the length of control.

We are also continuing to test potato beetles in the laboratory to understand how resistance to Admire occurs, and how fast it might increase. The answers to the questions are important if we are to understand how we can manage and slow the development of resistance to Admire.

Colorado potato beetle will continue to adapt and show increased resistance if control is entirely reliant on Admire. Crop rotation, alternation of Admire/Provado treatment with other new insecticides, and the use of resistant potato varieties will reduce the impact of Admire resistance on the potato industry.

_Bt_ transgenic potato plants as a barrier to Colorado potato beetles

In 1997, we again tested Bt transgenic potato plants as a border barrier against Colorado potato beetle. Previous research has indicated that Colorado potato beetles will quickly move through barriers up to 24 rows of Bt transgenic plants.

Genetically-engineered Atlantic potatoes (NewLeaf®, NatureMark) and regular Atlantics were planted on two commercial potato farms in Montcalm County, Michigan. Site 1 was planted on 4 May, 1997. The first 36 rows of the field were Atlantic NewLeaf potatoes, and the rest of the field was normal Atlantics. Site 2 was planted on 23 April, 1997. The first 96 rows in this field were Atlantic NewLeaf potatoes and the rest of the field was normal Atlantics.

Colorado potato beetles were collected from the MSU Montcalm Research Farm and brought back to the laboratory for treatment, marking and release. One half of the beetles were kept at room temperature for one week without food, and the other half were kept at room temperature for one week and provided with fresh potato foliage daily. Beetles were marked with fluorescent paint pens (DecoColor®, Uchida of America, Corp.) according to treatment and day or release. Beetles were transported to the field for release in ice-filled coolers (to slow down movement and make them less likely to immediately fly away after being released). Both starved and fed potato beetles were released at two different points at Site 1. The first was immediately to the East of the field, in front of the first row of Bt potatoes. The second release point was in row 20. Beetles were released on 30 June and 7 July 1997. At site two, beetles were released immediately to the East of the field across a shallow ditch from the first row of Bt potatoes. Potato beetles were released at site two on 8 July 1997 only. To check for movement of marked Colorado potato beetles through the Bt transgenic plants, we examined a 150 feet section of selected potato rows opposite the release point for the presence of marked potato beetles. Dead marked potato beetles were removed, but live marked beetles were left in the field. Row 1 was searched each time, as was row 19 and row 21 at Site 1 only (at this site the second release point was in row 20). At Site 1, potatoes were examined for marked beetles on 1, 3, 7, 9 10, 15 and 17 July. At Site 2, potatoes were searched for marked potato beetles on 9, 11 and 16 July.

At Site 1, a total of 1497 marked beetles were released on 30 June and 1174 marked beetles were released on 7 July. Approximately between 1% and 20% of these beetles were found each day of the search (Table 2 and 3). Overall, more starved beetles were found than fed beetles each day. For the first few days following release, more potato beetles that were released adjacent to the first row of potatoes were found than beetles released into row 20. By a week after release, the percentages were nearly equal. This may be because potato beetles released into row 20 remained in that row for several days (which was not searched for marked beetles) before moving on .

The difference in the percentage of marked Colorado potato beetles found between fed and starved beetles exists only for beetles released adjacent to row 1. There is no obvious and consistent difference in the percentage of potato beetles found between fed and starved beetles released into row 20. This is true for both releases and for all dates.

Table 2. Percent of marked Colorado potato beetles found after being released into and across from a Bt transgenic potato border. Site 1.

	Days After Release (30 June)					
	1 day	3 days	7 days	9 days	10 days	15 days
Fed Beetles	6.6 %	8.7%	3.4 %	1.8 %	1.3 %	0.3 %
Starved Beetles	9.0 %	12.8 %	8.2 %	5.0 %	4.2 %	1.0 %
Row 1	12.6 %	12.3 %	5.6 %	3.0 %	2.6 %	0.3 %
Row 20	3.0 %	9.1 %	5.9 %	3.8 %	2.9 %	0.9 %
Row 1 Fed	9.7 %	7.7 %	2.8 %	1.5 %	1.0 %	0.3 %
Row 1 Starved	15.9 %	17.7 %	8.7 %	4.7 %	4.4 %	0.3 %
Row 20 Fed	3.2 %	9.7 %	4.0 %	2.2 %	1.6 %	0.3 %
Row 20 Starved	2.8 %	8.5 %	7.7 %	5.4 %	4.1 %	1.6 %

Table 3. Percent of marked Colorado potato beetles found after being released into and across from a Bt transgenic potato border. Site 1.

	Days After Release (July 7)		
	2 days	3 days	8 days
Fed Beetles	12.1 %	6.3 %	0.5 %
Starved Beetles	26.4 %	18.2 %	3.6 %
Row 1	24.6 %	17.2 %	1.7 %
Row 20	13.7 %	7.1 %	2.5 %
Row 1 Fed	9.9 %	6.8 %	0.3 %
Row 1 Starved	39.7 %	27.9 %	3.1 %
Row 20 Fed	14.2 %	5.8 %	0.6 %
Row 20 Starved	13.0 %	8.5 %	4.6 %

At Site 2, a total of 1,147 marked beetles were released on 9 July. Approximately between 0.6% and 15% of these beetles were found on any given day As with Site 1, more starved beetles were found each day than were fed beetles.

Table 4. Percent of marked Colorado potato beetles found after being released across from a Bt transgenic potato border. Site 2.

	Days After Release (July 9)		
	1 day	3 days	8 days
Fed Beetles	15.5 %	4.1 %	0.6 %
Starved Beetles	11.8 %	8.2 %	2.5 %

We were surprised to find more starved potato beetles than fed potato beetles (Figure 5). We expected that starved beetles would be more likely to fly, and therefore we would find fewer of them. It may have been that starved beetles react differently than fed beetles when exposed to Bt transgenic potato plants. Alternatively, the potato beetles that we starved were overwintering adults that had been collected from plants. It may be that some feeding on potatoes reduces the inclination of overwintering potato beetles to fly when starved.

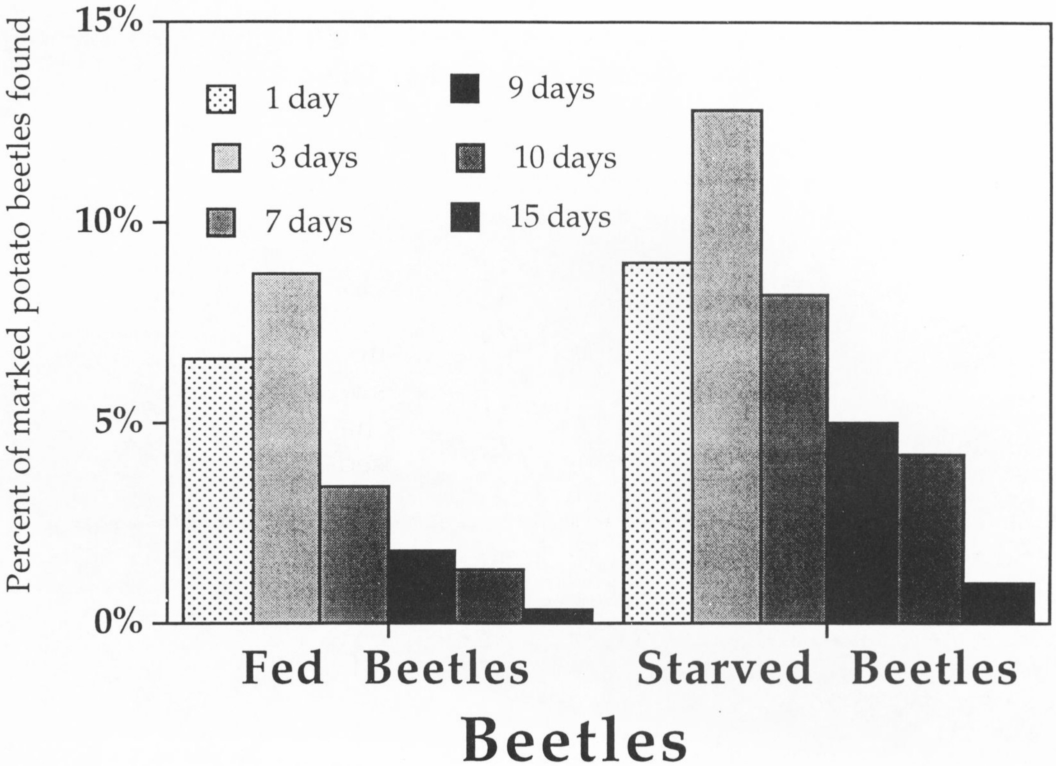


Figure 5. Percent of marked, released Colorado potato beetles that were found in Bt transgenic potatoes at varying intervals after release. "Fed" potato beetles were provided with potato foliage for at least seven days prior to release. "Starved" beetles were kept in the same environment, but without access to foliage, for seven days prior to release.

In any case, the data seems to indicate that starved beetles are more attracted to plants than fed beetles. They may move to plants more readily, including Bt transgenic plants, and they may remain on Bt transgenic plants longer than fed beetles. The reason there was not a difference between fed and starved potato beetles found when they were released into row 20 may have been that these beetles had a ready food source (the plants in row 20) and did not need to move.

We were also surprised to find how long marked potato beetles remained on the Bt transgenic potato plants. Even 10 days after release, 1/3 as many marked potato beetles were found as were found 1 day after release. These results contrast with other findings that indicate that Colorado potato beetles move quickly through Bt transgenic plants.

Insecticide Efficacy Tests for Colorado Potato Beetle Control

Seventeen insecticide treatments were tested at the MSU Research Farm, in Entrican, MI, for the control of Colorado potato beetles (CPB). ' Snowden' potatoes were planted 12 inches apart with a 34 inch row spacing on 21 May. Treatments were replicated four times and assigned to plots in a RCB design. Plots were 45 ft long and three rows wide. The Admire, CGA 293343 4FS, CGA 293343/CGA 173506 1.5%, CGA 293343/CGA173506 2.0%, and Temik treatments were all applied at planting. The first foliar treatment was applied at 40% CPB hatch, on 23 June using a tractor-mounted sprayer (30 gal/acre, 40 psi). Subsequent first generation sprays were applied on 1 July and 7 July. Agrimek and Agenda were applied on 23 June and 7 July only. Spintor (two rates) was applied on both 23 June and 27 June. Alert and Acrobat were applied on each of the spray dates Insecticide effectiveness was determined by counting various stages of CPB on four (25 June) or three (3 July, 10 July, and 18 July) randomly selected plants from the middle row of each plot. Because CPB pressure was light due to a cooler than normal spring and early summer, second generation sprays were not applied. All plots were sprayed with Agrimek on 23 July to suppress second generation potato beetles. Each plot was assessed for defoliation on 3 July and 10 July. The middle row of potatoes from each plot was harvested on 4 Sept, separated by size, and weighed.

There was a significant difference in the number of small and large larvae per plant among treatments and control plots. Admire had the fewest number of Colorado potato beetle throughout the season. Temik and the CGA products also did well throughout the season. The high number of Colorado potato beetles found in the Agrimek data may be due to the timing of the insecticide applications. There were also significant differences in defoliation and yield with Admire and Temik performing the best.

Table 5. Mean defoliation and harvest weights for 17 different insecticide treatments.

		Mean yield (lbs) ± SEM[a]			Defoliation Rating[c]	
Treatment	Rate (per Acre)	Size A	Size B	Total	3 Jul	10 Jul
Untreated		33.7±9a	5.7±.6bcde	57.0±9.6	1.4	1.75
Agrimek	8.0 oz prod	45.3±6.6bcdef	4.0±.2a	49.3±6.8	1.8	1.5
Admire[b]	0.9 fl oz/ 1000 ft	61.5±12f	4.5±.5ab	66.0±12.5	0.0	0.0
Admire[b]	0.9 fl oz/ 1000ft	51.0±5.9cdef	5.4±.4bcde	55.4±6.3	0.0	0.0
Confirm[d]	4.0 oz prod					
Temik[b]	3.0 lb AI	61.8±10.4f	4.8±.5abc	66.6±10.9	0.0	0.0
Agenda if needed	0.025 lb AI					
Agenda (EXP 60154A)	0.050 lb AI	47.5±13.5bcde	5.1±.5abcde	52.6±14	0.9	1.12
Alert low	0.10 lb AI	56.7±12.7cdef	5.1±.5abcde	61.8±13.2	1.1	1.12
Alert high	0.20 lb AI	47.5±7.5bcdef	4.8±.6abc	52.3±8.1	1.1	0.87
Alert low	0.10 lb AI	51.4±8.2cdef	5.1±.2abcde	56.5±8.4	1.1	1.0
Acrobat[e]	1.553 AI					
Alert high	0.20 lb AI	50.4±6.9bcdef	4.8±.1abc	55.2±7	1.0	1.12
Acrobat[e]	1.553 AI					
Trigard 1st spray	280 g AI/H	43.2±11.3abc	5.1±.6abcde	48.3±11.9	1.0	1.12
Trigard	140 g AI/H					
CGA 293343	8.0 oz/ 100 wt	57±9.8ef	6.4±.9de	63.4±10.7	0.0	0.0
CGA 173506 1.5%[b]						
CGA 293343	8.0 oz/ 100 wt	43± 6.7bcde	6.4±.4e	49.4±7.1	0.25	0.25
CGA 173506 2.0%[b]						
Spinosad low	0.053 lb	36.6±3ab	4.9±.5abcd	41.5±3.5	0.75	1.0
Spinosad high	0.07 lb AI	39.8± 3.7abcd	5.0±.4bcde	44.8±4.1	0.75	1.0
Temik 15G[b]	3.0 lb AI	59±3.0f	6.0±.5cde	65.0±3.5	0.0	0.5
CGA 293343 4FS[b]	1.4g ai/100m	54.5±6.5def	5.2±0.3abcde	59.7±6.8	0.0	0.0

Means within a column followed by different letters are significantly different ($p<0.05$, Fisher's Protected LSD)

[a]Data transformed for analysis with log (x + 1)

[b]treatment applied in furrow at planting

[c]Defoliation Rating. 0-1, no defoliation; 1-2, 0%-5% defoliation; 2-3, 5%-25% defoliation (some whole leaflets eaten); 3-4, 25%-50% defoliation (some whole leaves eaten); 4-5, 50%-100% defoliation (whole stems bare)

[d]treatment applied for European Corn Borer test

[e] was tested to see if the addition of Acrobat affected the effectiveness of Alert

Table 6. Mean number first generation Colorado potato beetles per plant for 17 different insecticide treatments.

Treatment	Rate (per Acre)	Mean number of 1st generation CPB per plant ±SEM[a]			
		Egg Masses	Small Larvae	Large Larvae	Adults
Untreated		27.0±18.4b	32.0±11.8d	23.2±12.2efg	2.7±1.2c
Agrimek	8.0 oz prod	3.5±3.5ab	20.2±7.4cd	29.5±5.7g	1.2±0.9abc
Admire[b]	0.9 fl oz/ 1000 ft	0.0±0.0a	0.0±0.0a	0.0±0.0a	0.5±0.5ab
Admire[b]	0.9 fl oz/ 1000ft	0.0±0.0a	0.0±0.0a	0.0±0.0a	0.5±0.5ab
Confirm[d]	4.0 oz prod				
Temik[b]	3.0 lb AI	0.5±0.3a	10.5±10.5ab	0.25±0.25ab	0.25±0.25ab
Agenda if needed	0.025 lb AI				
Agenda (EXP 60154A)	0.050 lb AI	6.0±15.6ab	4.2±3.3ab	6.0±3.5cdef	0.7±0.5abc
Alert high	0.20 lb AI	10.5±6.3ab	15.0±11.1bcd	3.0±2.0abcd	0.5±0.3ab
Alert low	0.10 lb AI	2.5±2.5ab	10.5±4.9bcd	6.0±4.3cde	0.7±0.5abc
Alert low	0.10 lb AI	4.5±4.5ab	5.7±5.1ab	6.7±2.7def	0.0±0.0a
Acrobat[e]	1.553 AI				
Alert high	0.20 lb AI	1.25±0.9ab	2.0±1.0ab	5.4±4.2bcd	0.2±0.2ab
Acrobat[e]	1.553 AI				
Trigard 1st spray	280 g AI/H	5.5±4.8ab	19.7±11.8bcd	13.25±1.7fg	1.2±0.5bc
Trigard	140 g AI/H				
CGA 293343	8.0 oz/ 100wt	1.0±1.0a	0.0±0.0a	0.0±0.0a	1.2±0.5bc
CGA173506 1.5%[b]					
CGA 293343	8.0 oz/100wt	0.0±0.0a	0.25±0.25a	0.75±0.5abc	0.5±0.5ab
CGA173506 2.0%[b]					
Spinosad low	0.053 lb AI	11.75±11.4ab	7.7±5.6abc	3.75±2.2bcd	1.0±0.7abc
Spinosad high	0.07 lb AI	0.5±0.3a	15.5±8.4bcd	1.7±1.1abcd	0.5±0.3ab
Temik 15G[b]	3.0 lb AI	0.0±0.0a	3.0±3.0ab	0.0±0.0a	0.2±0.2ab
CGA 293343 4FS[b]	1.4g AI/100m	0.0±0.0a	0.0±0.0a	1.0±1.0abc	2.0±0.4c

Means within a column followed by different letters are significantly different ($p<0.05$, Fisher's Protected LSD)

[a]Data transformed for analysis with log (x +1)

[b]treatment applied in furrow at planting

[d]treatment applied for European Corn Borer test

[e] was tested to see if the addition of Acrobat affected the effectiveness of Alert

Funding MPIC

COLORADO POTATO BEETLE RESISTANCE MANAGEMENT
1997 REPORT

Mark E. Whalon, Mike Bush, David Mota-Sanchez, and Utami R. DiCosty
Department of Entomology and Pesticide Research Center
Michigan State University, East Lansing, MI

Cooperators:
Ed Grafius, Department of Entomology, Michigan State University
Dr. P. Wegorek, Institute of Plant Protection in Poznan, Poland.

INTRODUCTON

Colorado potato beetle, *Leptinotarsa decemlineata* Say (CPB) is one of the principal potato pests in the U.S. and many areas of the world. In Michigan, CPB has developed resistance to nearly every insecticide applied for its control. As soon as imidacloprid (Admire & Provado, Bayer Corp) was registered for potatoes, it became the sole means to control pesticide resistant-CPB in Michigan. Prior to the release of this insecticide, the annual losses attributed to CPB in Michigan were estimated at 14% of gross crop value or $13 million. We estimate that over 90% of Michigan growers used Admire/Provado to control CPB in 1996. Most of Michigan's potato growers are dependent on Admire/Provado to control CPB resistant to all other insecticides. Admire/Provado are insecticides, that target the nicotinic acetylcholine receptors in insect nervous systems.

Another nicotine-like insecticide is bensultap (Bancol, Takeda Chemical Industry, Ltd). Bancol is used to control Colorado potato beetle (CPB) in Europe. Researchers in Poland reported that CPB shows 18-fold resistance to Bancol. Since both Bancol and Admire are neriestoxins that affect the nicotine acetylcholine receptors, the mechanism of resistance to one pesticide may convey resistance to the other-a phenomenon known as cross-resistance. Thus, we examined the resistance mechanism of the beetle from Europe (Poland) towards Bancol as a model to understand the likelihood of resistance development in CPB towards Admire. In 1996, low levels of resistance to Admire were detected in a field population from an Admire-treated commercial potato field in Michigan. The focus of this project was to examine aspects of insect resistance and develop strategies to delay the development of resistance in CPB to nereistoxins before these resistances occur in the field.

A. SELECTION FOR RESISTANCE IN COLORADO POTATO BEETLE TO ADMIRE

Our objective was to determine the levels of CPB resistance in Michigan potato fields treated with Admire/Provado. This information will provide researchers with a measure of variation in CPB response to Admire/Provado and the potential for CPB to develop resistance to these widely applied insecticides. This information will also provide a base-line for future resistance monitoring.

Populations. We collected six adults populations of CPB from Michigan, four of them with a history of at least three Admire/Provado treatments. We also received a population from Beckler, Minnesota. The susceptible colony (S59) used as a control was collected in 1986 in Michigan and it has been reared for 59 generations without exposure to insecticides.

Bioassays. Leaf-dip bioassay was used to evaluate CPB response to Admire. Potato petioles (5 leaflets) were inserted into 2 ml vials filled with water, dipped five times into the Admire solution and allowed to dry before being transferred to individuals petri dishes (15 cm diameter). Eight to ten CPB adults were exposed for 4 to days on the treatments. Five to six dilutions of Admire were tested in each population. After exposure, the adults were placed on untreated foliage. We used 3 replications per treatment, except when there were too few beetles, in which case we used 2 replications. In previous bioassays we observed that some "dying" beetles recovered 3 to 10 days after exposure, thus we assessed mortality 10 days after the treatment. Some adults may not die in 10 days, but are inactive or 'dying' with very little chance to recover. Only those beetles that could walk and hold onto a pencil were considered alive and survivors from the treatment. The results of mortality were analyzed by probit analysis.

Table 1. Susceptibility of adults of Colorado Potato Beetle to Admire. The resistance ratio indicates how much more Admire is needed to kill 50% of the beetle populations compared with the susceptible population is needed (S59).

Population	Number of beetles used for bioassay	Estimated Concentration that kills 50 % (LC_{50}) of the treated beetles. mg AI per liter	Resistance Ratio
S59	138	10.48	1
UP	93	33.98	3.2
Minnesota	130	63.12	6.0
Neff	145	78.76	7.5
Rod	87	85.73	8.1
3 K	180	105.91	10.1
13M	178	167.89	16.0

Results. The LC_{50} for adults from the susceptible laboratory strain was 10.5 mg AI Admire/liter. The responses of all other colonies were significantly different and the resistance ratios ranged from 3.2 to a high of 16.0-fold in a population collected in Michigan potatoes. Admire/Provado resistance is developing in field populations of CPB. An alternative CPB control needs to be considered to reduce the rate of resistance to Admire, thus to prolong the effectiveness of the insecticide.

B. RESISTANCE AND CROSS-RESISTANCE OF COLORADO POTATO BEETLE TO NICOTINYL INSECTICIDES (NEREISTOXINS)

We currently maintain laboratory strains of CPB resistant to Admire here at Michigan State. Recent studies at the Institute of Industrial Organic Chemistry in Warsaw, Institute of Plant Protection in Poznan and Potato Research Institute in Bonin, Poland, found field CPB populations with resistance to Bancol. Resistance levels as high as 18-times have been reported in Poland, Czech Republic and Hungary (Przybysz, E., P. Wegowrk & M. Pawinska, personal communication). We have been able to maintain at least one Bancol-resistant laboratory strain from Winnagora, Poland here at MSU. We will use these colonies to determine the resistance levels and cross-resistance patterns of CPB to Admire and Bancol. We continue to examine the genetic basis of laboratory-selected resistance to nereistoxin in CPB. Once the genetic of the resistance to nereistoxin is known, we could develop strategies (for example: preservation of susceptible gene or refugee) to slow development of resistance to Admire in CPB.

Insecticides:
Admire/Provado:Soil, seed or foliar treatment of this insecticide is effective to control many insect species. Highly systemic, particularly from the seed and soil treatment. The formulation can be wettable powder, flowable or granular. Basic producer is Bayer Corp.
Bancol.: This insecticide is effective against beetles and caterpillars especially beet tortoise beetle, Colorado potato beetles, corn weevil, diamond back moth, grape berry moth, rice stem borers, etc. The formulations can be dust, granule, or wettable powder. Basic Producer is Takeda Chemical Industries, Ltd. (Japan). This pesticide is not available in the US, but is widely used in Europe to control Colorado potato beetle.

History of colonies:
SUS: CPB colony that has been maintained in laboratory for 62 generations. This colony has never been exposed to Admire/Provado or Bancol.
13M: Collected from Michigan in summer 1997. The adults showed 16X more resistance to Admire than the SUS colony. Second generation of selected colony was used for the study.
WINR: Collected from Winna Gora, Poland in summer 1996. This population was controlled with Bancol in 1994-1996. The adults showed low level of resistance (Dr. P. Wegorek, personal communication). The second instars were selected with Bancol (LC_{50}). Adult emergence ~ 35%. Third generation of selected colony was used for the study.
WIN: The origin is the same as WINR, but it has never been selected with Bancol in our laboratory.

Selection: To select beetles, potato petioles (5 leaflets) were inserted into 2-ml vials filled with water, dipped five times into the Admire or Bancol solution (LC_{50}), and allowed to air dry before being transferred to individual petri-dishes (15 cm diameter). Twenty second instars (3 day old) were placed on each leaf and held at 25 ± 2°C and a photoperiod of 16:8 (L:D) h in a growth chamber. Foliage was checked daily and water was replenished as needed. Larvae were placed on the foliage within 30 min after the insecticides application had air dried; they were allowed to move and feed freely. After exposure to Admire or

Bancol for 96 hours, surviving larvae were transferred to untreated foliage of potted potato plants within rearing cages for 10-14 days until pupation. The number of larvae survived and adults emerged were recorded.

Bioassay:

Activity of Admire or Bancol on Colorado potato beetle was assessed with 3 day old larvae. Five or six serial dilutions of Admire or Bancol were made to expose CPB to solutions ranging from 0.05 to 16 times the LC_{50}. Potato foliage was trimmed to the terminal five leaflets and the petiole was inserted into a 2-ml vial containing water. Each petiole was dipped five times into one of Admire or Bancol solutions and allowed to air dry before being placed in a 15-cm petri-dish. At least five petioles were prepared per concentration; we used no more than 10 larvae on each leaf at each concentration and at least 30 larvae per concentration. Larvae were held at 25 ± 2°C, 50 - 60% RH, and a photoperiod of 16:8 (L:D) h in a growth chamber. Mortality was assessed 96 h after treatment. A larva was considered dead if it does not move its legs when probed with soft brush. The mortality data was subjected to probit analysis to detemine the LC_{50} values.

Results.

Table 2. Admire and Bancol concentrations that kill 50% (LC_{50}) of treated second instar larvae from CPB colonies susceptible and resistance to these insecticides. The lower the LC_{50} the more susceptible the population.

CPB STRAIN	LC_{50} mg/L (95% fiducial limit)[1]	
	Admire	Bancol
SUS (Susceptible)	0.103 (0.047-0.194)	0.0081 (0.0022-0.0136)
13M (Resistance to Admire)	0.0012 (0.0009-0.0018)	0.0108 (0.0086-0.0149)
WINR (Highly resistance to Bancol)	0.124 (0.068-0.226)	0.020 (0.001-0.057)
WIN (resistance to Bancol)	0.0044 (0.0031-0.0063)	0.0013 (0.0007-0.0031)

[1] When the fiducial limit of a strain does not overlap with the fiducial limit of the susceptible strain, the strain is considered significantly resistant.

Resistance Level:

	Admire	**Bancol**
Most Resistant	SUS, 13M	WINR
↓		
↓		
↓	WIN	13M
↓		
↓		
Most Susceptible	WINR	SUS, WIN

Summary of results:

1. There was a negatively correlated cross-resistance between Admire and Bancol in CPB second instars or larvae.
2. 13M second instars did not show the same level of resistance to Admire as the adults, but 15 times more resistant than the WINR.
3. WINR colony was 11 times more resistant to Bancol than SUS.
4. WIN was slightly more resistant to Admire than the WINR. The increase of resistance to Bancol in WINR increases the sensitivity to Admire.
5. 13M was more sensitive to Bancol than the WINR.
6. Admire and Bancol probably act on different active sites on the nicotinic acetylcholine receptors in CPB.

Conclusion.

We have established of laboratory colony of CPB collected in Winnagora, Poland, reported as resistant to Bancol. Since Bancol is another nereistoxic insecticide with a similar mode of action as Admire—a nicotinic acetylcholine receptors, we anticipated cross-resistance. Leaf-dip bioassays confirmed 11-times resistance to Bancol in 3-day-old larvae from this colony. Leaf-dip bioassays with 3-day-old larvae revealed that Bancol-resistant CPB were 15-times more susceptible to Admire than the susceptible laboratory colony. To our surprise, these initial results indicate a negative cross-resistance between CPB second instars resistance to Admire and Bancol. Adults and larval (young) stages may have different physiological properties, thus may show difference responses towards Admire and Bancol. Further study needs to be done to observe the cross-resistance in adult CPB to Admire and Bancol. If the response in adult CPB is consistent with the response in the larvae, this indicates that despite similarity in the target site (nervous system), Admire and Bancol attack different active sites. Admire and Bancol (or other nereistoxic insecticides) can be applied alternately to avoid intense selection pressure from either insecticide, therefore prolong the effectiveness of both insecticides. We are in the process of selecting colonies with either Bancol or Admire to confirm cross-resistance spectra, inheritance and mechanism of resistance.

Funding MPIC

1997 NEMATOLOGY RESEARCH REPORT

George W. Bird, Fred Warner and John Davenport
Department of Entomology
Michigan State University
East Lansing, MI

The 1997 Michigan State University Potato Nematode Program consisted of four separate projects. The objective of this report is to present the results of these research activities to the Michigan Potato Industry Commission (MPIC). The report is presented in the following four sections:

- Varietal Susceptibility to Nematodes (Federal Grant)
- 1997 Nematicide Evaluation Trial (MPIC)
- Long-Term Potato Farming System-Nematode Management Project (MPIC)
- Potato-Carrot Rotation System Research (MPIC and MI Carrot Research Committee)

VARIETAL SUSCEPTIBILITY TO NEMATODES.- Although the Michigan State University Nematology Program has had a potato research project for more than 25 years, 1997 was the first year of a formal program designed to evaluate the susceptibility of potato germplasm to plant-parasitic nematodes and soil-borne fungi: with the overall subproject consisting of five objectives. Development of the interactive database of potato germplasm with known resistance, tolerance and susceptibility to *Pratylenchus* spp., *Meloidogyne* spp., *Verticillium* spp., *Ditylenchus destructor*, *Globodera rostochiensis* and *G. pallida* has been initiated and will be completed and available on the MSU Department of Entomology website by June 1, 1998. The site for the permanent *P. penetrans-V. dahliae* nursery was selected at the Montcalm Potato Research Farm in Entrican, Michigan, and planted to potato in 1997, for development of population densities of these organisms suitable for use in the 1998 potato germplasm evaluation program. It was determined in 1997 that most of the breeding lines reported in the literature as having tolerance or resistance to *P. penetrans* and other *Pratylenchus* spp. are not being propagated for further evaluation in relation to future potato cultivars. Seven existing cultivars (Atlantic, Chieftain, Onaway, Russett Burbank, Russett Norkotah, Shepody and Snowden) were evaluated in relation to their susceptibility to *P. penetrans* and *V. dahliae* under field conditions at the MSU Montcalm Potato Research Farm.

In the first test, mid-season population densities of *P. penetrans* recovered from soil and root tissue associated with Shepody grown in the absence of aldicarb were 65.2% less than the mean density recovered from the other six cultivars, and at-harvest stem colonization by *V. dahliae* was 53.3% lower, compared to the other cultivars (Table 1). The results were the same for Shepody in the second test in relation to *V. dahliae* (49.2% less) when the plants were grown in the presence of aldicarb. The number of *V. dahliae* colonies recovered from stem tissue was lower for Shepody and Chieftain than for the other five cultivars. Compared to the other six cultivars, the sum of the U.S. No. 1 and Jumbo tuber yields of Shepody were competitive (Table 2).

Twelve of the breeding lines evaluated at MSU in 1997 exhibited less severe early-die symptoms than the other lines. These lines, including E-018-1, will be field tested in 1998 in relation to their susceptibility to *P. penetrans* and *V. dahliae*. The glucose-oxidase gene has been incorporated into 21 potato lines. Tissue culture plantlets of one or more of these will be evaluated in 1998, in relation to susceptibility to *P. penetrans* and *V. dahliae* under both tissue culture and field conditions.

1997 POTATO NEMATICIDE EVALUATION TRIAL.- Snowden was used in the 1997 Potato Nematicide Trial. One soil fumigant, three non-fumigant nematicides, one biopesticide and one soil amendment were evaluated in this experiment. Each treatment was replicated six times in a randomized block design. Population densities of the root-lesion nematode (*P. penetrans*) were uniform throughout the experimental site at the beginning of the spring of 1997 (Table 3). Data were also recorded for other microorganisms recovered from this site. Application of Vapam at 50 gallons per acre broadcast provided excellent and immediate nematode population reduction. This was also reflected in the mid-season and end-of-season population densities of this nematode. Mid-season population density reduction of this nematode was also observed for the combined Mocap and Vydate treatment, but not for Temik or ABG 9088 (Diterra). End-of-growing season population densities were lowest for Vapam, intermediate for Temik and Mocap-Vydate, and highest for the control, both rates of ABG 9008 and the compost treatment. Tuber yields of Snowden were directly related to the degree of nematode control obtained (Table 4). The largest tuber yields were from plants grown in soil treated with Vapam, intermediate for tubers grown in the presence of Temik or Mocap-Vydate, and lowest for these grown with the two rates of ABG9008, compost and control.

LONG-TERM POTATO FARMING SYSTEM-NEMATODE MANAGEMENT PROJECT.- The Long-Term Potato Farming System-Nematode Management Project was initiated at the Michigan State University Montcalm Potato Research Farm in Entrican, Michigan in 1991. The assumption for initiation of this project was that relatively few nematicides would be available for use in Michigan potato production by the year 2000, and there was a need to develop highly productive and profitable alternative nematode management systems to replace current technology. The project consists of ten potential potato farming systems (Table 5). Prior to 1997, the research was based primarily on rotation crops; however, in 1995, the soil in some of the systems were amended with compost. Based on the results through the 1996 growing season, the research was modified beginning in 1997 to consist of the following two soil nutrition programs (Conventional and Alternative) with five farming systems maintained under each of the programs:

1997 Conventional Soil Nutrition Program (Systems 1, 2, 4, 5 and 9)

Systems 1, 4, 5 & 9

2.0 tons per acre of dolomite lime pre-plant incorporate
250 lbs per acre 0-0-60 at plow-down (0-0-150 nutrients)
300 lbs per acre of 20-10-10 in-furrow (60-30-30 nutrients)
225 lbs per acre of 45-0-0 at hilling (101-0-0 nutrients)

System 2

200 lbs per acre of 20-10-10 pre-plant incorporated
10 lbs per acre of borate pre-plant incorporated

1997 Alternative Soil Nutrition Program (Systems 3, 6, 7, 8 and 10)

Systems 3 & 10

2.0 tons per acre of limestone flour (calcium carbonate) pre-plant incorporated
5.0 tons per acre of cow manure compost pre-plant incorporated
0.5 tons per acre of blood meal at hilling

Systems 6 & 7

2.0 tons per acre of limestone flour (calcium carbonate) per-plant incorporated
0.5 tons per acre Glauconite (greensand) pre-plant incorporated

System 8

2.0 tons per acre of limestone flour (calcium carbonate) pre-plant incorporated
0.5 tons per acre of Canola Meal pre-plant incorporated
0.5 tons per acre of Rock Phosphate pre-plant incorporated

Each treatment is replicated eight times in a randomized block design.

The mean soil pH at the end of the 1997 growing season associated with the conventional soil nutrition program was 5.60, which was the same as at the beginning of both the 1996 and 1996 growing seasons (Table 6). The mean soil pH associated with the five farming systems maintained under the alternative soil nutrition program increased to 7.16. The cation ion exchange capacity was lower at the end than at the beginning of the 1997 growing season; however, it was the same under both soil nutrition programs. The most significant change in soil nutrients between the two programs was with calcium: where this nutrient decreased 35% under the conventional program, and increased 27% under the alternative program.
During the 1997 growing season, plant parasitic nematodes (root-lesion and northern root-knot) increased 9.64-fold under the conventional program, and only 38% of this amount under the alternative program (Table 7). The reverse was not only true, but even more striking for bacterial feeding nematodes. Population densities of these species declined 64% under the conventional program; whereas, they increased 2.21-fold under the alternative program. These observations were also reflected in a modified Berney Index that was originally developed through research at the Kellogg Biological Station to differentiate between various types of farming systems.

Russet Norkotah tuber yields in 1997 were slightly higher following oats when the potato crop was grown under the alternative soil nutrition program, compared to the standard system of two years of alfalfa maintained under the conventional soil nutrition program (Table 8). 1997 was the second year in a row that one of the alternative farming systems over-yielded the standard farming system. It is anticipated that the highest yields in 1998 will be associated with System No. 10, a two year buckwheat rotation grown under the alternative soil nutrition program. While nematode and *Verticillium* data associated with this research will be reported and discussed in another section of this report, it is becoming very clear that both soil quality management and cropping system diversity will become important components of future potato production systems designed to minimize risk from the potato early-die disease complex caused by the joint action of the root-lesion nematode (*P. penetrans*) and the *Verticillium*-wilt fungus (*V. dahliae*). A second important observation is that nematode community structure can change over time. At this research site, it appears that the northern root-knot nematode is becoming an increasingly important component of the ecosystem. This factor must be taken into consideration when selecting rotation crops for profitable potato production systems under Michigan growing conditions. The lowest tuber yields in 1997 were associated with both the lowest Modified Berney Index at both the beginning and the end of the growing season (Table 9).

As indicated above, the nematode community ecology associated with the research site has changed since the beginning of the project in 1991. The northern root-knot nematode was not known to exist at this site in the beginning of the study. During the past seven years this species, however, has become increasingly prominent at the beginning of the growing season, middle of the growing season, and end of the growing season, as reflected in the decline in the prominence of the root-lesion nematode.

Throughout the experiment, initial spring population densities of the root-lesion nematode have ranged from 2 to 31 per 100 cm^3 of soil. Mid-season population densities of this nematode have ranged from 6 to 1,103 nematodes per 100 cm^3 + 1.0 gram of root tissue; whereas, the end-of-growing season population densities have ranged from 7 to 1144 nematodes per 100 cm^3 + 1.0 gram of root tissue. The most significant results concerning the population dynamics of the root-lesion nematode is that alfalfa is not as good a host for this nematode following two years of field-grown alfalfa, compared to the host suitability of this crop studied under short-term greenhouse, growth chamber and field investigations. The second important finding is that buckwheat appears to be a relatively poor host for the root-lesion nematode under Michigan potato production conditions.

The northern root-knot nematode was not detected in the experimental site until 1994. Initial spring population densities of this species have ranged from 0 to 1,184 per 100 cm^3 of soil and appear to be increasing significantly. While there are similar trends in the mid-season population density data for the northern root-knot nematode, it appears that the optimal sampling date for this species under Michigan potato production conditions is later than the optimal date for the root-lesion nematode. Final fall population densities between 1995 and 1997 for this nematode have ranged from 2 to 8,356 per 100 cm^3 soil + 1.0 gram of root tissue. Oats, buckwheat and oil seed radish are essentially non-hosts for the northern root-knot nematode. The fact that buckwheat is a poor host for the root-lesion nematode and a non-host for the northern root-knot nematode may make it very useful in the design of future potato production systems under Michigan growing conditions.

The clover cyst nematode (*Heterodera trifolii*) has been detected in the research site associated with farming systems using hairy vetch or alfalfa. This species was not previously known to exist at the Montcalm Potato Farm. Relatively little is known about its pathogenicity in relation to legumes grown under Michigan conditions.

Although the long-term farming system-nematode management project was not initially designed to study the overwintering of plant parasitic nematodes, the data are ideal for this purpose. The Michigan State University Nematology Program participates in a regional research program (NC-215) on the overwintering of nematodes. Data from the Montcalm Potato Farm will be used in this project. While it appears that the normal overwintering mortality of the root-lesion nematode is about 50% following a potato crop grown under a conventional crop rotation and soil nutrition system. Overwintering of this species can vary greatly when associated with other crops or a potato monoculture system. Overwintering mortality of the northern root-knot nematode appears to be much higher following potatoes than overwintering mortality for the root-lesion nematode. This, however, may be an artifact of the sampling and nematode processing procedure which does not detect nematode eggs. Using the present techniques, population densities of the northern root-knot nematode will appear to increase during the winter. This is probably the result of spring egg hatch.

Three different assays are being used to study *Verticillium dahliae* associated with the project. These include quantification of spores from soil at the beginning of the growing season and two types of analyses of stem infection at the end of the growing season. At the beginning of the 1997 growing season the population densities of this fungus ranged from 0.0 to 5.2 per gram of air dried soil, with the highest population densities associated with the second-year of alfalfa and the oats-red clover systems in 1996 (Table 10). Oil seed radish was associated with the lowest population density. Fall stem infection were similar among the five systems used for potato production in 1997, ranging from 31.3 to 41.4%. The number of colonies of *V. dahliae* recovered from 0.5 grams of potato stem tissue was similar in 1992 and 1997 for the potato monoculture, oats-potato and oats/red clover-potato systems. A larger number of colonies were associated with the 2-year alfalfa-potato and oil seed radish-potato systems.

POTATO-CARROT ROTATION SYSTEM PROJECT.- The long-term potato-carrot rotation system project was initiated in 1994 at the Michigan State University Montcalm Potato Research Farm. It consists of nine rotation systems, each replicated six times in a randomized block design, and is scheduled to continue through 2003. After four years of growing root-knot nematode susceptible crops in a mineral soil with no history of this nematode, carrot yield losses due to this pest ranged from 59-90%. Potato yields were also impacted in 1997 in a negative manner (11).

Although the northern root-knot nematode could not be detected at the beginning of the research, early-season population densities of this nematode were recovered in 1995 and increased to very high levels by 1997. Mid-season population densities of the northern root-knot nematode appear to be more difficult to detect than those of the root-lesion nematode. It is likely that a slightly later sampling date is needed for optimal detection. Population densities of the northern root-knot nematode at the end of the growing season were high on both carrot and potato. Oat was a non-host for this nematode. Vapam provided good control of the northern root-knot nematode. Vydate did not provide control at this research site. Marigold provided excellent control of the northern root-knot nematode. Beginning of the growing season population densities of the root-lesion nematode were typical for sandy loam soils and were much lower than densities of the root-lesion nematode. Vapam provided excellent control of the root-lesion nematode. Oats were a good host for this species. Late season population densities of the root-lesion nematode varied with crop and nematode management procedure. Populations of this species declined on both alfalfa and hairy vetch during the second year of growth. Marigold is a host for the root-lesion nematode.

The clover cyst nematode (*Heterodera trifolii)* is highly host specific, and was not known to exist in the research site until one year of hairy vetch had been grown. Mid-season population densities of the clover cyst nematode were difficult to detect; however they were extremely host specific and increased to high levels by the end of the growing season.

Potato stand, soil Verticillium densities and Verticillium stem infection were relatively similar regardless of the rotation or nematode management procedure (Table 12). The number of Verticillium colonies recovered from stem tissue, however, was much lower when the soil was treated with Vapam, compared to non-treated soil. Overall diversity of nematode community ecology appeared to be greatest under the alfalfa, hairy vetch and compost systems. Taxa of the Dorylamida were susceptible to Vapam. It is highly probable that peaks of population densities of microbiotropihc nematodes are directly related to peaks in decomposition rates of soil organic matter and various nutrient conversions. The highest population density of mycorrhizal spores at the beginning of the 1997 growing season was associated with rotation No. 4. At the end of the 1997 growing season, the highest population densities of both mycorrhizae spores and ologocheates were associated with rotation No. 4.

Table 1. Root-lesion nematodes and Verticillium associated with seven potato cultivars grown in the presence and absence of aldicarb.

Cultivar	Mid-season *Pratylenchus penetrans* population density		*Verticillium dahliae* Stem infection (%)		*Verticillium dahliae* Colonies (0.5 g stem)	
	- Aldicarb	+ Aldicarb	- Aldicarb	+ Aldicarb	- Aldicarb	+ Aldicarb
Atlantic	29	21	62	60	10	25
Chieftian	20	6	43	44	5	15
Onaway	20	18	59	67	110	75
Russet Burbank	27	20	51	74	120	200
Russet Norkotah	20	29	44	67	155	125
Shepody	**8**	23	**23**	**32**	**10**	**5**
Snowden	27	11	56	63	20	57

Table 2. 1997 US No. 1 plus jumbo tuber yields of seven potato cultivars grown in the presence and absence of aldicarb.

Cultivar	A & J potato tuber yield (cwt/A)	
	- Aldicarb	+ Aldicarb
Atlantic	263	220
Chieftian	303	295
Onaway	287	206
Russet Burbank	159	177
Russet Norkotah	178	180
Shepody	220	245
Snowden	220	221

Table 3. Root lesion nematodes (Pratylenchus penetrans) associated with the 1997 potato nematicide trial at the Montcalm Potato Research Farm.

Treatment	P. penetrans/100 cm³ soil + 1.0 g root tissue			
	Pi[1]	Pap[2]	Pm[3]	Pf[4]
Vapam (50 gal/A)	38	0	0	5
Compost (5 tons/A)	40	38	31	311
Vapam & Compost (50 gal + 5 tons/A)	40	1	4	4
Temik 15G (3.0 lbs a.i./A)	60	33	22	84
Mocap 10G + Vydate 2L (9 lbs + 2.0 lbs/A)	36	76	8	84
ABG 9008 (50 lbs/A)	53	75	26	382
ABG 9008 (100 lbs/A)	61	60	26	406
Control	38	39	42	368

[1]Pi = initial population density.
[2]Pap = at-planting population density.
[3]Pm = mid-season population density.
[4]Pf = final population density.

Table 4. Tuber yields associated with the 1997 potato nematicide trial.

Treatment	A	B	K	J	Total	Marketable
Vapam 50G/A	243.1 cd	13.5 abcd	11.9	124.4 b	392.8 e	367.4 f
Compost 5 T/A	183.5 ab	16.4 bcde	14.8	53.6 a	268.3 abcd	237.2 abcde
Vapam 50G/a w/Compost	222.1 bcd	13.2 abc	13.3	124.5 b	373.2 e	346.6 f
Temik 15G 3.0 lbs/A	191.5 abc	16.8 cde	20.0	65.2 a	293.5 bcd	256.7 bcde
Mocap 15G 9.0 ai + Vydate	192.5 abc	17.3 cde	18.6	66.5 a	294.9 cd	259.0 cde
Abbott 50 lbs/a ppi	178.0 ab	18.5 cde	18.9	44.5 a	259.9 abc	222.5 abcd
Abbott 100 lbs/a ppi	187.6 ab	15.4 abcde	17.1	40.8 a	269.9 abc	228.4 abcde
Untreated check	179.7 ab	16.7 de	18.1	39.5 a	254.0 abc	219.2 abc
ANOVA	0.000	0.024	0.171	0.000	0.000	0.000

Table 5. Description of the crops and soil nutrition programs used in a 10-Year Farming System - Nematode Management Research Project (1991-2000) at the Montcalm Potato Research Farm in Entrican, Michigan.

Farming System	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]
2	Alfalfa[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Hairy vetch[1]	Potato Rye[1]	Buckwheat[1]	Potato Rye[1]	Buckwheat[1]	Potato Rye[1]
3	Oats[1]	Alfalfa[1]	Potato[1]	Potato[1]	Nematode mix[1]	Oats[1]	Potato Rye[3]	Potato Rye[3]	Potato Rye[3]	Potato Rye[3]
4	Oats[1]	Alfalfa[1]	Alfalfa[1]	Potato Rye[1]	Alfalfa[1]	Alfalfa[1]	Potato Rye[1]	Alfalfa[1]	Alfalfa[1]	Potato Rye[1]
5	Oats[1]	Potato Rye[1]	Potato Rye[1]	Potato Rye[1]	Annual rye grass[1]	Oats/Red Clover[1]	Potato Rye[1]	Oats/Red Clover[1]	Potato Rye[1]	Oats/Red Clover[1]
6	Oats[1]	Soybean Rye[1]	Alfalfa[1]	Alfalfa[1]	Potato Rye[2]	Alfalfa[1]	Alfalfa[1]	Potato Rye[3]	Alfalfa[3]	Alfalfa[3]
7	Oats[1]	Soybean Rye[1]	Light red kidney beans, Rye[1]	Alfalfa[1]	Alfalfa[1]	Potato Rye[1]	Alfalfa[3]	Alfalfa[3]	Potato Rye[3]	Alfalfa[3]
8	Oats[1]	Soybean Rye[1]	Light red kidney beans, Rye[1]	Green pea[1]	Oil seed radish[1]	Potato Rye[1]	Oil seed radish[3]	Potato Rye[3]	Oil seed radish[3]	Potato Rye[3]
9	Oats[1]	Soybean Rye[1]	Light red kidney beans, Rye[1]	Green pea[1]	Potato Rye[2]	Oil seed radish[1]	Potato Rye[1]	Oil seed radish[1]	Potato Rye[1]	Oil seed radish[1]
10	Oats[1]	Soybean Rye[1]	Light red kidney beans, Rye[1]	Green pea[1]	Buckwheat[2]	Potato Rye[1]	Buckwheat[3]	Potato Rye[3]	Buckwheat[3]	Potato Rye[3]

[1]Conventional soil nutrition program.
[2]30 T/A cow manure compost.
[3]Alternative soil nutrition program.

Table 6. **Soil pH, cation exchange capacity, and % bases associated with two soil nutrition programs.**

Soil nutrition program	pH			CEC 1997		1997 % Bases					
						K		Ca		Mg	
	Apr 96	Mar 97	Sep 97	Mar	Sep	Mar	Sep	Mar	Sep	Mar	Sep
Conventional[1]	5.62	5.62	5.60	7.24	4.82	9.0	12.4	67.0	73.4	26.0	14.0
Alternative[2]	5.80	5.64	7.16	6.26	4.76	6.8	6.4	66.8	87.6	26.2	6.6

[1]Conventional soil nutrition program.
[2]Alternative soil nutrition program.

Table 7. 1997 nematode populaiton dynamics associated with two soil nutrition programs.

Soil nutrition program	Nematode population change (Pf97/Pi97)[1]		Modified Berney Index (Bv/(Pp+Mh)[2]		
	Plant parasites[3]	Bacterial feeders	Pi (April)	Pf (Sept)	Pf/Pi
Conventional[4]	9.64	0.64	6.40	0.34	0.05
Alternative[5]	3.68	2.21	8.58	8.63	1.01

[1]Pi = initial population density (April), Pf = final population density (September).
[2]Bv (Bacterial feeding nematodes), Pp = Pratylenchus penetrans (root-lesion nematode), Mh = Meloidogyne hapla (root-knot nematode)
[3]Sum of the population densities of P. penetrans and M. hapla.
[4]Conventional soil nutrition program.
[5]Alternative soil nutrition program.

Table 8. Relative potato tuber yields associated with a Ten-Year Farming System/Nematode Management Research Project at the Michigan State University Montcalm Potato Research Farm in Entrican, Michigan.

Farming system	Crop							Relative Yield, U.S. No. 1 Potato Tubers[1]						
	1991	1992	1993	1994	1995	1996	1997	1991	1992	1993	1994	1995	1996	1997
1	Potato[2]	Potato[2]	Potato[2]	Potato[2]	Potato[2]	Potato[2]	Potato[2]	**1.00**	0.69	0.34	0.29	0.79	0.87	0.45
2	Alfalfa[2]	Potato[2]	Potato[2]	Potato[2]	Hairy vetch[2]	Potato[2]	Buck-wheat[2]	—	**1.00**	0.54	0.34	—	0.95	—
3	Alfalfa[2]	Alfalfa[2]	Potato[2]	Potato[2]	Nematode tri-mix[2]	Oats[2]	Potato[4]	—	—	**1.00**	0.57	—	—	**1.05**
4	Oats[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	—	—	—	**1.00**	—	—	**1.00**
5	Oats[2]	Potato[2]	Potato[2]	Potato[2]	Annual rye grass[2]	Oats/Red clover[2]	Potato[2]	—	0.97	0.53	0.32	—	—	0.88
6	Oats[2]	Soybean[2]	Alfalfa[2]	Alfalfa[2]	Potato[3]	Alfalfa[3]	Alfalfa[4]	—	—	—	—	**1.00**	—	—
7	Oats[2]	Soybean[2]	Light red kidney beans[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	Alfalfa[4]	—	—	—	—	—	**1.00**	—
8	Oats[2]	Soybean[2]	Light red kidney beans[2]	Green peas[2]	Oil seed radish[2]	Potato[2]	Oil seed radish[4]	—	—	—	—	—	**1.14**	—
9	Oats[2]	Soybean[2]	Light red kidney beans[2]	Green peas[2]	Potato[3]	Oil seed radish[2]	Potato[2]	—	—	—	—	0.93	—	0.97
10	Oats[2]	Soybean[2]	Light red kidney beans[2]	Green peas[2]	Buck-wheat[3]	Potato[2]	Buck-wheat[4]	—	—	—	—	—	**1.35**	—

[1]Relative yields calculated by assigning a yield of 1.0 to the standard farming system (2 years of alfalfa followed by one year of potato) and dividing the U.S. No. 1 tuber yields for each farming system by the U.S. No. 1 tuber yield for the standard. The two exceptions were in 1991 and 1992, where the U.S. No. 1 tuber yields for the only potato system and the potato system following a single year of alfalfa were used as the standard.

[2]Conventional potato production soil nutrition program.
[3]Application of 30 T/A of cow manure compost.
[4]Alternative potato production soil nutrition program.

Table 9. Association between the Modified Berny Index, soil pH and marketable potato tuber yields.

1996-97 Crop-Nutrition System	Soil pH (9/97)	Marketable Tuber Yield (cwt/A)	Modified Berney Index (5/97)	Modified Berney Index1 (9/97)
Potato-Potato[2]	5.3	59	0.26	0.09
Potato-Buckwheat[2]	5.9	—	0.22	0.84
Oats[2]-Potato[3]	6.9	144	9.83	0.56
Alfalfa-Potato[2]	5.6	135	2.19	0.18
Oats/Red Clover-Potato[2]	5.4	115	25.40	0.30
Alfalfa-Alfalfa[3]	7.3	—	30.60	6.33
Potato[2]-Alfalfa[3]	7.5	—	0.80	0.82
Potato[2]-Oil seed radish[3]	7.0	—	0.67	33.24
Oil seed radish-Potato[2]	5.8	128	3.94	0.30
Potato [2]-Buckwheat [3]	7.1	—	1.00	2.22

[1]Modified Berney Index = Bacterivores/(<u>Pratylenchus penetrans</u> + <u>Meloidogyne hapla</u>)
[2]Conventional soil nutrition program.
[3]Alternative soil nutrition program.

Table 10. Verticillium dahliae associated with 10 potato farming systems.

Farming system	Crop							V. dahliae colonies per 0.5 g stem tissue		V. dahliae % stem infection (Sept. 1992)	V. dahliae spores per soil (April 1997)
	1991	1992	1993	1994	1995	1996	1997	1992 (Sept)	1997 (Sept)		
1	Potato[2]	Potato[2]	Potato[2]	Potato[2]	Potato[2]	Potato[2]	Potato[2]	314	334	31.3	0.6
2	Alfalfa[2]	Potato[2]	Potato[2]	Potato[2]	Hairy vetch[2]	Potato[2]	Buck-wheat[2]	304	---	---	0.4
3	Alfalfa[2]	Alfalfa[2]	Potato[2]	Potato[2]	Nematode tri-mix[2]	Oats[2]	Potato[4]	---	328	**41.4**	0.9
4	Oats[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	---	**545**	35.1	**5.2**
5	Oats[2]	Potato[2]	Potato[2]	Potato[2]	Annual rye grass[2]	Oats/Red clover[2]	Potato[2]	315	328	36.9	**2.5**
6	Oats[2]	Soybean[2]	Alfalfa[2]	Alfalfa[2]	Potato[3]	Alfalfa[3]	Alfalfa[4]	---	---	---	1.8
7	Oats[2]	Soybean[2]	Light red kidney beans[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	Alfalfa[4]	---	---	---	0.2
8	Oats[2]	Soybean[2]	Light red kidney beans[2]	Green peas[2]	Oil seed radish[2]	Potato[2]	Oil seed radish[4]	---	---	---	1.0
9	Oats[2]	Soybean[2]	Light red kidney beans[2]	Green peas[2]	Potato[3]	Oil seed radish[2]	Potato[2]	---	**768**	33.6	0.0
10	Oats[2]	Soybean[2]	Light red kidney beans[2]	Green peas[2]	Buck-wheat[3]	Potato[2]	Buck-wheat[4]	---	---	---	0.8

[1]First seven years of a 10-year research project.
[2]Conventional potato production soil nutrition program.
[3]Application of 30 T/A of cow manure compost.
[4]Alternative potato production soil nutrition program.

Table 11. 1997 potato yield data associated with the long-tem potato-carrot rotation project.

1994-1997 Rotation (Treatment)	Yield (cwt)			
	As	Bs	Js	Total
Green peas/Potato/Carrots/Carrots	---	---	---	---
Green peas/Carrots/Potato (Vapam)/Carrots	---	---	---	---
Green peas/Carrots/Oats/Potato	126	18	4	148
Green peas/Carrots (Vapam)/Potato/Carrots (Vapam)	---	---	---	---
Green peas/Potato (Vapam)/Carrots (Vapam)/ Potato	159	18	10	177
Green peas/Carrots (Vydate)/Potato/Potato (Vapam)	176	22	10	208
Hairy vetch/Hairy vetch/Potato/Hairy vetch	---	---	---	---
Alfalfa/Alfalfa/Potato/Oats	---	---	---	---
Fallow/Marigold compost/Potato/Carrots compost	---	---	---	---

Table 12. 1997 potato data.

1994-1997 Rotation (Treatment)	Observation			
	Stand	Soil Vert. (Pi)	Stem Vert. (% infection)	Colonies/ 0.5 g stem
Green peas/Potato/Carrots/Carrots	---	10	---	---
Green peas/Carrots/Potato (Vapam)/Carrots	---	5	---	---
Green peas/Carrots/Oats/Potato	61	8	68	1155
Green peas/Carrots (Vapam)/Potato/Carrots (Vapam)	---	6	---	---
Green peas/Potato (Vapam)/Carrots (Vapam)/ Potato	70	14	66	1500
Green peas/Carrots (Vydate)/Potato/Potato (Vapam)	70	0	53	35
Hairy vetch/Hairy vetch/Potato/Hairy vetch	---	8	---	---
Alfalfa/Alfalfa/Potato/Oats	---	16	---	---
Fallow/Marigold compost/Potato/Carrots compost	---	7	---	---

Combining Varietal Resistance with Managed Fungicide Applications for the Control of Potato Late Blight

W. W. Kirk[1], D. S. Douches, B.A. Niemira, R. Hammerschmidt and J. A. Stein.
Michigan State University Late Blight Project

Departments: Botany and Plant Pathology (WWK, BAN, RH)
Crop and Soil Sciences (DSD)

[1] Contact address, 35 Plant Biology, Botany and Plant Pathology, Michigan State University, East Lansing MI48824, (517) 353-4481, Fax (517) 353-1926, e-mail kirkw@pilot.msu.edu

INTRODUCTION

Late blight (*Phytophthora infestans*) is a major threat to the production of high quality potatoes in Michigan. The appearance of a more aggressive strain of *P. infestans* (US8), resistance in this pathogen to metalaxyl and the potential loss of some currently effective protective fungicides, compounds the serious nature of this problem. Moreover the economics of crop production demand that cost effective crop protection is a prime concern for the whole industry. Simultaneously, political pressure to reduce to reduce crop production inputs without compromising crop quality are increasing. The North American late blight workshop held at Tucson, AZ in 1997 identified that the development of integrated crop protection programs that focus on durable resistance to potato late blight should be considered as a priority for the North American potato industry. Durable resistance was defined as production systems that utilized potato cultivars with reduced susceptibility to late blight in combination with managed fungicide applications. Successful, long-term control of this disease will require a combined effort that will incorporate the use of carefully managed fungicide programs, resistant varieties developed through breeding and the use of novel resistance mechanisms achieved via genetic engineering. The objective of this research was aimed at developing the tools necessary to control late blight using fungicides in combination with heritable host resistance.

Experiments were set up to evaluate the efficacy of crop protection programs against potato late blight utilizing fungicides with a) reduced amounts of commercially available fungicide and b) with reduced amounts of novel fungicides with lower amounts of active ingredient fungicides. These fungicides were applied with managed application amounts and at different application frequencies in combination with potato varieties with different levels of late blight susceptibility. A third field experiment was designed to evaluate a broad range of cultivars and advanced breeding lines for their reaction to the US8 biotype of potato late blight.

MATERIALS AND METHODS

General

Potatoes (transplants, experiment 1; cut and whole potato seed pieces, experiment 2) were planted at the Michigan State University Muck Soils Experimental Station, Bath, MI on 1 June into two-row by 25-foot plots (34-inch row spacing) replicated four times in a randomized complete block design (further details for individual experiments are given below). The two-row beds were separated by a five-foot blank row. Plots were irrigated as needed with sprinklers and were hilled immediately before sprays began. The center and outside guard double rows were inoculated (100 ml/25-foot row) with a zoospore suspension of *Phytophthora infestans* US8 (insensitive to metalaxyl, A2 mating type) genotype (10^3 conidia/ml) on 30 Jul. Fungicides were applied from 25 Jun to 28 Aug with an ATV rear-mounted R&D spray boom delivering 25 gal/A (80 p.s.i.) and using three XR11003VS nozzles per row. Weeds were controlled by hilling and with one application of Dual 8E (2 pt/A on 10 Jun), two applications of Basagran (2 pt/A on 20 Jun and 10 Jul) and one application of Poast (1.5 pt/A on 28 Jul). Insects were controlled with applications of Admire 2F (20 fl oz/A at planting on 1 June), Sevin 80S (1.25 lb on 1 and 25 Jul), Thiodan 3EC (2.33 pt/A on 4 and 26 Aug) and Pounce 3.2EC (8 oz/A on 18 Jul). Plots were rated visually for percentage foliar area affected by late blight on 30 Jul, 13, 18 and 25 Aug and 2 Sep.

Experiment 1

Potato plants for experiment one were generated by tissue culture and transplanted into soil when the plants were established and had well developed root systems. The treatments used in experiment 1 are shown in Table 1.

Table 1. Treatments in experiment 1.

Chemical	Application rate % of full recommended rate	Variety
Untreated	0	A, S, M, Z[1]
Bravo WS 6SC	100	A, S, M, Z
Bravo WS 6SC	67	A,S, M, Z
Bravo WS 6SC	33	A, S, M, Z
Fluazinam 5SC	100	A, S, M, Z
Fluazinam 5SC	67	A, S, M, Z
Fluazinam 5SC	33	A, S, M, Z

[1] varieties: susceptible (A=Atlantic and S = Snowden), moderately resistant (M = Matilda), resistant (Z = Zarevo)

Potato varieties were planted in adjacent rows. Treatments were applied in a random-block design. Chemical treatments were begun before inoculation with the US8-A2 biotype of *P. infestans* (minimum of two applications). Foliar disease was assessed at various points after inoculation, with 33 days after inoculation (d.a.i.) taken as a key reference point. Relative area under the disease progress curve (RAUDPC) was calculated to evaluate disease development across the season. Comparisons for each factor were made separately and collectively with multi-way ANOVA. In all cases, "significance" refers to the P=0.05 level

Experiment 2.

Potato tubers for experiment 2 were planted into open ridges. The treatments used in experiment 2 are shown in Table 2

Table 2. Treatments in experiment 2

Application frequency days between applications	Application rate % of full recommended rate[1]	Variety
0	0	S, M[2]
5	100	S, M
10	100	S, M
15	100	S, M
5	67	S, M
10	67	S, M
15	67	S, M
5	33	S, M
10	33	S, M
15	33	S, M

[1] Fungicide used, Bravo WS 6SC

[2] Two varieties: moderately susceptible (S = Snowden), moderately resistant (M = Matilda)

Experiment 3.

One hundred and seventy six cultivars and advanced breeding lines were planted at the Muck Soil Research Farm in 5-plant plots with three replications. This material consisted of commercial cultivars, putative resistant germplasm and advanced breeding lines from MSU and other university potato breeding programs. No fungicides were applied during the season. Inoculation with the US8 biotype of *P. infestans* was made in mid-July when foliage was vigorous and healthy. Foliar disease was assessed frequently after`inoculation (minimum 5 days) with 33 days after inoculation (dai) taken as a key reference point. Relative area under the disease progress curve (RAUDPC) was calculated to evaluate disease development over the season.

RESULTS, 1997 FIELD SEASON:

Experiment 1

Reduced levels of fungicide applications resulted in reduced foliar disease at 33 d.a.i. when combined with varietal resistance (Table 3). The novel fungicide Fluazinam was effective at 33% of recommended rates on all varieties, providing disease control that was not significantly different from the full rate applications. The conventional fungicide Bravo WS was effective at 33% of recommended rates only on the resistant varieties Matilda and Zarevo. Both fungicides were effective at 67% of recommended rate on all varieties. RAUDPC values show no significant differences between 100, 67 and 33% application rates for either chemical on any variety.

Experiment 2

Reduced levels of fungicide resulted in increased foliar disease at 33 d.a.i. for both varieties at all application intervals (Table 4a). Where full (100%) rates were applied, the different spray intervals did not result in significantly different foliar disease levels or RAUDPC values. Where 67% rates were applied, foliar disease is significantly increased for all application intervals, while RAUDPC values are significantly increased only in the 10 and 15 day intervals.

The interactions of the factors tested (variety, application rate, application interval) are presented in Table 4b. When the factors are considered individually, discounting all others, clear differences arise. The moderately resistant Matilda shows reduced foliar infection vs. the susceptible Snowden, although RAUDPC values are not significantly different. Reducing the application rate from 100% to 67 and 33% caused significant increases in foliar disease and RAUDPC values. Similarly, lengthening the spray interval from 5 days to 10 and 15 days caused significant increases in foliar disease and RAUDPC values.

When application interval is discounted, no combination of variety and application rate is significantly different from any other combination, either for foliar disease or RAUDPC value. The combinations of varieties and application intervals give similar results. Where variety is discounted, combinations of application intervals with the full (100%) rate show no significant differences. Combinations with the 67% application rate show increasing foliar disease and RAUDPC value with increasing application interval. Combinations with the 33% application rate show increasing RAUDPC value with increasing application interval, although foliar disease levels are not significantly different.

Experiment 3

Late blight disease was high following inoculation. The results are summarized in Table 5. Susceptible varieties reached 100% foliar`infection within three weeks. The majority f the materials tested in this experiment were classified into this susceptible category. Thirty eight lines and varieties with reduced susceptibility had slower disease progress but this group of material was at 100% infection level by the end of the evaluation period. Many of these lines have commercial qualities. Twenty seven lines and varieties were classified as moderately resistant. This group included many unadapted varieties and breeding lines. Some of these lines have been used as parental material in the MSU Potato Breeding Project. In addition, four`breeding lines from the MSU Potato Breeding Project were in this group. Some of these lines with moderate resistance will be candidates for variety x fungicide management profiles in 1998. Only eight lines were classified as resistant, however significant defoliation occurred in most lines 33 dai. The MSU advanced selection , MSG274-3, was the line with the most outstanding foliar`resistance in the trial. This line is also very exciting because it has good horticultural characteristics (unlike any other of the resistant lines). Therefore, we will use MSG274-3 as a parent to transfer resistance to other genetic backgrounds and pursue this line as a commercial line.

DISCUSSION

Combination of varietal resistance with chemical applications can provide effective disease control, as shown in Experiment 1. This can be accomplished with conventional fungicide applications (Bravo WS). In this study, the novel fungicide with reduced a.i. (Fluazinam) was effective at all application rates tested, on all varieties. This suggests that reductions below 33% of recommended rate should be tested for efficacy.

Experiments 1 and 2 gave different results with regard to efficacy at reduced application rates. Applications of Bravo WS at 67 and 33% of recommended rate were significantly less effective at controlling disease. Analysis of combinations of factors was complicated by high variability within the data sets. Potato variety in combination with changes in application rate or application interval did not result in significant differences in disease. Different application intervals resulted in significant differences only at reduced application rates.

These differences between experiments indicate the need for further study, particularly with regard to the effect of application interval on disease progress. In 1998, we plan to expand these variety x fungicide management profile studies with additional advanced breeding lines that have moderate to strong resistance to late blight. In addition, the investigators are willing to consider other candidate fungicides (especially low active ingredient products) to include in the program.

Table 3. Control of potato late blight in susceptible and moderately resistant potato varieties with reduced rates of two residual protectant fungicides at different rates of application.

Application rate % of full recommended rate	Variety	Bravo WS 6SC		Fluazinam 5SC	
		% foliar disease[1] 33 dai[2]	raudpc max = 100	% foliar disease 33 dai	raudpc max = 100
100	Atlantic	4.0a[3]	1.15a	2.0a	0.71a
67		3.5a	1.66a	2.8a	1.17a
33		28.8 b	6.67a	3.5a	1.42a
0		100 c	42.8 b		
100	Zarevo	1.0a	0.37a	1.0a	0.37a
67		2.0a	1.07a	1.0a	0.31a
33		4.0a	1.32a	2.3a	0.85a
0		83.3 c	28.6 b		
100	Snowden	2.5a	1.43a	1.5a	0.68a
67		5.8a	2.41a	2.0a	0.93a
33		42.0 b	7.37a	2.8a	1.51a
0		96.3 c	39.9 b		
100	Matilda	1.0a	0.59a	1.0a	0.31a
67		2.5a	1.56a	1.3a	0.93a
33		7.0a	1.97a	4.8a	1.47a
0		100.0 c	41.8 b		

[1] final assessment of late blight taken on same as desiccation materials applied

[2] days after inoculation

[3] values followed by the same letter are not significantly different at $p = 0.05$ (Tukey Multiple Comparison)

Table 4a. Control of potato late blight in a susceptible and a moderately resistant potato variety with reduced rates of fungicide (chlorothalonil, Bravo WS 6SC) at different application frequencies.

Variety	Application interval days	Application rate % of full recommended rate	% foliar disease[1] 33 dai[2]	raudpc max = 100
Snowden	5	100	6.0ab[3]	2.4a
		67	56.3 cd	13.0abc
		33	86.3 de	21.3 bcdef
	10	100	4.8a	2.2a
		67	88.8 e	25.9 cdefg
		33	93.8 e	27.6 defg
	15	100	8.8ab	3.0a
		67	98.8 e	31.6 efg
		33	100 e	34.2 fg
	untreated		100 e	38.0 g
Matilda	5	100	3.0a	1.3a
		67	37.8 cd	9.8ab
		100	75.0 de	17.3 bcd
	10	67	3.8a	1.6a
		33	71.0 de	20.1 bcde
		33	78.8 de	22.2 bcdefg
	15	100	7.3ab	2.4a
		67	90.8 e	26.9 efg
		33	97.3 e	32.6 fg
	untreated		99.5 e	34.9 fg

[1] final assessment of late blight taken on same as desiccation materials applied
[2] days after inoculation
[3] values followed by the same letter are not significantly different at $p = 0.05$ (Tukey Multiple Comparison)

Table 4b. Differences in level of control of potato late blight achieved in two potato varieties differing in susceptibility to potato late blight with reduced rates of fungicide at different application frequencies. The differences are expressed as % control in comparison with untreated checks.

Source of variation	Treatment	% control relative to untreated checks	
		% foliar infection 33 dai	raudpc
Variety	Snowden	0.604a[1]	0.474
	Matilda	0.519 b	0.428
Fungicide application rate	1.00	0.441a	0.298a
	0.67	0.570 b	0.457 b
	0.33	0.673 c	0.599 c
Application interval (days)	5	0.056a	0.058a
	10	0.740 b	0.581 b
	15	0.887 c	0.715 c
Variety and fungicide application rate	Snowden x 1.0	0.495	0.325
	Snowden x 0.67	0.624	0.491
	Snowden x 0.33	0.692	0.606
	Matilda x 1.0	0.387	0.271
	Matilda x 0.67	0.515	0.422
	Matilda x 0.33	0.654	0.592
Variety and application interval	Snowden x 5	0.065	0.067
	Snowden x 10	0.813	0.618
	Snowden x 15	0.933	0.737
	Matilda x 5	0.047	0.050
	Matilda x 10	0.668	0.544
	Matilda x 15	0.841	0.692
Fungicide application rate and application interval	100 x 5	0.045	0.049
	100 x 10	0.470	0.312
	100 x 15	0.808	0.532
	67 x 5	0.043a	0.051a
	67 x 10	0.801 b	0.626 b
	67 x 15	0.865 b	0.693 b
	33 x 5	0.080	0.074a
	33 x 10	0.950	0.804 b
	33 x 15	0.989	0.919 b

[1] Means followed by the same letter are not statistically different at p = 0.05 (Tukey) and treatment comparison sets are separated within table sections by double lines

Table 5. Summarized results from the MSU late blight variety trial[1] showing advanced breeding lines and varieties which have reduced susceptibility, are moderately resistant or are resistant to the US8,A_2 biotype of potato late blight (*P. infestans*)

Resistant [2]	Moderately resistant		Reduced susceptibility			Susceptible [3]
AWN86514-2	A080432-1	Lily	A84118-3	MSB027-1R	MSF165-6R	Atlantic
B0288-7	A082611-7	Matilda	Allegany	MSB040-3	MSF373-8	Cent Russet
B0692-4	A084275-3	MSE230-6	Alpha	MSB107-1	MSG007-1	Onaway
B0718-3	B0749-2F	MSE246-5	B0811-13	MSB103-2	MSG050-2	R. Norkotah
B0767-2	C0083008-1	MSG139-1	B0856-4	MSC120-1Y	MSG135-5	R. Burbank
Bertita	Dorita	MSG163-1	B0915-3	MSE009-1	MSG297-4R	Shepody
Bzura	Elba	Nordonna	Dali	MSE018-1	ND2676-10	Yukon Gold
MSG274-3	Greta	Obelix	Desiree	MSE222-5Y	Pike	Norchip
	Hindenburg	Ontario	FL1879	MSE263-10	R.Norland	
	IS. Sunshine	Pimpernel	Hampton	MSF001-2	Russian Blue	
	Krantz	Robijn	Is. Sunset	MSF015-1	Snowden	
	Latona	Strobrawa	MN16489	MSF019-11		
	Libertas	Zarevo	MSA091-1	MSF105-10		

[1] 33 days after`inoculation with US8 genotype of *P. infestans*

[2] RAUDPC < 0.15 = Resistant; 0.16 - 0.30 = Moderately Resistant; 0.31- 0.45 = Reduced Susceptibility; >0.45 = Susceptible

[3] only named cultivars are listed

Funding Federal Grant/MPIC/Industry

Chemical Control of Potato Late Blight — 1997

W.W. Kirk, J.M. Stein, B.J. Kitchen, B.A. Niemira, and N.M Kirk
Room 35 Plant Biology Building, Department of Botany and Plant Pathology
Michigan State University, East Lansing, MI 48824, USA

INTRODUCTION

Potato late blight (*Phytophthora infestans*) is the most important potato pathogen in Michigan. For three years in succession, successful epidemics have been established at the Michigan State University Experimental Research Farm, Bath, MI. In 1997, several foliar fungicide efficacy trials were carried out to establish the efficacy of fungicides applied to control established infections and to prevent infections from becoming established. The following report outlines the efficacy of many products tested under different levels of disease conditions.

METHODS

Potatoes (cut seed) cv. Snowden, were planted at the Michigan State University Muck Soils Experimental Station, Bath, MI on 1 June into two-row by 25-foot plots (34-inch row spacing) replicated four times in a randomized complete block design. The two-row beds were separated by a five-foot blank row. Plots were irrigated as needed with sprinklers and were hilled immediately before sprays began. The center and outside guard double rows were inoculated (100 ml/25-foot row) with a zoospore suspension of *Phytophthora infestans* US8 (insensitive to metalaxyl, A2 mating type) genotype (10^3 conidia/ml) on 30 Jul. Fungicides were applied weekly (unless otherwise stated) from 25 Jun to 13 Aug (9 applications) with an ATV rear-mounted R&D spray boom delivering 25 gal/A (80 p.s.i.) and using three XR11003VS nozzles per row. Weeds were controlled by hilling and with one application of Dual 8E (2 pt/A on 10 Jun), two applications of Basagran (2 pt/A on 20 Jun and 10 Jul) and one application of Poast (1.5 pt/A on 28 Jul). Insects were controlled with applications of Admire 2F (20 fl oz/A at planting on 1 June), Sevin 80S (1.25 lb on 1 and 25 Jul), Thiodan 3EC (2.33 pt/A on 4 and 26 Aug) and Pounce 3.2EC (8 oz/A on 18 Jul). Plots were rated visually for percentage foliar area affected by late blight on 30 Jul, 13, 18 and 25 Aug and 2 Sep. Vines were killed with Diquat 2EC (1 pt/A on 10 and 17 Sep). Plots were harvested on 5 Oct. and individual treatments were weighed and graded. Samples of 50 tubers from each plot (4 replicates/treatment) were stored in plastic bags for 90 days after harvest at 10°C (50°F). Tubers were cut through the longitudinal plane and scored for presence of late blight. In the National Potato Late Blight trial, at harvest, both the total number and number of rotted tubers of marketable size were counted per treatment.

Results (general)

Late blight developed rapidly during August and untreated controls reached 85 - 95% foliar infection by 25 Aug. All fungicide programs with seven-day application intervals applied as protectants reduced the level of late blight foliar infection significantly compared to the untreated control. Results are presented by trial blocks. Yields in 1997 were generally lower than in previous years. This was due to the combination of several factors a) late planting to avoid early floods, b) a cool summer with low levels of insolation and c) early desiccation to avoid late flooding and early frosts.

General Conclusion

Under the conditions experienced at the research farm in 1997, it was clear that the initial applications of protectant fungicides are vital for effective control of potato late blight. Protectant products must be applied in order to build up a residual base to prevent initial infections of potato late blight.

Trial 1 Comparison of control of potato late blight (*Phytophthora infestans*) attained with combinations of Curzate 60DF with different fungicides applied as a protectant strategy.

Introduction

Curzate 60DF contains only the cymoxanil component of Curzate M8 72WP which has been tested in previous trials. This trial compared different dose rates of cymoxanil in combination with different formulations of chlorothalonil and also with an EBDC fungicide.

Foliar disease (Table 1)

All treatments gave significantly better control in comparison with untreated check plots but no fungi cde treatments were statistically different at p = 0.05 (Tukey). All differences commented on relate to numerical differences between treatments. The amount of chlorothalonil in the Curzate 60DF was critical for overall disease reduction.

The best level of control was attained with a combination of Curzate 60DF + Manzate 75WP + Bravo WS 6SC.

The combination of Curzate 60DF + Manzate 75DF always gave lower levels of disease control than combinations of Curzate 60DF + chlorothalonil-based products e.g. Bravo WS 6SC, Bravo ZN 4FL and Bravo Ultrex 82.5DG.

The addition of Tactic EC to the Curzate 60DF + Bravo WS 6SC did not improve efficacy. Alternating Curzate 60DF + Manzate 75DF with Bravo WS 6SC resulted in poorer disease control than applications of Curzate 60DF + chlorothalonil-based products during the middle portion of the growing season. Curzate 60DF + Manzate 75WP applied at 0.16 + 1.5 lb/acre respectively gave poor disease control.

Phytotoxicity was not noted in any of the treatments

Yield

Total yields were very low in this block. The yields did not correlate well with observed disease.

Tuber disease

Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at p = 0.05 between tubers samples from any treatments or from untreated plots.

Recommendations

Curzate 60 DF applied at 0.21 lb/acre should be recommended as a highly effective fungicide applied within protectant protection programs in combination with an appropriate residual fungi cde protectant partner for the control of foliar late blight.

The most effective combination from this trial was a mixture with chlorothalonil and EBDC and this combination should be recommended as optimal for late blight control.

Curzate 60DF should also be recommended for late blight control in combination with any of the chlorothalonil-based products at the higher rate tested in this trial.

The optimal position for Curzate 60DF-based fungicide programs is after canopy closure, from applications 3 - 7, which were during the main portion of the growing season and preceded crop senescence.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 1. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - DuPont

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre) US1	Yield (cwt/acre) Total
1	Bravo Ultrex 82.5DG Curzate 60DF + Bravo Ultrex 82.5DG Bravo Ultrex 82.5DG	1.4 0.21 0.91 1.4	lb lb lb lb	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	25.5a[3]	4.94a	1.25	167a	206
2	Bravo Ultrex 82.5DG Curzate 60DF + Bravo Ultrex 82.5DG Bravo Ultrex 82.5DG	1.4 0.21 1.1 1.4	lb lb lb lb	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	5.8a	1.62a	1.25	111ab	162
3	Bravo ZN 4FL Curzate 60DF + Bravo ZN 4FL Bravo ZN 4FL	2.25 0.21 1.5 2.25	pt lb pt pt	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	12.0a	3.23a	0	114ab	173
4	Bravo ZN 4FL Curzate 60DF + Bravo ZN 4FL Bravo ZN 4FL	2.25 0.21 1.75 2.25	pt lb pt pt	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	9.3a	2.55a	0	141ab	193
5	Bravo WS 6SC Curzate 60DF + Manzate 75WP + Bravo WS 6SC Bravo WS 6SC	1.5 0.21 1.28 0.75 1.5	pt lb lb pt pt	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	5.0a	1.40a	1.25	166a	213
6	Bravo WS 6SC Curzate 60DF + Manzate 75WP Bravo WS 6SC	1.5 0.21 1.5 1.5	pt lb lb pt	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	38.0a	8.30a	0	120ab	172
7	Bravo WS 6SC Curzate 60DF + Manzate 75WP Bravo WS 6SC	1.5 0.16 1.5 1.5	pt lb lb pt	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	36.8a	7.54a	0	158ab	202
8	Bravo WS 6SC Curzate 60DF + Bravo WS 6SC Bravo WS 6SC	1.5 0.21 1.2 1.5	pt lb lb pt	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	7.3a	1.84a	1.25	140ab	190
9	Manzate 75WP Curzate 60DF + Bravo WS 6SC + Tactic EC Bravo WS 6SC	1.5 0.21 1.2 0.25 1.5	lb lb pt pt pt	7 day (apps 1 - 2) 7 day (apps 3 - 7) 7 day (apps 8 - 9)	9.0a	2.44a	0	145ab	203
10	Bravo WS 6SC Curzate 60DF + Manzate 75WP Bravo WS 6SC	1.5 0.16 1.5 1.5	pt lb lb pt	7 day (apps 1 - 2) 7 day (alt - end) 7 day (alt - end)	17.0a	3.84a	0	144ab	187
11	Untreated				100 b	48.2 b	2.5	159ab	203

[1] final assessment of late blight taken on same as desiccation materials applied

[2] days after inoculation

[3] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)

[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Trial 2 Comparison of control of potato late blight (*Phytophthora infestans*) attained with
a) combinations of Cymoxanil 60DF with different fungicides,
b) EBDC-based programs,
c) copper fungicide-based programs applied as a protectant strategy and
d) the containment of established late blight infection with high rates of triphenyltin hydroxide (Supertin 80WP).

Introduction

Cymoxanil 60DF contains only the cymoxanil component of Manex C8 72WP which has been tested in this and previous trials. This trial compared different combinations of cymoxanil with non-systemic mixture partners, chlorothalonil, triphenyltin hydroxide (Supertin 80WP) and copper-based fungicide (Kocide 2000 WP) with the traditional Manex C8 formulated product (cymoxanil + EBDC). The use of Manex 4FL in combinations with Supertin 80WP and a formulated product (Protex 6SC) applied as protectant strategies and containment strategies was also compared.

Foliar disease results (Table 2a)

All treatments, other than Protex 6SC and the containment strategy (initiated at 10% foliar infection) gave significantly better control in comparison with untreated check plots at the final disease assessment. Cymoxanil 60DF + Supertin 80WP, Cymoxanil 60DF + Kocide 2000 20WP and Manex C8 72WP gave significantly poorer control than Cymoxanil 60DF + Bravo WS 6SC. These fungi cde treatments were statistically different at p = 0.05 (Tukey). Manex 4FL + Supertin 80WP protectant programs were the most effective programs in comparison with all other programs although some differences commented on relate to numerical differences between treatments rather than statistically significant differences. Kocide 2000 20WP + Manex 4FL applied season long did not give good disease control. Comparisons of treatments with reference to the average amount of disease over the growing season (the relative area under the disease progress curve) indicated the same overall pattern although differences were often numerical rather than statistically significant differences. The application of high rates of Supertin 80WP, twice the labeled rate per application but within the permitted seasonal amount, only gave good disease control where the infection had reached up to 5% foliar infection. Some suppression of the epidemic was seen when the initial application was applied at 10% foliar infection but the final level and the raudpc was higher than when disease was controlled by protectant applications of fungicides.

Phytotoxicity (Table 2b)

Phytotoxicity observed as inter-veinal leaf scorch, compound leaf and/or lateral leaflet loss (Table 2b) was noted in the Cymoxanil 60DF + Supertin 80WP, Protex 6SC and both the Manex 4FL + Supertin 80WP disease containment treatments. Other treatments showed minimal phytotoxicity. The amount of phytotoxicity did not increase with time. Manex 4FL, Bravo WS 6SC and Kocide 2000 20WP appear to reduce the leaf scorch observed on plants exhibiting leaf scorch.

Yield

Total yields were very low in this block. The yields generally correlated well with observed disease but Manex C8 and Kocide 2000 20WP + Manex 4FL gave unexpected high yields.

Tuber disease
Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at $p = 0.05$ between tubers samples from any treatments or from untreated plots.

Recommendations
Cymoxanil 60 DF applied at 0.21 lb/acre should be recommended as a highly effective fungicide applied within protectant protection programs in combination with an appropriate residual fungicide protectant partner for the control of foliar late blight. The most effective combination from this trial was a mixture with chlorothalonil.

Various programs with application timings suited to varietal or cultural constraints of Manex 4FL applied in combination with Supertin 80WP should be recommended for late blight control.

Kocide 2000 20WP should be re-evaluated with alternative mixture combinations to determine its appropriate position within potato late blight protection programs.

Protex 6SC should not be recommended for control of potato light blight.

Application of twice the recommended rate of Supertin 80WP in combination with the full recommended rate of Manex 4FL (two applications) gave acceptable control of an epidemic (estimated to be established at a 5% foliar infection level) and could be recommended for management of late blight where disease had become established.

Once disease has become established at more than 5% it is unlikely that any treatment can successfully contain disease spread.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 2a. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - Griffin.

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre) US1	Yield (cwt/acre) Total
1	Manex 4FL + Supertin 80WP Manex 4FL	3.2 0.16 3.2	pt lb pt	7 day (apps 1 - 9) 7 day (to 3 day PHI)	9.8ab[3]	2.51a	0	214ab	260abc
2	Manex 4FL Manex 4FL + Supertin 80WP Supertin 80WP	3.2 3.2 0.16 0.16	pt pt lb lb	7 day (apps 1 - 5) 7 day (apps 6 - 9) 7 day (@14 and 7 day PHI)	5.8a	1.83a	0	225a	274ab
3	Cymoxanyl 60DF + Supertin 80WP	0.21 0.23	lb lb	7 day	40.0 bcd	6.62ab	0	198abc	242abc
4	Cymoxanyl 60DF + Bravo WS 6SC	0.21 1.0	lb pt	7 day	10.3ab	2.74a	0	194abc	240abc
5	Cymoxanyl 60DF + Kocide 2000 20WP	0.21 3.0	lb lb	7 day	57.5 de	9.54ab	1.25	172abc	229abc
6	Manex C8 72WP	1.5	lb	7 day	43.8 cd	9.02ab	0	251a	313a
7	Kocide 2000 20WP+ Manex 4FL	3.0 1.5	lb lb	7 day	43.8 cd	7.13ab	0	241a	301a
8	Protex 6SC	3.0	pt	7 day	71.3 def	15.0 bc	2.5	167abc	214abc
9	Manex 4FL + Supertin 80WP Manex 4FL	3.2 0.47 3.2	pt lb pt	7 day (2 applns at 5% infection) 7 day to 3 day PHI	14.8 bc	3.25a	0	213ab	259abc
10	Manex 4FL + Supertin 80WP Manex 4FL	3.2 0.47 3.2	pt lb pt	7 day (2 applns at 10% infection) 7 day to 3 day PHI	78.8 ef	18.0 c	0	115 bc	161 c
11	Untreated				100 f	51.4 d	0	112 c	166 bc

[1] final assessment of late blight taken on same as desiccation materials applied

[2] days after inoculation

[3] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)

[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Table 2b. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - Griffin.

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% phytotoxicity[1]	
					8/18 19 dai	8/25 26 dai 9/2 33 dai
1	Manex 4FL + Supertin 80WP Manex 4FL	3.2 0.16 3.2	pt lb pt	7 day (apps 1 - 9) 7 day (to 3 day PHI)	0.5a[2]	0.5a
2	Manex 4FL Manex 4FL + Supertin 80WP Supertin 80WP	3.2 3.2 0.16 0.16	pt pt lb lb	7 day (apps 1 - 5) 7 day (apps 6 - 9) 7 day (@14 and 7 day PHI)	1.0a	1.0a
3	Cymoxanyl 60DF + Supertin 80WP	0.21 0.23	lb lb	7 day	6.5ab	6.5ab
4	Cymoxanyl 60DF + Bravo WS 6SC	0.21 1.0	lb pt	7 day	0.8a	0.8a
5	Cymoxanyl 60DF + Kocide 2000 20WP	0.21 3.0	lb lb	7 day	0.5a	0.5a
6	Manex C8 72WP	1.5	lb	7 day	0.5a	0.5a
7	Kocide 2000 20WP+ Manex 4FL	3.0 1.5	lb lb	7 day	0.8a	0.8a
8	Protex 6SC	3.0	pt	7 day	3.3ab	3.3ab
9	Manex 4FL + Supertin 80WP Manex 4FL	3.2 0.47 3.2	pt lb pt	7 day (2 applns at 5% infection) 7 day to 3 day PHI	14.5 b	14.5 b
10	Manex 4FL + Supertin 80WP Manex 4FL	3.2 0.47 3.2	pt lb pt	7 day (2 applns at 10% infection) 7 day to 3 day PHI	40.0 c	40.0 c
11	Untreated				0a	0a

[1] Phytotoxicity measured as complete leaf abscission or abscission in combination with severe scorch lesions
[2] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)

Trial 3. Comparison of control of potato late blight (*Phytophthora infestans)* attained with
a) combinations of Acrobat 50WP with different rates of chlorothalonil-based fungicides and other fungicides
b) WP and WDG formulations of Acrobat MZ
c) section 18 fungicides.

Introduction

Acrobat 50WP contains only the dimethomorph component of Acrobat MZ 69WP which has been tested in this and previous trials. This trial compared different combinations of dimethomorph with non-systemic mixture partners, chlorothalonil and fluazinam and with the systemic fungicide Banol 6.65FL (a.i. propamocarb) and with the traditional Acrobat MZ 69WP formulated product (dimethomorph + EBDC).

Foliar disease results (Table 3)

All treatments, gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). Acrobat 50WP + Banol 6.65SC gave significantly poorer control than all the other Acrobat 50WP-based treatments and the Acrobat MZ formulations and the Bravo Ultrex 82.5WG standard. These fungi cde treatments were statistically different at p = 0.05 (Tukey). All the fungi cde treatments other than the Acrobat 50WP + Banol 6.65SC treatment were the most effective programs although some differences commented on relate to numerical differences between treatments rather than statistically significant differences.

No differences were observed between treatments with increased rates of chlorothalonil + Acrobat 50WP. The best disease control was attained by the Acrobat 50WP + fluazinam combination. The Acrobat 69WDG formulation gave disease control equal to the Acrobat MZ 69WP formulation. Tattoo C 6.25SC, Curzate M8 72WP + Manzate 75WP and the Acrobat MZ formulations all gave similar levels of disease control.

Comparisons of treatments with reference to the average amount of disease over the growing season (the relative area under the disease progress curve) indicated the same overall pattern although differences were often numerical rather than statistically significant differences..
Phytotoxicity was not observed.

Yield

The yields generally correlated well with observed disease but of note was the increased yield observed from the Acrobat 50WP + fluazinam 5SC and the Acrobat MZ 69WDG treatments.

Tuber disease

Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at p = 0.05 between tubers samples from any treatments or from untreated plots.

Recommendations

Acrobat 50WP applied at 0.41 lb/acre should be recommended as a highly effective fungicide applied within protectant protection programs in combination with an appropriate residual fungicide protectant partner for the control of foliar late blight.

The most effective combinations from this trial were the mixtures with chlorothalonil, EBDC and fluazinam.

Future work should concentrate on appropriate positioning of Acrobat 50WP based products in relation to host and pathogen development.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 3. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - American Cyanamid

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre)	
					9/2 33 dai[2]			US1	Total
1	Acrobat 50WP + Bravo Ultrex 82.5WDG	0.41 0.68	lb lb	7 day	10.0a[3]	2.33a	1.25	223ab	288ab
2	Acrobat 50WP + Bravo Ultrex 82.5WDG	0.41 1.02	lb lb	7 day	9.0a	2.32a	0	224ab	297ab
3	Acrobat 50WP + Bravo Ultrex 82.5WDG	0.41 1.36	lb lb	7 day	8.8a	2.13a	1.25	281a	339a
4	Bravo Ultrex 82.5WDG	1.36	lb	7 day	7.3a	2.21a	2.5	237a	292ab
5	Tattoo C 6.25 SC	2.3	pt	7 day	10.8a	2.42a	1.25	244a	303ab
6	Curzate 72WP+ Manzate 75WP	1.5 0.64	lb lb	7 day	9.3a	3.13a	3.75	201ab	250ab
7	Acrobat MZ 69WP	2.25	lb	7 day	6.8a	2.53a	0	274a	330a
8	Acrobat MZ 69WDG	2.25	lb	7 day	7.5a	1.79a	0	314a	370a
9	Acrobat 50WP + Banol 6.65FL	0.41 1.08	lb pt	7 day	32.0 b	8.75 b	0	223ab	283ab
10	Acrobat 50WP + Fluazinam 5FL	0.41 0.6	lb pt	7 day	7.3a	1.56a	1.25	291ab	348a
11	Untreated				100 c	47.3 c	1.25	106 b	167 b

[1] final assessment of late blight taken on same as desiccation materials applied

[2] days after inoculation

[3] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)

[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Trial 4 Comparison of control of potato late blight (*Phytophthora infestans*) attained with a) EXP 10623A 4.17SC in combinations with EXP 10673A 4.5SC, chlorothalonil and EBDC-based fungicides

Introduction

This trial was conducted to determine the dose rate response of EXP 10623A 4.17SC an experimental fungicide in combination with different dose rates of chlorothalonil (Bravo WS 6SC) and its efficacy in combination with EXP 10673A 4.5SC or an EBDC (Dithane 75DF). Some confidential treatments were also included in this trial. Confidential treatments represent experimental compounds and/or mixtures.

Foliar disease results (Table 4)

All EXP 10623A 4.17SC treatments in combination with other mixture partners gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). These fungicide treatments were statistically different at $p = 0.05$ (Tukey).

All the fungicide treatments were effective and no significant differences were measured at $p = 0.05$. Some observed differences relate to numerical differences between treatments rather than statistically significant differences.

EXP 10623A 4.17SC was numerically most effective in combination with Bravo WS 6SC at respective combination rates of 0.34 pt + 1.5 pt/acre. This combination had at least half the amount of any other treatment in terms of final foliar disease but averaged over the season gave similar control to all other treatments. Comparisons of treatments with reference to the average amount of disease over the growing season (the relative area under the disease progress curve) indicated the same overall pattern although differences were often numerical rather than statistically significant differences. Phytotoxicity was not observed.

Yield

The yields generally correlated well with observed disease.

Tuber disease

Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at $p = 0.05$ between tubers samples from any treatments or from untreated plots.

Recommendations

EXP 10623A 4.17SC applied at 0.34 pt/acre should be recommended as a highly effective fungicide applied within protectant protection programs in combination with an appropriate residual fungicide protectant partner for the control of foliar late blight.

The most effective combinations from this trial were the mixtures of EXP 10623A 4.17SC with chlorothalonil applied at 1.5 pt/acre.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 4. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - Rhone-Poulenc and Agraquest

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre) US1	Yield (cwt/acre) Total
1	EXP10623A 4.17 SC + Bravo WS 6SC	0.26 1.05	pt pt	7 day	10.8a[3]	3.12a	0	193ab	249ab
2	EXP10623A 4.17 SC + EXP10673A 4.5SC + Bond 8.33 SC	0.34 1.5 0.25	pt pt pt	7 day	17.0a	3.96a	2.5	200a	259ab
3	EXP10623A 4.17 SC + Bravo WS 6SC	0.26 0.75	pt pt	7 day	13.3a	4.06a	0	209a	258ab
4	EXP10623A 4.17 SC + Bravo WS 6SC	0.34 1.05	pt pt	7 day	19.3a	4.47a	0	223a	285a
5	EXP10623A 4.17 SC + Bravo WS 6SC	0.34 1.5	pt pt	7 day	6.3a	2.35a	0	241a	285a
6	Bravo WS 6SC Bravo WS 6SC	0.75 1.5	pt pt	7 day (apps 1 - 2) 7 day (apps 3 - 9)	12.0a	3.32a	0	160abc	217abc
7	EXP10623A 4.17 SC + Dithane 75DF + Bond 8.33 SC	0.34 2.0 0.25	pt lb pt	7 day	14.0a	3.53a	0	220a	287a
8	Untreated				100 b	52.2 b	0	89 c	149 c

[1] final assessment of late blight taken on same as desiccation materials applied

[2] days after inoculation

[3] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)

[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Trial 5 Comparison of control of potato late blight (*Phytophthora infestans)* attained with different residual fungicides.

Introduction

This trial was conducted to determine the efficacy of fungicides known to have contact-only activity applied season long. Comparison of some programs utilizing increasing rates of fungicides in relation to canopy expansion and combinations of protectant fungicides were also made. Confidential treatments represent experimental compounds and/or mixtures.

Foliar disease results (Table 5)

All treatments except gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). These fungicide treatments were statistically different at p = 0.05 (Tukey).

All the other fungicide treatments were effective and no significant differences were measured at p = 0.05. Some observed differences relate to numerical differences between treatments rather than statistically significant differences.

The activity of Polyram 80DF was improved slightly by the addition either Supertin 80WP or by Norplex Calcium 6SC. The Polyram 80DF-based programs gave similar blight control to the standard (Bravo WS 6SC). The activity of Penncozeb 75DF (increasing rate applications) was slightly improved by the addition of Supertin 80WP to the final three applications and gave similar blight control to the standard (Bravo WS 6SC). Phytotoxicity was not observed.

Yield

The yields generally correlated well with observed disease.

Tuber disease

Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at p = 0.05 between tubers samples from any treatments or from untreated plots.

Recommendations

Polyram 80DF-based programs incorporating either Supertin 80WP or by Norplex Calcium 6SC can be used for effective control of potato late blight. Programs should begin before disease is established in the crop.

Penncozeb 75DF-based programs incorporating Supertin 80WP for the final three applications can be used for effective control of potato late blight. Programs should begin before disease is established in the crop.

Bravo WS 6SC programs can be used for effective control of potato late blight. Programs should begin before disease is established in the crop.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 5. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - UAP and Elf Atochem.

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre)	
								US1	Total
1	Polyram 80DF	2.0	lb	7 day	14.5a[3]	4.62a	2.5	216a	266abc
2	Polyram 80DF + Supertin 80WP + Tactic EC	2.0 0.16 0.25	lb lb pt	7 day	12.0a	3.86a	1.25	221a	276ab
3	Polyram 80DF + Supertin 80WP	2.0 0.16	lb lb	7 day	10.5a	3.01a	0	212a	271abc
4	Norplex Calcium 6SC Polyram 80DF + Norplex Calcium 6SC	0.26 2.0 0.26	pt lb pt	7 day pre-program 7 day	9.0a	3.15a	0	204ab	252abc
5	Bravo WS 6SC	1.5	pt	7 day	17.5a	5.56a	0	221a	282ab
6	Penncozeb 75DF Penncozeb 75DF Penncozeb 75DF	1.0 1.5 2.0	lb lb lb	7 day (appln 1) 7 day (appln 2 - 5) 7 day (appln 6 - 9)	20.0a	7.35a	2.5	218a	295a
7	Penncozeb 75DF Penncozeb 75DF Penncozeb 75DF + Supertin 80WP	1.0 1.5 2.0 0.16	lb lb lb lb	7 day (appln 1) 7 day (appln 2 - 5) 7 day (appln 6 - 9)	12.3a	4.17a	2.5	214a	261abc
8	Untreated				100 b	52.2 b	0	117 b	192 bc

[1] final assessment of late blight taken on same as desiccation materials applied

[2] days after inoculation

[3] values followed by the same letter are not significantly different at $p = 0.05$ (Tukey Multiple Comparison)

[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Trial 6 Comparison of control of potato late blight (*Phytophthora infestans)* attained and phytotoxicity of combinations of fungicides with novel insecticides
a) Acrobat MZ69 in combinations with Alert 2SC
b) Agrimek in combinations with Acrobat MZ69, Polyram 80DF and Bravo WS 6SC

Comparison of control of potato late blight (*Phytophthora infestans)* attained with copper-based fungicides

Introduction

This trial was conducted to determine the efficacy of fungicides in combination with two novel insecticides and to determine if the combination caused phytotoxic symptoms on potato foliage. This trial also contained treatments comparing two copper-based fungicides, one in combination with a chlorothalonil-based treatment.

Foliar disease results (Table 6)

a) Fungicides plus insecticides
All treatments gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). These fungicide treatments were statistically different at $p = 0.05$ (Tukey).

The combination of Alert 2SC with Acrobat MZ69 caused no phytotoxicity and did not reduce fungicide efficacy. The insecticide was combined with the fungicide in all applications.

Agrimek was added to the fungicides tested at only three application timings (2, 5 and 8) of a total of 9 applications. No phytotoxicity was observed. In combination with Acrobat MZ69 the addition of Agrimek did not affect efficacy against late blight. The level of disease control in combination with Polyram 80DF was less than in combination with Bravo WS 6SC. Where the fungicide was not included at application timings 2, 5 and 8 the level of disease control was reduced to a level intermediate between the program with Polyram 80DF and Bravo WS 6SC.

b) Copper-based fungicides
All treatments gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). These fungicide treatments were statistically different at $p = 0.05$ (Tukey).

All the fungicide treatments were effective and no significant differences were measured at $p = 0.05$. Some observed differences relate to numerical differences between treatments rather than statistically significant differences.

Champ 2 4.6FL in combination with Bravo ZN 4FL applied at rates intended to correspond to the amount of canopy development gave excellent control of late blight. The level of control was slightly reduced where Champ 2.4 6FL was applied alone. Kocide 2000 20WP applied season-long gave inadequate control of late blight. Comparisons of treatments with reference to the average amount of disease over the growing season (the relative area under the disease progress curve) indicated the same overall pattern although differences were numerical rather than statistically significant differences.

Phytotoxicity was not observed.

Yield
The yields generally correlated well with observed disease.

Tuber disease
Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at p = 0.05 between tubers samples from any treatments or from untreated plots.

Recommendations
a) Fungicides plus insecticides
Alert 2SC can be safely mixed with Acrobat MZ 69WP at application rates ap to 0.8 pt/acre without compromising disease control.
Agrimek can be safely mixed with Polyram 80WP, Acrobat MZ 69WP and Bravo WS 6SC.
Agrimek applied in the absence of a fungicide (Bravo WS 6SC) reduced overall disease control and should therefore be applied in combination with a fungicide during weather periods or in other conditions conducive to late blight.
Programs containing Polyram 80WP plus Agrimek applications **alone** can not be recommended for late blight control.

b) Copper-based fungicides
Combination programs utilizing increasing rates of Champ 2.4 6FL + Bravo ZN 4FL can be recommended for control of potato late blight.
Champ 2.4 6FL applied alone season long at 2.67 pt/acre can only be recommended for control of potato late blight during conditions which are considered to be low risk exposure.
Kocide 2000 20WP applied alone season-long at 3.0 lb/acre can not be recommended for control of potato late blight.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 6. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - American Cyanamid, Merck (Novartis) and Agtrol

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre) US1	Yield (cwt/acre) Total
1	Acrobat MZ69 + Alert 2SC	2.25 0.4	lb pt	7 day	9.0a[3]	2.68a	0	245a	307a
2	Acrobat MZ69 + Alert 2SC	2.25 0.8	lb pt	7 day	8.8a	2.96ab	3.75	241a	289a
3	Acrobat MZ69	2.25	lb	7 day	12.0ab	3.55ab	0	235a	293a
4	Acrobat MZ69 Acrobat MZ69 + Agrimek	2.25 2.25 0.02	lb lb pt	7 day 7 day apps 2,5,8	7.8a	2.71a	0	203ab	258ab
5	Polyram 80DF Polyram 80DF + Agrimek	2.0 2.0 0.02	lb lb pt	7 day 7 day apps 2,5,8	43.3 b	10.5ab	0	193ab	245ab
6	Bravo WS 6SC Bravo WS 6SC + Agrimek	1.5 1.5 0.02	pt pt pt	7 day 7 day apps 2,5,8	14.3ab	3.9ab	0	209ab	249ab
7	Bravo WS 6SC Agrimek	1.5 0.02	pt pt	7 day 7 day apps 2,5,8	25.0ab	7.29ab	0	163ab	211ab
8	Champ 2 4.6FL	2.67	pt	7 day	16.3ab	5.92ab	2.5	166ab	214ab
9	Champ 2 4.6FL + Bravo ZN 4FL Champ 2 4.6FL + Bravo ZN 4FL	2.67 1.8 2.67 2.0	pt pt pt pt	7 day apps 1 - 2 7 day apps 3 - 9	10.0ab	2.77ab	1.25	170ab	212ab
10	Kocide 2000 20WP	3.0	lb	7 day	40.0ab	12.5 b	0	171ab	234ab
11	Untreated				100 c	49.3 c	0	131 b	177 b

[1] final assessment of late blight taken on same as desiccation materials applied
[2] days after inoculation
[3] values followed by the same letter are not significantly different at $p = 0.05$ (Tukey Multiple Comparison)
[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Trial 7 - The National Potato Late Blight Trial

Introduction

This trial was conducted as part of the National Potato Late Blight Trial (full results available from Inglis and Powelson, Oregon State University) to determine the efficacy of three fungicides registered under the emergency Section 18 provision of the Environmental Protection Agency. In addition, comparisons of fungicide programs based on protectant products with the Section 18 programs were also made.

Foliar disease (Table 7)

All treatments gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). These fungicide treatments were statistically different at $p = 0.05$ (Tukey).

All the fungicide treatments were effective and only the Kocide 2000 20WP plus Manex 4FL based program had significantly more foliar disease at the final assessment of late blight in comparison with the Tattoo C 6.25SC-based program. No other treatments showed significant differences between means ($p = 0.05$). Some observed differences relate to numerical differences between treatments rather than statistically significant differences.

The Tattoo C 6.25SC alternated with Bravo WS 6SC and Acrobat MZ 69WP alternated with Bravo WS 6SC programs had around half the final foliar disease as the next best treatment. These programs also had slightly lower disease progress and slightly larger final yield in comparison to the other fungicide programs. The Tattoo C 6.25SC program had significantly lower final foliar disease than Kocide 2000 20WP + Manex 4FL. The Quadris 2.1 SC-based program gave similar blight control to the standard (Bravo WS 6SC).

Yield

Only the programs Tattoo C 6.25SC alternated with Bravo WS 6SC, Acrobat MZ 69WP alternated with Bravo WS 6SC, and Polyram 80DF alternated with Polyram 80DF + Supertin 80WP had significantly higher yields than the untreated control.

Tuber disease

Polyram 80DF alternated with Polyram 80DF + Supertin 80WP had the lowest percentage of rotted tubers rotted at harvest. This treatment had significantly a lower number of rotted tubers at harvest than the Kocide 2000 20WP + Manex 4FL treatment but not statistically differ from the others. The number of tubers relative to the untreated control is a measure of tuber loss. The Polyram 80DF alternated with Polyram 80DF + Supertin 80WP program has the greatest number of tubers compared to the untreated control. The Acrobat MZ 69WP alternated with Bravo WS 6SC program ranked second in the number of tubers produced relative to the untreated control. This may be a measure of the anti-sporulant properties of Supertin 80WP and Acrobat MZ 69WP.

Phytotoxicity was not noted in any of the treatments.

Recommendations

All the programs tested can be recommended for control of potato late blight although under high disease pressure the programs incorporating Acrobat or Tattoo C should be used.

Under high disease pressure, the programs with section 18 fungicides (Tattoo C 6.25SC, Acrobat MZ 69WP) should be used to either prevent disease or reduce the impact of established disease.

The programs reliant on protectants alone can be recommended for late blight control (Bravo WS 6SC, Polyram 80WP + Supertin 80WP and Dithane 75WP) .

Curzate M8 72WP should be used in a similar way to protectant products (see previous) for control of potato late blight.

In seasons when the severity of weather conditions would not favor severe late blight development, programs based on Bravo WS 6SC, Polyram 80WP + Supertin 80WP, Dithane 75WP and Curzate 72WP would give excellent disease control.

The observations of individuals responsible for implementing programs should determine when best to change from one product to another.

The appropriate placement of section 18 products within programs is determined by the mode of action of the product in relation to host and disease development. For example, Tattoo C should be applied to protect new growth early in development, Curzate M8 should be applied while the canopy is expanding but before senescence and Acrobat MZ is most effective as a post-senescence product and can be applied up to late crop senescence.

Quadris 2.1 SC + Bond 3.75SC alternating with Bravo WS 6SC can be recommended for control of potato late blight.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 7. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - National.

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	% rotten tubers at harvest	Tuber number relative to untreated at harvest (%)	Yield (cwt/acre) US1	Yield (cwt/acre) Total
1	Bravo WS 6SC	1.5	pt	7 day	15.8ab[3]	4.68a	0	3.4ab	110ab	138ab	193ab
2	Kocide 2000 20WP + Manex 4FL	3.0 1.5	lb pt	7 day	24.5 b	7.26a	0	4.7a	132ab	139ab	185ab
3	Polyram 80DF Polyram 80DF + Supertin 80WP	2.0 2.0 0.16	lb lb lb	7 day apps 1 - 3 7 day apps 4 - 9	17.0ab	5.32a	1.25	0.7 b	150a	199a	251a
4	Dithane 75DF	2.0	lb	7 day	14.0ab	4.84a	0	2.3ab	129ab	172ab	233ab
5	Bravo WS 6SC Curzate 60DF + Manzate 75WP Bravo WS 6SC	1.5 0.21 1.75 1.5	pt lb lb pt	7 day apps 1 - 3 7 day apps 4 - 8 7 day app 9	16.5ab	5.23a	0	3.0ab	111ab	165ab	224ab
6	Bravo WS 6SC Acrobat MZ69 Bravo WS 6SC Acrobat MZ69	1.5 2.25 1.5 2.25	pt lb pt lb	7 day apps 1 - 3 7 day apps 4,5 7 day apps 6 - 8 7 day app 9	8.8ab	3.04a	0	2.3ab	138ab	194a	252a
7	Bravo WS 6SC Tattoo C 6.25SC Bravo WS 6SC	1.5 2.3 1.5	pt pt pt	7 day apps 1 - 2 14 day apps 3, 5, 7 14 day apps 4, 6, 8, 9	6.3a	2.2a	0	3.2ab	122ab	223a	273a
8	Quadris 2.1 SC + Bond 3.75SC Bravo WS 6SC	1.14 0.13 1.5	pt pt pt	14 day alternate 14 day alternate	12.3ab	4.62a	0	2.4ab	135ab	166ab	219ab
9	Untreated				100 c	49.2 b	0	1.7ab	100 b	76 b	132 b

[1] final assessment of late blight taken on same as desiccation materials applied
[2] days after inoculation
[3] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)
[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Trial 8 Comparison of control of potato late blight (*Phytophthora infestans*) attained with
a) EBDC and chlorothalonil–based products
b) alternative application timings of Tattoo C 6.25SC

Introduction

This trial was conducted as to compare the efficacy of chlorothalonil-based (Bravo WS and Terranil) programs. The efficacy of some novel formulations of chlorothalonil-based fungicides were compared against established formulations. Application timings for Tattoo C 6.25SC were also tested to determine the most effective timings to prevent the establishment of potato late blight.

Foliar disease (Table 8)

All treatments gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). These fungicide treatments were statistically different at $p = 0.05$ (Tukey).

Some observed differences relate to numerical differences between treatments rather than statistically significant differences.

The traditional formulations of chlorothalonil, Terranil FL 6SC, Terranil 90DF and Terranil ZN 4FL applied season long on a 7 day schedule all gave excellent control of potato late blight.

The Tattoo C 6.25SC alternated with Bravo WS 6SC program and the sequential applications of Tattoo C preceded by 2 applications and followed by 4 applications of Bravo WS 6SC gave a similar high level of disease control. The alternating program appeared to have a higher level of season long control (raudpc).

Yield

The yields generally correlated well with observed disease. Bravo ZN 4FL and the Tattoo C/Bravo WS 6SC alternate program had a significantly higher yield of US1 potatoes in comparison with the untreated control but not with other treatments.

Tuber disease

Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at $p = 0.05$ between tubers samples from any treatments or from untreated plots.

Phytotoxicity was not noted in any of the treatments.

Recommendations

Bravo ZN 4FL can be recommended at an application rate of 2.13 pt/acre on a 7 day schedule for control of potato late blight.

In seasons when the severity of weather conditions would favor severe late blight development, programs based on 7 day application schedules of Bravo WS 6SC, Bravo ZN 4FL, Terranil FL 6SC, Terranil 90DF and Terranil ZN 4FL would give excellent disease control.

Tattoo C 6.25 SC should be recommended for potato late blight control as a component of a managed disease control program. The preferred application of Tattoo C 6.25 SC would be in an alternating program with e.g. Bravo WS 6SC.

All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 8. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - ISK, Agrevo, Terra.

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre) US1	Yield (cwt/acre) Total
1	Bravo WS 6SC Tattoo C 6.25SC Bravo WS 6SC Bravo WS 6SC	1.5 2.3 1.5 1.5	pt pt pt pt	7 day apps 1 - 2 10 day alter 3,5,7 10 day alter 4,6,8 7 day app 9	5.3a	0.09a	0	141ab	193
2	Bravo WS 6SC Tattoo C 6.25SC Bravo WS 6SC	1.5 2.3 1.5	pt pt pt	7 day apps 1 - 2 7 day alter 3 - 5 7 day alter 6 - 9	8.8a	1.52a	0	166a	213
3	Bravo WS 6SC	1.5	pt	7 day	16.8a	1.64a	0	120ab	172
4	Bravo ZN 4FL	2.13	pt	7 day	16.8a	2.66a	0	158ab	202
5	Terranil 6L 6SC	1.5	pt	7 day	8.3a	1.21a	0	147ab	188
6	Terranil 90DF	1.25	lb	7 day	13.8a	1.26a	0	181a	234
7	Terranil ZN 4FL	2.13	pt	7 day	12.5a	1.88a	1.25	144ab	188
8	Untreated				100 c	30.3 c	0	60 b	110

[1] final assessment of late blight taken on same as desiccation materials applied
[2] days after inoculation
[3] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)
[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Trial 9 - Comparison of control of potato late blight (*Phytophthora infestans*) attained with
a) alternative application timings of Tattoo C 6.25SC
b) alternative application targets (soil and lower foliage) of Tattoo C 6.25SC
c) Ridomil Gold (mefonoxam) formulations,
d) novel fungicides, fluazinam and Quadris 2.1SC

Introduction

This trial was conducted as to compare the efficacy of different systemic fungicide products applied as component fungicides within a management strategy for control of potato late blight. The efficacy of some novel fungicide products, Fluazinam 5SC and Quadris 2.1 SC were compared against established formulations. Application timings and targets for Tattoo C 6.25SC were also tested to determine the most effective timings and targets to prevent the establishment of potato late blight.

Foliar disease (Table 9)

This trial block was under the most severe pressure at the Muck Farm site in 1997. The block was situated contiguous with an anti-sporulation trial and the inoculum production from that area was higher than in other areas of the farm. All treatments, other than the Tattoo C 6.25SC lower foliage application, gave significantly better control in comparison with untreated check plots at the final disease assessment and season-long average disease (raudpc). These fungicide treatments were statistically different at $p = 0.05$ (Tukey).

The Tattoo C 6.25SC lower foliage application had a greater average amount of foliar disease at the final assessment of late blight and also when assessed as the season-long average disease (raudpc) in comparison with the other programs. No other treatments showed significant differences between means ($p = 0.05$). Some observed differences relate to numerical differences between treatments rather than statistically significant differences.

The Fluazinam 5SC applied on a 7 day schedule at 0.6 pt/acre gave excellent control of late blight and had less disease at the final assessment and lower season-long average in comparison with all other treatments. Bravo WS 6SC applied season-long at full rate (1.5 pt/acre) had an intermediate level of disease between the systemic programs and the purely protectant programs based on residual contact fungicides.

The Tattoo C 6.25SC, Ridomil Gold Bravo 69WP and the Ridomil Gold MZ 69WP programs showed higher disease levels than the standard Bravo WS 6SC program. The application of Tattoo C 6.25 SC as a soil treatment gave about 60% disease control in comparison with the untreated plots and may demonstrate some ability of the fungicide to be move systemically by root uptake. Trials in controlled environments have confirmed that soil uptake of Tattoo C 6.25SC by potato roots takes place (data to follow). The uptake by lower foliage was not demonstrated in the field trial. The fungicide was applied to leaves which had probably begun to senesce and therefore active transport was not obvious by biological assay.

Quadris 2.1 SC applied in an alternating 7 day application schedule with Bravo WS 6SC showed a clear dose response. The level of control was improved at an application rate of 1.14 pt/acre (almost double the amount of disease was observed at the 0.76 application rate). Initiation of the program with three applications of Bravo WS 6SC then switching to Quadris 2.1 SC applied at 0.76 pt/acre in an alternating

7 day application schedule with Bravo WS 6SC also gave improved control in comparison with the season long alternating program at the same application rate of Quadris 2.1 SC. Phytotoxicity was not noted in any of the treatments.

Yield

The yields generally correlated well with observed disease. Bravo ZN 4FL and the Tattoo C/Bravo WS 6SC alternate program had a significantly higher yield of US1 potatoes in comparison with the untreated control but not with other treatments.

Tuber disease

Low numbers (<5% of the sample) of late blight infected tubers were observed after 90 days in storage. There were no significant differences at $p = 0.05$ between tubers samples from any treatments or from untreated plots.

Recommendations

Under severe disease pressure conditions:

Fluazinam 5SC should be recommended at an application rate of 0.6 pt/acre on a 7 day schedule for control of potato late blight.

Bravo WS 6SC can be recommended to give moderate disease control of potato late blight at an application rate of 1.5 pt/acre on a 7 day schedule.

Quadris 2.1SC can be recommended to give moderate disease control of potato late blight at managed application rates in alternate applications with e.g. Bravo WS 6SC (1.5 pt/acre) of e.g. 1.14 pt/acre, or after application of an initial fungicide build up on the lower canopy of e.g. Bravo WS 6SC (1.5 pt/acre) of e.g. 1.14 pt/acre on a 7 day schedule.

Tattoo C 6.25 SC can be recommended to give moderate disease control of potato late blight as a component of a managed disease control program.

The application of Tattoo C 6.25 SC as a soil applied fungicide requires further work although initial studies indicate that the fungicide is taken up by the roots.

The application of Tattoo C 6.25 SC as a lower canopy applied fungicide requires further work although initial studies indicate that the fungicide is not effectively taken up by the lower leaves or stem tissue, probably due to the senescent properties of these tissues and the impermeable nature of lignified stem tissue.

Ridomil Gold Bravo and MZ (both 69WP) can be recommended to give moderate disease control of potato late blight as a component of a managed disease control program.

Under these conditions, the importance of the initial applications is clear. Protectant products must be applied in order to build up a residual base to prevent initial infections of potato late blight.
All products are applied at full recommended rate, unless specified. No recommendations can be made for the application of any product at rates less than those tested.

Table 9. Control of potato late blight with foliar applied fungicides, 1997. Sponsors - Agrevo, Zeneca

	Chemical	Rate Formulation pints or lbs/acre		Spray Schedule	% foliar late blight[1] 9/2 33 dai[2]	Relative area under disease progress curve max=100	Tuber blight % incidence[4]	Yield (cwt/acre) US1	Yield (cwt/acre) Total
1	Bravo WS 6SC	1.5	pt	7 day	18.8a[3]	4.32a	0	220a	290a
2	Bravo WS 6SC Tattoo C 6.25SC Bravo WS 6SC	1.5 2.3 1.5	pt pt pt	7 day apps 1 - 2 7 day alter 3 - 5 7 day alter 6 - 9	33.7a	7.48a	0	200ab	265ab
3	Bravo WS 6SC Tattoo C 6.25SC Bravo WS 6SC Bravo WS 6SC	1.5 2.3 1.5 1.5	pt pt pt pt	7 day apps 1 - 2 14 day alter 3,5 14 day alter 4,6 7 day app 7 - 9	31.3a	5.21a	0	213a	275ab
4	Bravo WS 6SC Ridomil Gold Bravo 69WP Bravo WS 6SC Bravo WS 6SC	1.5 2.0 1.5 1.5	pt lb pt pt	7 day apps 1 - 2 14 day alter 3,5 14 day alter 4,6 7 day app 7 - 9	25.0a	5.12a	0	245a	302a
5	Tattoo C 6.25SC Bravo WS 6SC	2.3 1.5	pt pt	7 day two soil apps at app 4 and 5 7 day to end	36.3a	6.45a	0	178ab	228ab
6	Tattoo C 6.25SC Bravo WS 6SC	2.3 1.5	pt pt pt	7 day two lower foliage apps at app 4 and 5 7 day to end	100 b	38.0 b	0	132ab	182ab
7	Bravo WS 6SC Ridomil Gold Bravo 69WP	1.5 2.0	pt lb	14 day alternate 14 day alternate	32.5a	6.69a	0	218a	273ab
8	Bravo WS 6SC Ridomil Gold MZ 69WP	1.5 2.5	pt lb	14 day alternate 14 day alternate	33.8a	6.00a	0	238a	292a
9	Fluazinam 5SC	0.6	pt	7 day	11.5a	3.68a	0	242a	291a
10	Quadris 2.1SC + Bond 3.75SC Bravo WS 6SC	0.76 0.13 1.5	pt pt pt	14 day alternate 14 day alternate	33.8a	7.45a	0	209ab	270ab
11	Quadris 2.1SC + Bond 3.75SC Bravo WS 6SC	1.14 0.13 1.5	pt pt pt	14 day alternate 14 day alternate	20.0a	4.14a	0	216a	269ab
12	Bravo WS 6SC Quadris 2.1SC + Bond 3.75SC Bravo WS 6SC	1.5 0.76 0.13 1.5	pt pt pt pt	7 day apps 1 - 3 14 day alternate 14 day alternate	17.5a	4.75a	0	189ab	247ab
13	Untreated				100 b	52.1 c	0	93 b	154 b

[1] final assessment of late blight taken on same as desiccation materials applied
[2] days after inoculation
[3] values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison)
[4] the incidence of tuber blight was determined after storing samples of tubers from each replicate for 90 days in plastic bags. The tubers had been wetted prior to storage.

Funding Federal Grant/MPIC

CONTRIBUTION OF AMINO ACIDS AND REDUCING SUGARS TO COLOR DEVELOPMENT IN POTATO CHIPS

V. Chonhenchob, J.N. Cash and R. Brook

INTRODUCTION

Browning or darkening of potato chips has received a great deal of study because consumers usually equate light colored potato chips with good quality. This dark color formed under frying conditions is due to the Maillard reaction involving the interaction between reducing sugars and amino acids at high temperatures. Generally, potato chip processors rely upon using potatoes from storage but potato tubers stored at temperatures below 45 F (7C) have been shown to accumulate reducing sugars. Reducing sugar content in the tuber has normally been used to predict the fry color of potato chips since sugars are generally considered to be the limiting factor in color development in potato chips. Potato tubers containing high reducing sugar content usually process into dark colored chips. However, it has been shown that information on sugar alone may not be used to regularly predict the final fry color of chips. The variation in the chip color has been ascribed to the free amino acid content present in the tuber. Very few studies have been aimed at determining the effect of amino compounds on the formation of potato chip color. As the complexities of potato chip color development remain in question, more in depth studies are needed to further elucidate the factors affecting quality improvement of processed potatoes.

Objectives

This study was divided into a model system study and a potato storage study. The primary objectives of these studies were as follows:

1. To determine the differences between selected good chipping versus poor chipping cultivars in terms of sugar content, free amino acid composition, free amino group content and chipping performance.

2. To determine the effect of specific amino acids and sugars on color development in potato chips based on the model systems.

3. To determine the effect of amino acids and sugars on color development in potato chips made from stored potato tubers.

MATERIALS AND METHODS

A. Model Systems

Model systems using filter paper disks

The model system studies utilized filter paper disks impregnated with solutions of amino acids and sugars in order to determine the effect of individual amino acids and sugars on Maillard browning.

Stock solutions (0.05M) of L-isomer amino acids (arginine, aspartic acid, glutamic acid, glycine, isoleucine, leucine, lysine, methionine, tyrosine, valine) and sugars (D-fructose, D-glucose, and sucrose) were prepared for the study in 0.05M phosphate buffer solutions (pH 6.5). Filter paper disks were prepared by soaking 30 Whatman No. 3MM disks, 5.5 cm diameter, for 30

min in the appropriate solutions. The disks were then air dried and fried in fresh vegetable oil at 356 F for 2 min. Each sample was done in duplicate. Filter paper disks impregnated with phosephate buffer were fried as a control. The color of the filter paper disks was evaluated using Agtron E-10 colorimeter.
Filter paper disks were also impregnated with potato juices to show the effect of amino acid and sugar naturally present in various cultivars on Maillard browning intensity. Five potato varieties, Atlantic, Mainestay, Shepody, Snowden, and Superior were obtained from the Michigan State University Montcalm Research Farm. Filter paper disks were loaded with 1 mL of juice prepared from the tubers, air dried then fried in fresh vegetable oil at 356 F for 2 min. Potato chips were also made from each of the tuber varieties. The color of filter paper disks and potato chips was evaluated using Agtron E-10 colorimeter.

Model systems using potato slices.

Potato slices were vacuum infiltrated with varying concentrations of selected amino acids and sugars to determine the effects of relative proportion of selected amino acids on Maillard browning. In this model study, lysine, leucine, and aspartic acid were selected as representatives of high, intermediate, and low browning groups, respectively. Stock solutions (0.1M) of each amino acid and glucose were prepared for the study in 0.1M phosphate buffer (pH 6.5). To obtain the amino acid-glucose molar ratios of 10:1, 5:1, 2:1, and 1:1, varying quantities of each amino acid and glucose were mixed to a final volume of 200 mL. Snowden potato slices (10 slices for each solution) were vacuum infiltrated with each working solution. Potato slices were fried in fresh vegetable oil at 356 F for 2 min. Slices infiltrated with phosphate buffer solution were fried as controls. Each sample was done in duplicate.

Similar experiments were performed to determine the synergistic effect between each amino acid tested. The molar ratio of amino acid to glucose was 1:1. Slices infiltrated with each amino acid alone were fried to compare with those infiltrated with the mixture of amino acid and glucose. Slices infiltrated with phosphate buffer were fried as a control. All samples were done in duplicate.

Analytical methods

Sugar analysis

A 200 g sample of fresh peeled potato tissue was prepared from the center part of 8 uniform sized tubers. Potato juice was extracted from the prepared samples using an Acme juicerator. Following exctraction and dilution the potato juice was injected into the YSI analyzer to determine glucose and sucrose concentrations. All samples were analyzed in duplicate.

Chip Color

Color was determined by frying filter paper disks and potato chips in fresh vegetable oil at 356 F for 2 min. The color of fried paper disks and potato chips was measured using the Agtron process analyzer model M-35-D. Agtron readings were made on the red scale. The Agtron number corresponds to the chip color chart developed by the Potato Chip/Snack Food Association (1 = light chips, 5 = dark chips). Chips with Agtron number less than 45 were considered unacceptable (colors 3 through 5 on chip color chart). Chips with Agtron number greater than 60 were considered excellent (colors of 1 and 2).

Statistical Analysis

Single and multiple correlation and regression analyses were performed using SPSS program, version 6.1. The analysis of variance (ANOVA) was performed using Statview computer program

B. Potato Storage Studies

In 1995: Five potato cultivars, Atlantic, Mainestay, Shepody, Snowden and Superior were grown on a sandy loam at the Montcalm Research Farm of Michigan State University in west central Michigan. All potato tuber samples were harvested at maturityThe storage temperature for potato samples was at 55 F with 90% RH for 3 weeks. Subsequently, storage temperature was reduced by 1 F every 2-3 days until the temperature reached 48 F. The samples were stored at 48 F (90%RH) for six months.

In 1996: Five potato cultivars, Atlantic, Mainestay, Shepody, Snowden and Superior were grown at the Montcalm Research Farm and harvested at maturiy. Snowden(2) and 4 new midwestern selections, ND01496, ND2031, ND2417-6 and ND2471-8 were also grown in Montcalm, Michigan, and harvested at maturity. All new selections are thought to be good chipping varieties.. The samples were stored at 55 F (90%RH) for 3 weeks. The storage temperature was reduced to 48 F by 1 F every 2-3 day. The samples were stored at 48 F (90% RH) for six months.

Potato chip frying

Every month potato chips were prepared from potatoes taken directly from storage (ie. 48 F). Eight uniform sized tubers were randomly selected, peeled, washed and sliced longitudinally to approximately 0.125 to 0.175 cm thickness. Five slices from the center were taken from each tuber. The total of 40 slices were washed with cold tap water and then fried in fresh vegetable oil at 356 F for 2 min.

Analytical methods

Sugar analysis

Eight average sized tubers were selected at random, peeled and washed. The center longitudinal pieces were taken from each tuber and cubed. Two hundred grams of tuber cubes were homogenized in an Acme juicerator and prepared for YSI analysis as previously described.

Free amino acid analysis

Potato extract containing free amino acid was prepared by passing the juice through a C18 filter (Sep-Pak, Water Associates, Inc.), and washing twice with distilled water. Sample was derivatized with PITC (Phenylisothiocyanate) before injecting in the HPLC column. The analyzer unit (Water Associate, inc.) consisted of, the model 710B Waters WISP solvent delivery system, a Pico-Tag column (3.9 x 300 mm i.d.), and a model 440 UV-Visible wavelength detector at 254 nm. The flow rate was set at 1.0 ml/mint Standard amino acids were obtained from Sigma Chemical Company (St. Louis, MO).

Ninhydrin assay

NinLydrin reaction was used to determine the concentration of free amino groups in potato extract samples. Ninhydrin was prepared by dissolving 2.0g ninhydrin and 0.3g hydrindantin in 75 mL dimethyl sulfoxide (DMSO). To the mixture was then added 25 mL of 4M lithium acetate buffer, pH 5.2. Two mL of potato juice sample was prepared for free amino acid analysis by purification and elution from a C18 Sep-Pak cartridge (Waters Corporation, Milford, MA. One mL of the component eluted from the cartridge was mixed with 1 mL of ninhydrin solution and heated in a boiling water bath for 15 min. To the cool reaction solution was diluted with 50% ethanol-water, centrifuged and the absorbance at 570 nm was measured with an Ultraspec II LKB Biochrom spectrophotometer against a reagent blank. The concentration of free amino groups was determined using a leucine standard curve.

Chip color measurement

Color of potato chips was measured using the Agtron process analyzer model M-35-D as previously described.

Statistical Analysis

Single and multiple regression analyses were performed using SPSS program version 6.1. The statistical relationships between various factors were reported in terms of correlation coefficients (r), coefficient of determination (r^2), multiple correlation coefficient (R),and coefficient of multiple determination (R^2). The analysis of variance (ANOVA) was performed using Statview computer program.

RESULTS AND DISCUSSION--MODEL SYSTEMS STUDIES

Filter paper disks impregnated with solutions of amino acid and sugar

Amino acids were selected based on those present in greatest amounts in potato tubers. Primary sugars in potato tubers are glucose, fructose, and sucrose. The molar ratio of amino acid and sugar used for most experiments was 1:1 in order to obtain the stoichiometry of the initial stage of the Maillard reaction. The pH of all solution systems was 6.5 corresponding to the average pH of potato juice. The final concentration of amino acid was as low as 0.001 M in order to avoid the low solubility of some amino acids such as L-tryptophan and L-tyrosine. Color development of fried filter paper disks impregnated with various amino acid/sugar solutions is presented as percent of control and shown in Figure 1. Statistical results (F value) showed that the effect of sugars with different amino acids was significant at $P<0.01$. No significant differences were observed between the amino acid-buffer systems. Fructose/amino acid and glucose/amino acid systems were not significantly different. But both systems produced significantly darker colored disks than sucrose/amino acid systems. Although sucrose does not participate in the Maillard reaction, sucrose/amino acid systems resulted in darker colored disks than the control (filter paper disks impregnated with buffered solution). The reasons remain unclear, but it has been suggested that hydrolysis of sucrose may partly occur under frying conditions at 180 C and pH 6.5, resulting in the splitting of sucrose to fructose and glucose which are the reactive substrates for the Maillard reaction.

In a previous study, amino acids were classified into 3 groups according to the intensity of Maillard browning; high, intermediate, and low browning producing amino acids. High browning producing amino acids (Group 1) include lysine, glycine, and tyrosine. Intermediate browning producing amino acids (Group 11) include leucine, isoleucine, and methionine. Low browning producing amino acids (Group111) were arginine, aspartic acid, and glutamic acid. Lysine produced the highest intensity as expected since it contains both a- and E-amino groups on the structure, unlike other amino acids, which contain only an a-amino group. Although lysine is a basic amino acid, the relationship between Maillard browning intensity and the basicity of amino acid was not valid in the present study. The basic amino acid, L-arginine produced low browning intensity as compared to the neutral amino acids such as glycine. The results from this model study suggest that tubers containing high browning producing amino acids (lysine, glycine, and tyrosine) at consistent level of reducing sugars should produce darker chips. Arginine, aspartic acid and glutamic acid yielded the lowest browning intensity.

Filter paper disks impregnated with potato juices

Average Agtron number of simulated potato chips was compared with that of actual potato chips (Figure 2). The simultated chips were fried filter paper disks impregnated with potato juice from cultivars, Atlantic, Mainestay, Shepody, Snowden, and Superior. The order of browning intensity of simulated chips was in agreement with actual chips. Snowden and Atlantic processed into excellent potato chips (Agtron number > 60). Both simulated and actual chips from Superior and Shepody, were less acceptable and Mainestay produced unacceptable chips. Statistical results showed that actual potato chips from Snowden and Atlantic were significantly different ($P<0.01$) from other cultivars.

Potato slices

According to the filter paper disk study, lysine, leucine, and aspartic acid were selected as representatives of high, intermediate, and low browning producing groups, respectively, for further study. Figure 3 shows the effect of relative proportions of the selected amino acids on Maillard browning.

Figure 4 shows the effect of specific amino acids (lysine, leucine, and aspartic acid) on chip color made from slices infiltrated with these amino acids. Similar to the model filter paper disks, potato chips processed from slices infiltrated with lysine were darker than those with leucine and aspartic acid. There appeared to be no synergistic effect to increase browning among any of the amino acids tested. However, when aspartic acid was combined with either lysine or leucine, there were significant reductions in browning. Previous work has shown this same effect of aspartic acid in decreasing browning intensity in lysine systems.

CONCLUSION--MODEL SYSTEMS

The model studies simulating potato chip frying indicated that there are several factors affecting color development in potato chips. This study focused on type, and relative concentration of amino acids and sugars. Different amino acid-sugar systems produced varying degrees of Maillard browning. Lysine, glycine, and tyrosine-sugar systems produced the highest browning intensity, while arginine, aspartic acid, and glutamic acid produced the least. Differences in degree of browning between fructose and glucose systems were not significant, but sucrose system produced only slight color.

The results from the model system studies showed the significant effect of type of amino acids on color development in simulated potato chips. Specific amino acids, lysine, glycine, and tyrosine, which produced the most intense browning, may be important factors governing the extent of reaction and intensity of chip color. Hence, the concentration of these amino acids present in tubers may be helpful in chip color prediction, as tubers containing larger proportions of the high browning producing amino acids tend to produce poorer chips and vise versa.

However, in potatoes amino acids are present in excess of sugars, there may be no indication of specific amino acids reacting preferentially, as sugar is a limiting factor. In addition, potato tubers contain several components other than only amino acids and sugars present in the model systems. These unknown components may play an important role in chip color formation by enhancing or inhibiting the color reaction. Therefore, the second phase of this study was conducted with an attempt to determine the role of amino acids and sugars in color development in potato chips, based on the information obtained from the model system studies.

RESULTS AND DISCUSSION-STORAGE STUDIES

Sugar content

Changes in glucose content of tubers during storage in 1996 are shown in Figure 5. Glucose content generally increased during storage in Mainestay, Shepody, and Superior. Snowden and Atlantic, which are good chipping cultivars, contained less than 0.35 mg/g fresh weight of glucose throughout the storage period. Mainestay contained glucose greater than 1 mg/g fresh weight at 90 days of storage.

Figure 6 shows the Agtron chip color of Atlantic, Mainestay, Shepody, Snowden, and Superior. Chip color is thought to be determined by the total reducing sugar content since both glucose and fructose are involved in the Maillard reaction. However, because the ratio of glucose to fructose (1:1) is similar in most potato samples, the correlations between chip color and these sugars and total reducing sugar are similar. Thus only glucose content measured by YSI method is an accurate indication of total reducing sugars in most cases. Snowden and Atlantic were low in glucose and produced the lightest colored chips. Mainestay, which contained the highest concentrations of glucose, produced the darkest colored chips as expected. In general, chips were darker as the level of glucose increased, as has been well dfocumented in past work. However, in some cases chips made from tubers containing low amounts of glucose were unacceptable. A good example of this was Shepody, which generally contained lower amounts of glucose than Superior but produced significantly darker chips. This situation may be due to variations in free amino acids or the free amino groups between the two cultivars.

Total free amino acid content

Figure 7 shows the free amino acid composition of Atlantic, Mainestay, Shepody, Snowden, and Superior during storage in1996. In all cultivars, total free amino acid content generally increased over the storage period, which was consistent with the findings of other investigators. The accumulation of free amino acids is due to the breakdown of protein by proteinase enzyme, for providing an energy supply for tubers. In general, Snowden contained the lowest amounts of total free amino acids, followed by Atlantic. As expected, Snowden and Atlantic, which contained the lowest amounts of glucoseand total free amino acids produced the lightest colored chips. Mainestay had the highest amounts of glucose with low amounts of total free amino acids but produced the darkest chip

High browning amino acids (Lysine, glycine, and tyrosine)

According to the model systems previously described, type of amino acids may be as important (or perhaps more important) as concentration in chip color formation. Lysine, glycine, and tyrosine yielded the highest browning as compared to the other amino acids used in this work. Therefore, tubers containing higher amounts of these amino acids are thought to be poorer chipping cultivars. Figure 8 shows that Shepody generally contained the highest amounts of lysine, glycine and tyrosine and it was found that this cultivar produced unacceptable chips across the storage period. These results agree with the model system studies, which showed that lysine, glycine, and tyrosine produced high browning intensity. In general, the cultivars with low concentrations of lysine, glycine, and tyrosine produced acceptable chips except for Mainestay. Although it contained low amounts of high browning amino acids, Mainestay produced the darkest chips since it also had the greatest concentrations of glucose. This suggests that high browning producing amino acid content is significant in chip color in most cases, but may not be the most significant factor in tubers, such as Mainestay, which contain very high or very low amounts of glucose.

Free amino group content

Since the Maillard reaction involves the reaction between the free amino group present in protein and amino compounds, and the carbonyl group in reducing sugars, free amino group content may be one of the critical factors in color development in potato chips. Figure 9 shows free amino group contents of Atlantic, Mainestay, Shepody, Snowden, and Superior harvested in 1996 at different storage times. The results show that free amino group content generally increased over the storage period. Free amino acid and free amino group contents in tubers were in good agreement in terms of order. In general, Snowden and Atlantic contained the lowest amounts of free amino group and produced the most acceptable chips. Mainestay contained high concentrations of free amino groups and glucose, and generally produced unacceptable chips. Shepody and Superior contained similar amounts of both free amino groups and glucose and produced similar chip color. The results indicated that free amino groups play more significant role in chip color development in these cultivars than glucose content.

Correlation coefficient data from these 5 cultivars showed that chip color was better correlated with glucose and free amino groups ($R = 0.94$), than with glucose alone ($r = 0.89$) or with glucose and free amino acids ($R = 0.93$). Significant differences ($p<0.05$) in free aminogroup content were due to the effects of cultivar. Storage time and the interactive effect ofcultivar x storage time on free amino group content were not significant ($p>0.05$).

CONCLUSIONS-POTATO STORAGE STUDIES

The effects of sugars, free amino acids, and free amino groups in selected potatoes on chip color were investigated. Snowden and Atlantic, which are good chipping cultivars, generally contained low amounts of sugars, free amino acids, and free amino groups. Mainestay, which is a poor chipping cultivar, generally contained the highest glucose level, but free amino acid and free amino group levels were not significant in this case. Glucose content alone may not be used to regularly predict the fried color of chips made from Shepody and Superior. However, free amino acid and free amino group contents were found to be helpful in chip color prediction in those cases. Statistical results revealed that prediction of chip color can generally be improved by combining measures of free amino acid and/or free amino group contents with sugar contents.

The ninhydrin assay is potentially useful for measuring the free amino group content in potato tubers and it is helpful in chip color prediction. Statistical results demonstrated that free amino group content was generally better correlated with chip color than that with free amino acid. In addition, ninhydrin assay is simpler and requires less expensive equipment as compared to HPLC for free amino acid analysis.

Due to variable ratios and amounts of sugars and amino acids among different potato cultivars, future research is required to accumulate more data on color development in potato chips made from other cultivars. A number of good and poor chipping cultivars may be evaluated in terms of sugars, free amino acids, and free amino groups to determine their association to color development.

Figure 1. Color development of filter paper disks impregnated with amino acid-sugar solutions (molar ratio 1:1)

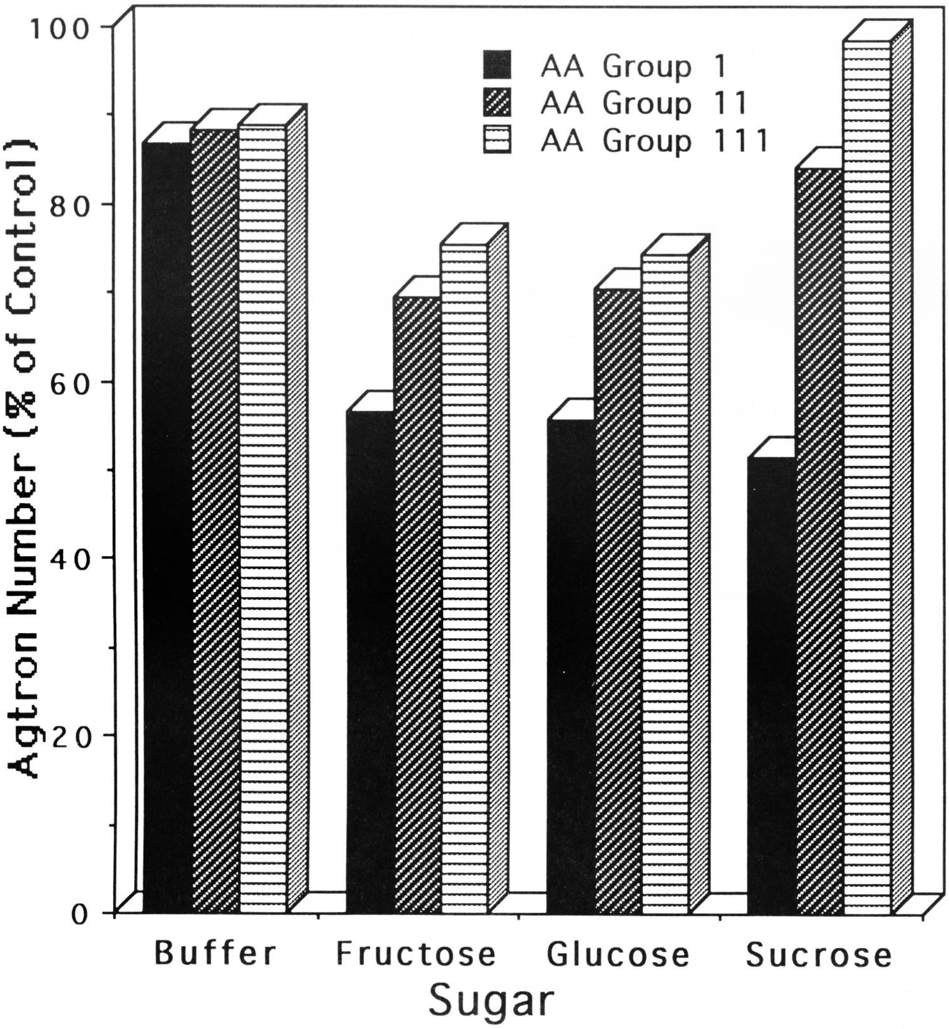


Figure 2. Color development of fried filter paper disks impregnated with potato juice and potato chips from selected cultivars, 1995.

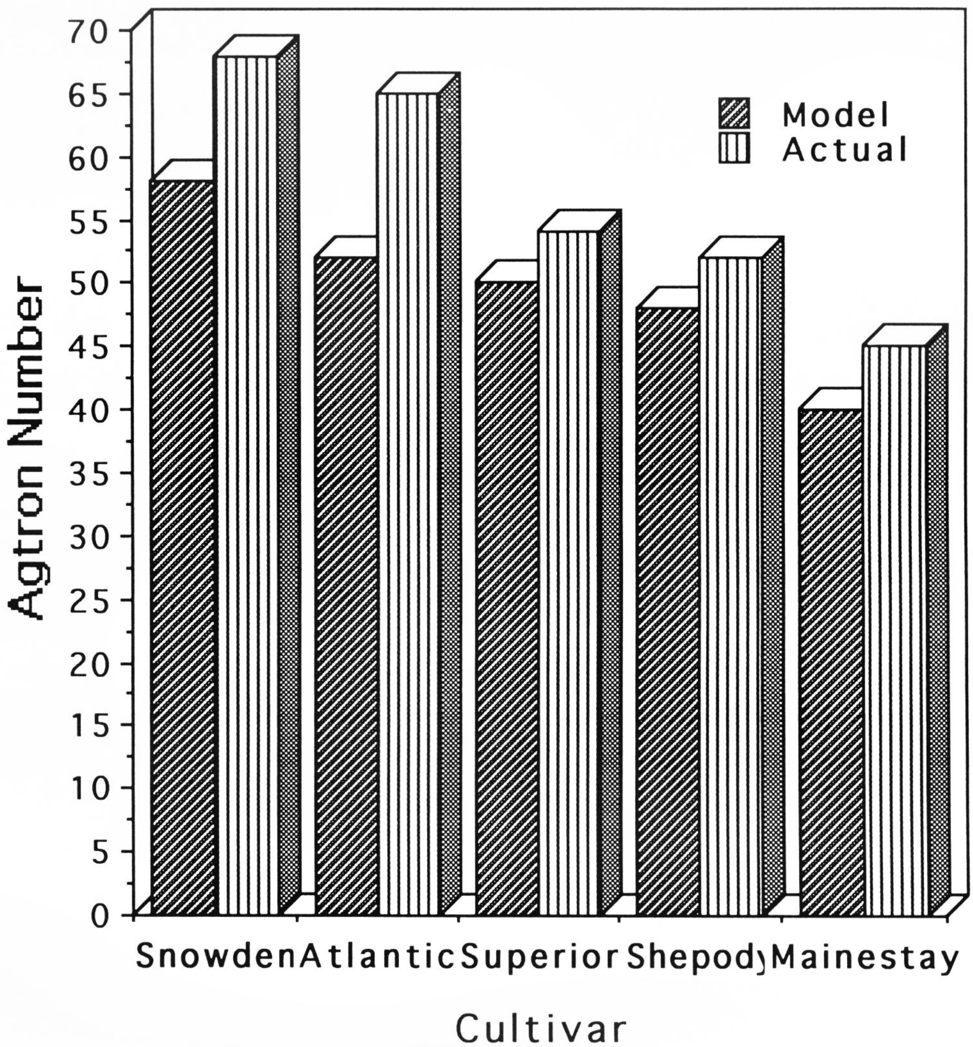


Figure 3. Average Agtron number for fried Snowden slices infilterated with various molar ratios of amino acid-glucose

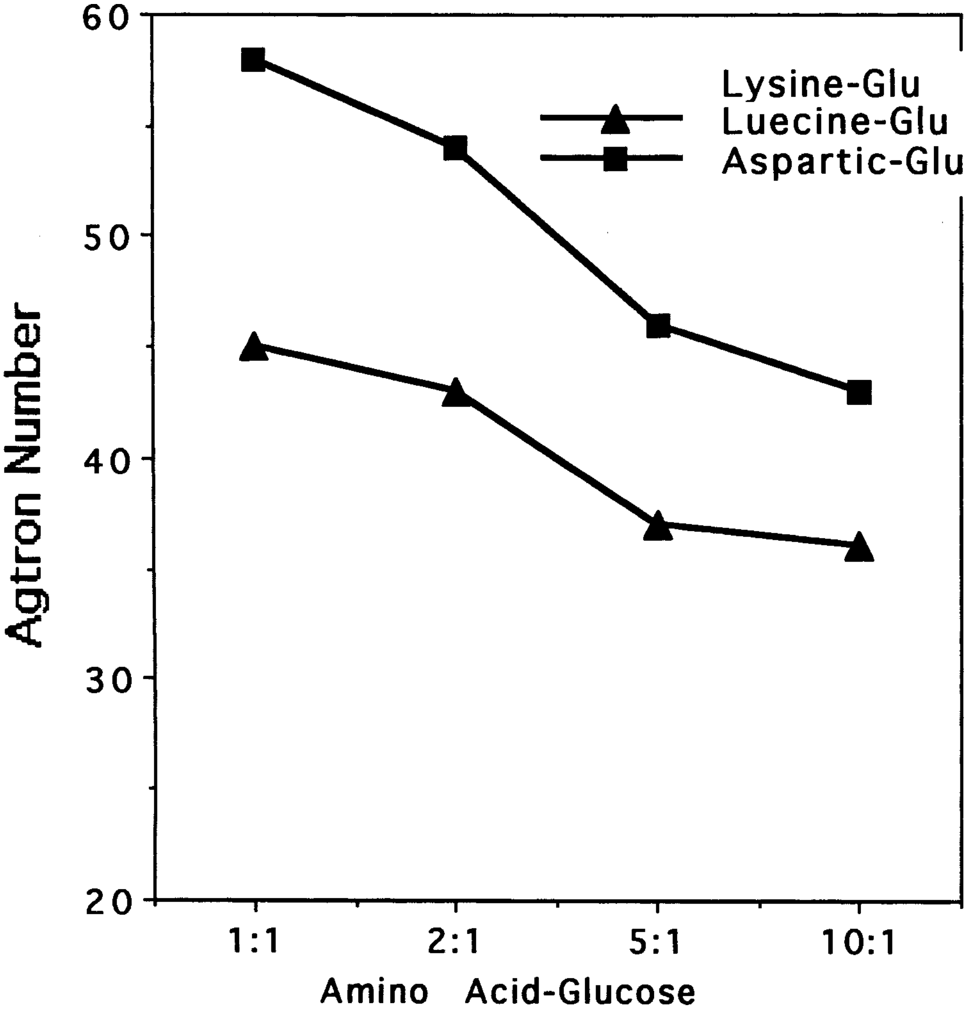


Figure 4. Average Agtron number of fried Snowden slices infiltrated with various combinations of amino acid-glucose solutions.

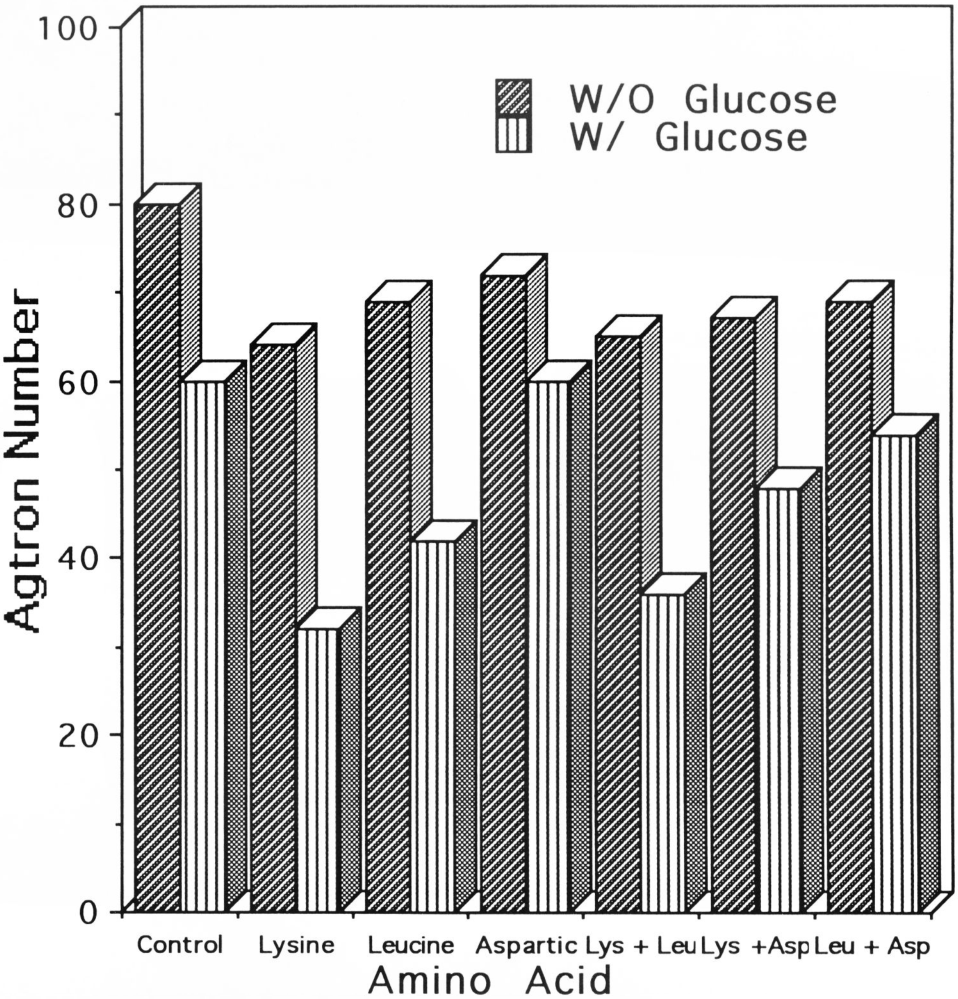


Figure 5. Glucose content of selected potato cultivars at varying storage times

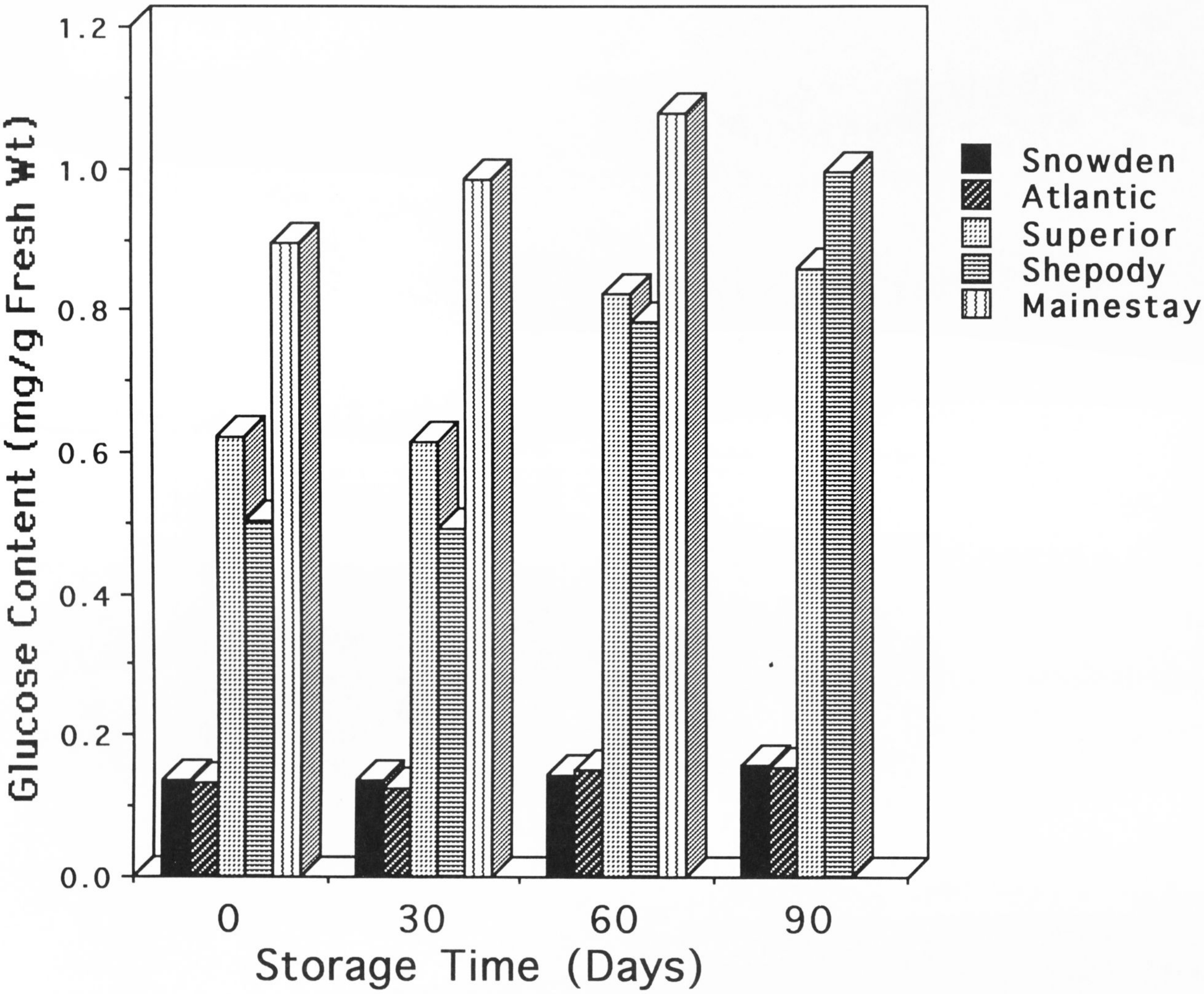


Figure 6. Agtron chip color of selected potato cultivars stored at varying times

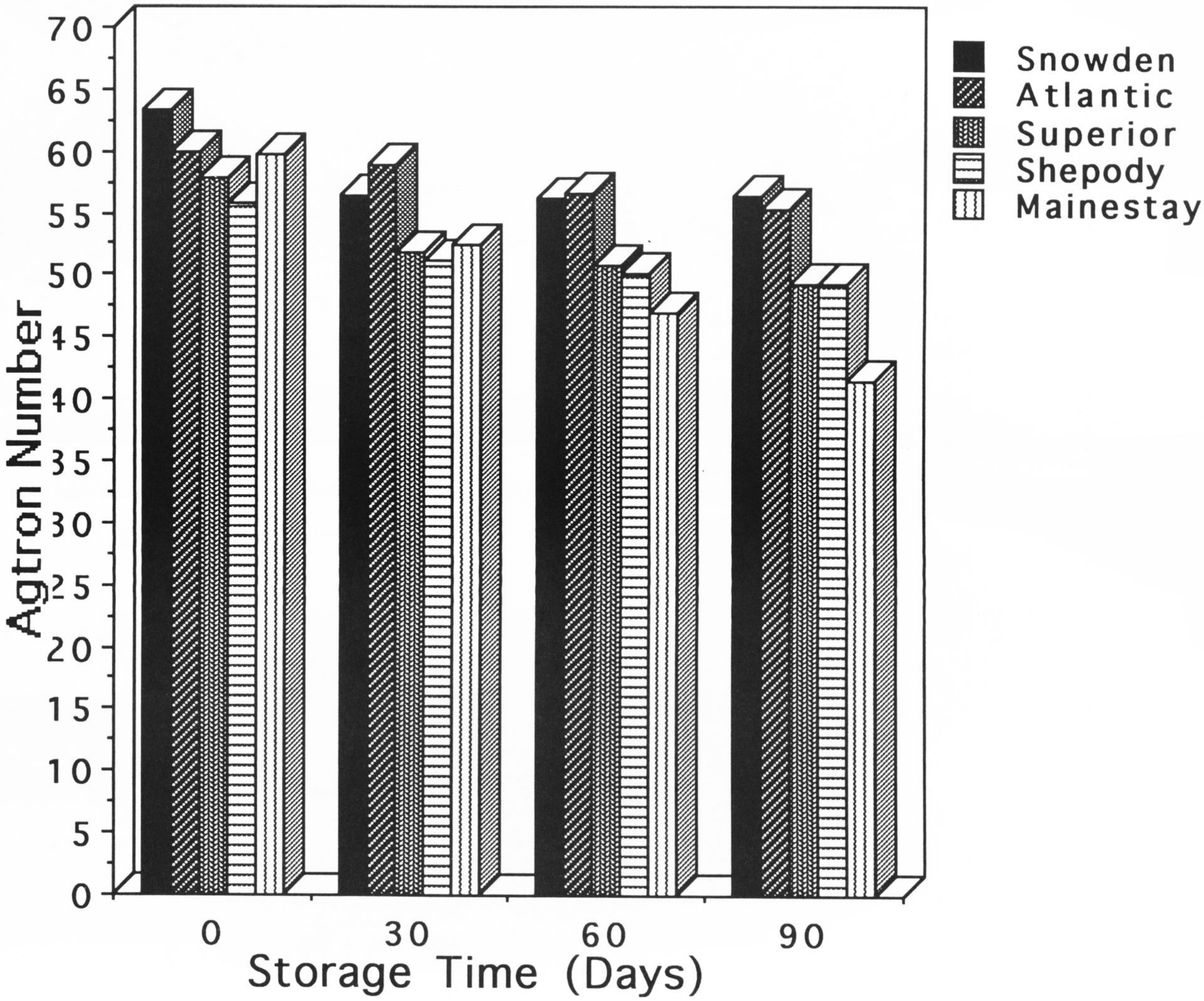


Figure 7. Total free amino acid content of selected potatocultivars at varying storage times.

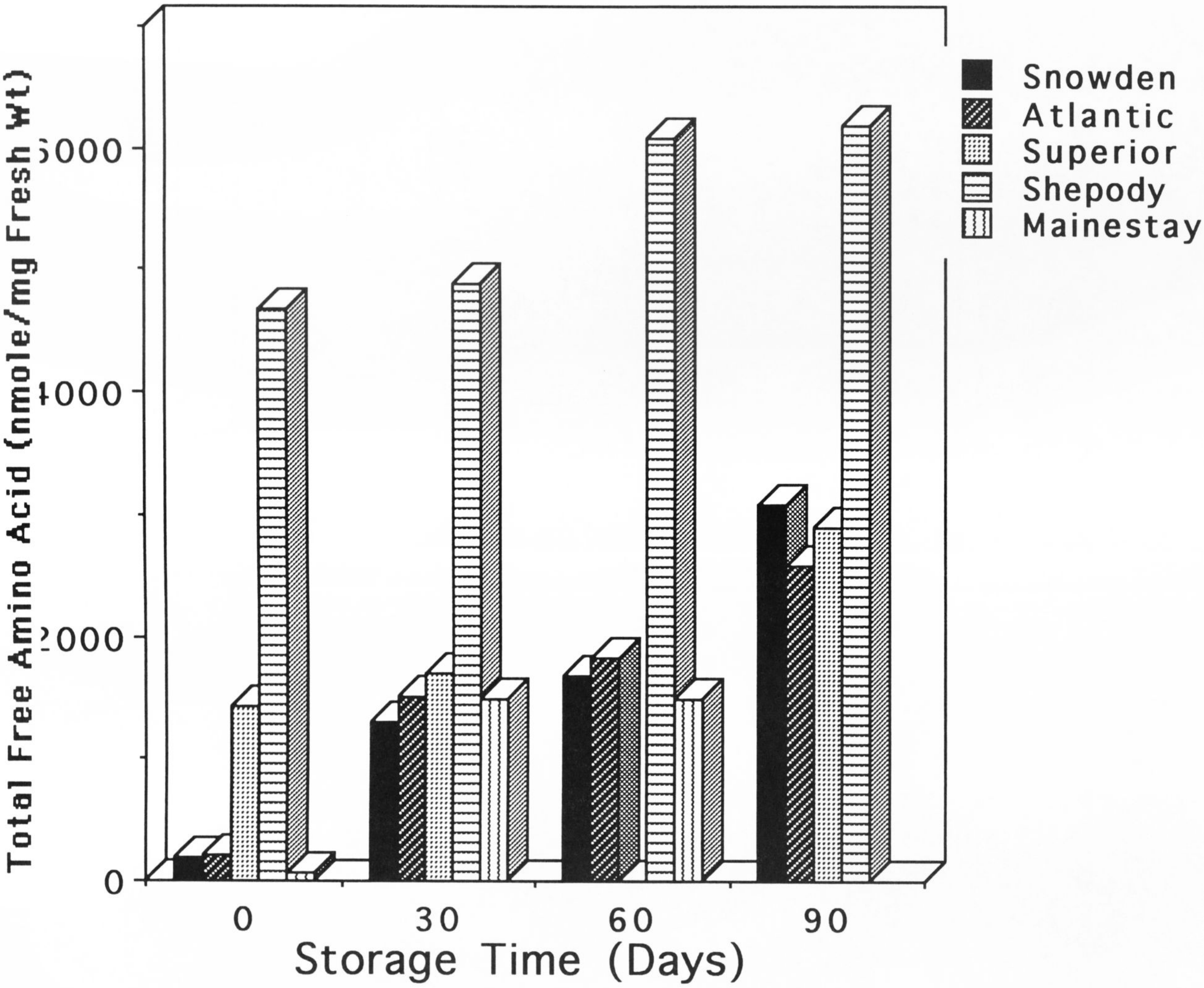


Figure 8. Sum of Group 1 (high browning) amino acid content of selected potato cultivars at varying storage time.

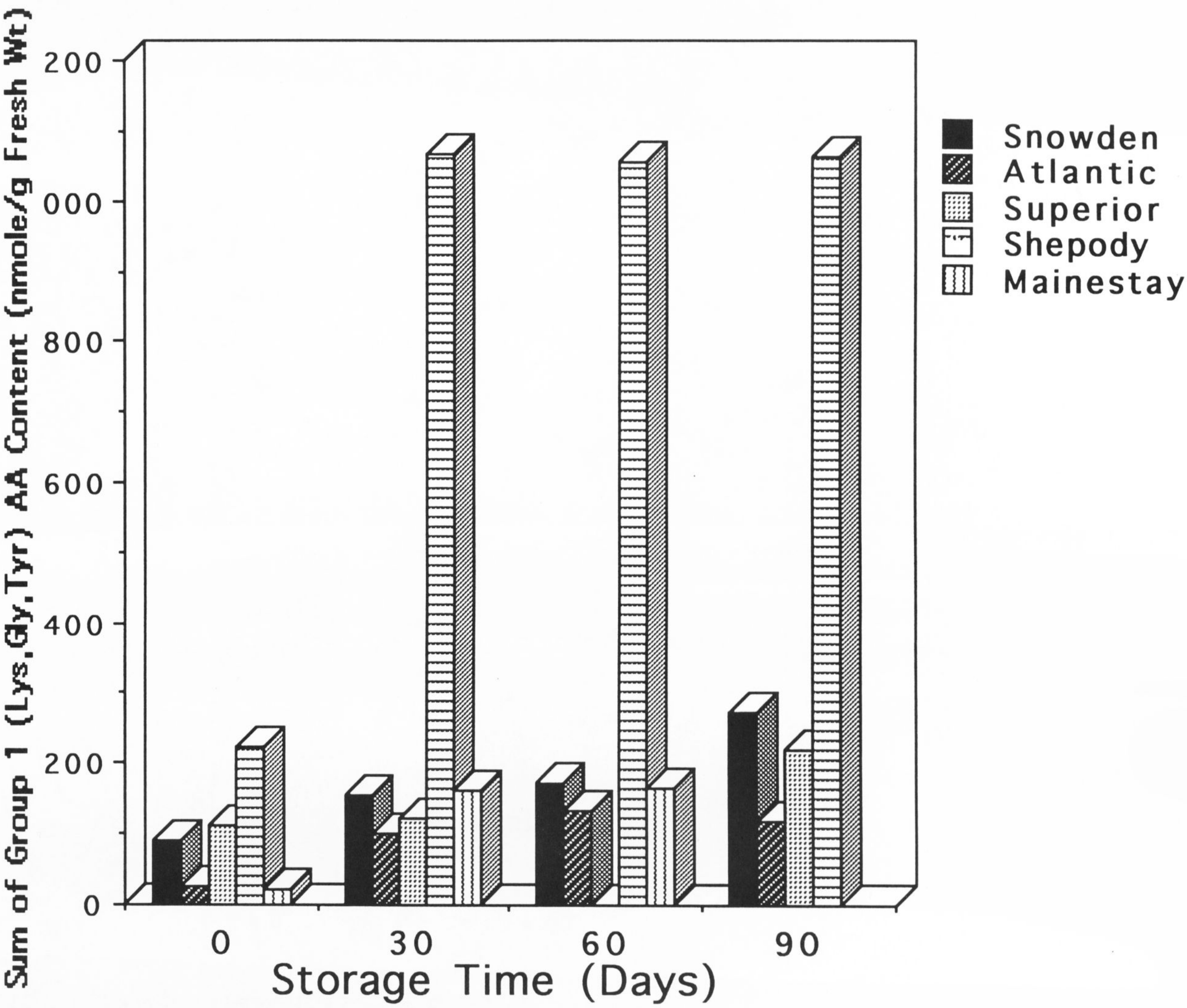
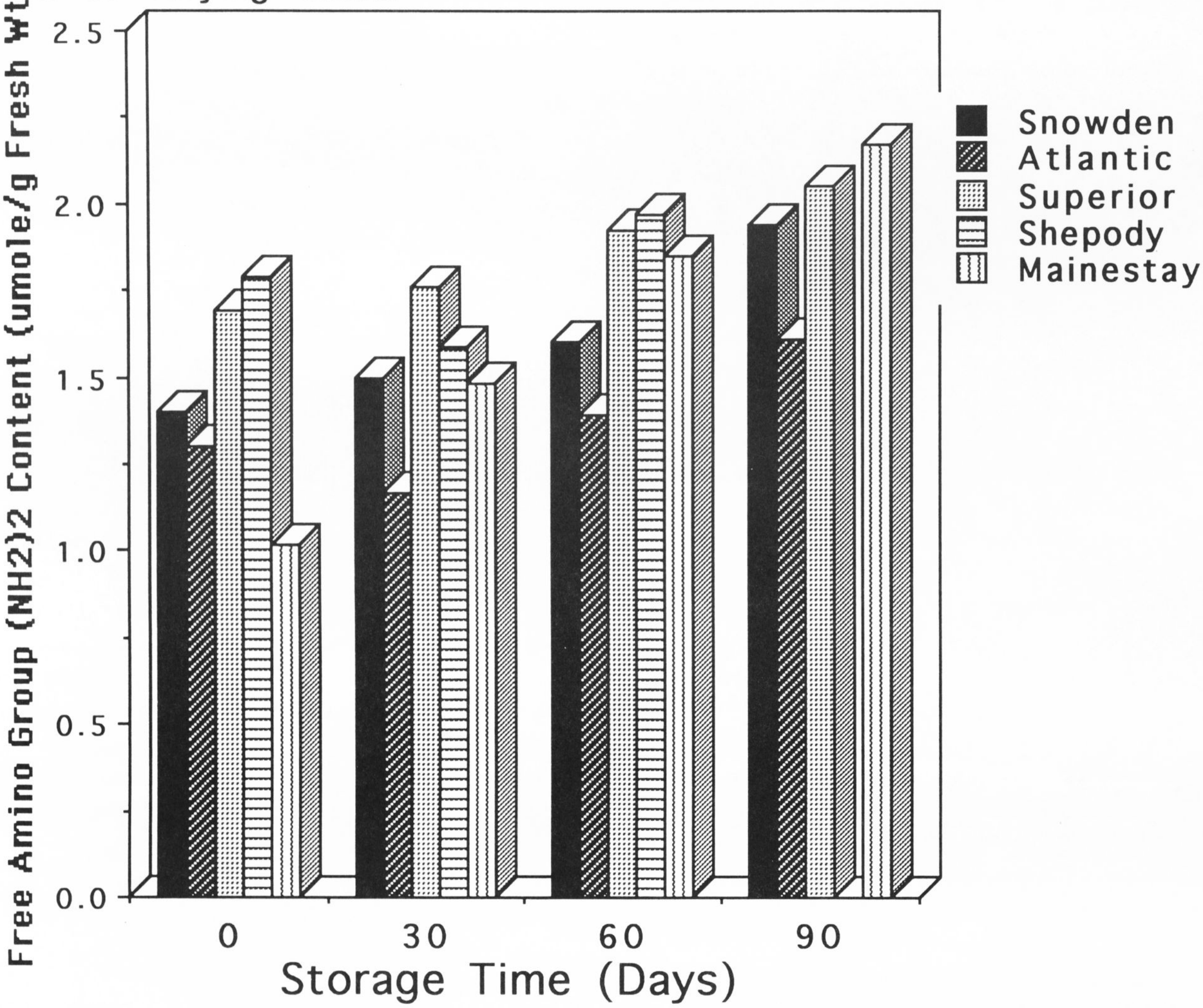


Figure 9. Free amino group content of selected potato cultivars sto d at varying times.



Funding MPIC

Continuous Weighing for Potato Pilers

A Senior Engineering Design Project

Scott Weliver, Melanie Carlson and Roger Brook
Agricultural Engineering Department
Michigan State University

During the fall semester of 1997, the opportunity existed to have two senior engineers in the Biosystems Engineering program (Agricultural Engineering Department) conduct a senior design project that involved the continuous weighting of potatoes. Continuous weighing of potatoes has been shown to be possible by Harvestmaster (Logan, Utah) as part of their root crop yield monitoring system. However, they are concerned about the noise in the signal as produce passes over the load cells. It is our desire to eventually implement continuous weighing on bin pilers for two purposes:

- to weigh potatoes going into specific storage bins to help track weight loss
- to weigh potatoes being loaded on a truck to help prevent over- or under-loading

Project Objectives:

- to construct a conveyor test stand
- to add load cells for continuous weighting of produce
- to test alternatives for mechanically reducing "noise" in the weight signal.

Project Description: An unused 24 in. by 8 ft. belt conveyor was supplied by a co-operating farm. This was dismantled and modified for test use. Idler wheels were mounted at 12 in. intervals on the inside rails of the conveyor. Heavy-duty, aluminum roller wheels with sealed bearings were used at one end of the conveyor for pivots. A hydraulic motor was mounted on the drive end of the conveyor.

The idler wheels that transferred the weight of passing material to the load cells were mounted on pivoting cantilever beams. These beams were designed to accommodate the normal 4-inch idler wheel configuration, as well as a walking beam configuration. The beam design allow primarily vertical forces to impact the load cells, absorbing any torsional or horizontal forces. Sketches of the cantilever beam designs are given in Figure 1.

It was calculated that the 2-foot long area of a 36-inch wide conveyor could apply a load of up to 60 pounds of potatoes. Tow compressive load cells were purchased, each with a 40 pound capacity. Mechanical stops were placed under each load cell to help avoid overloading each load cell.

A Campbell Scientific CR10 programmable data logger was used to convert the voltage signal from the load cells to digital data for computer storage and analysis. The load cells required a 5-volt input, and had a rated output signal of 2 mV/V. The data stream output from the CR10 was captured via a serial port on a personal computer for later data analysis.

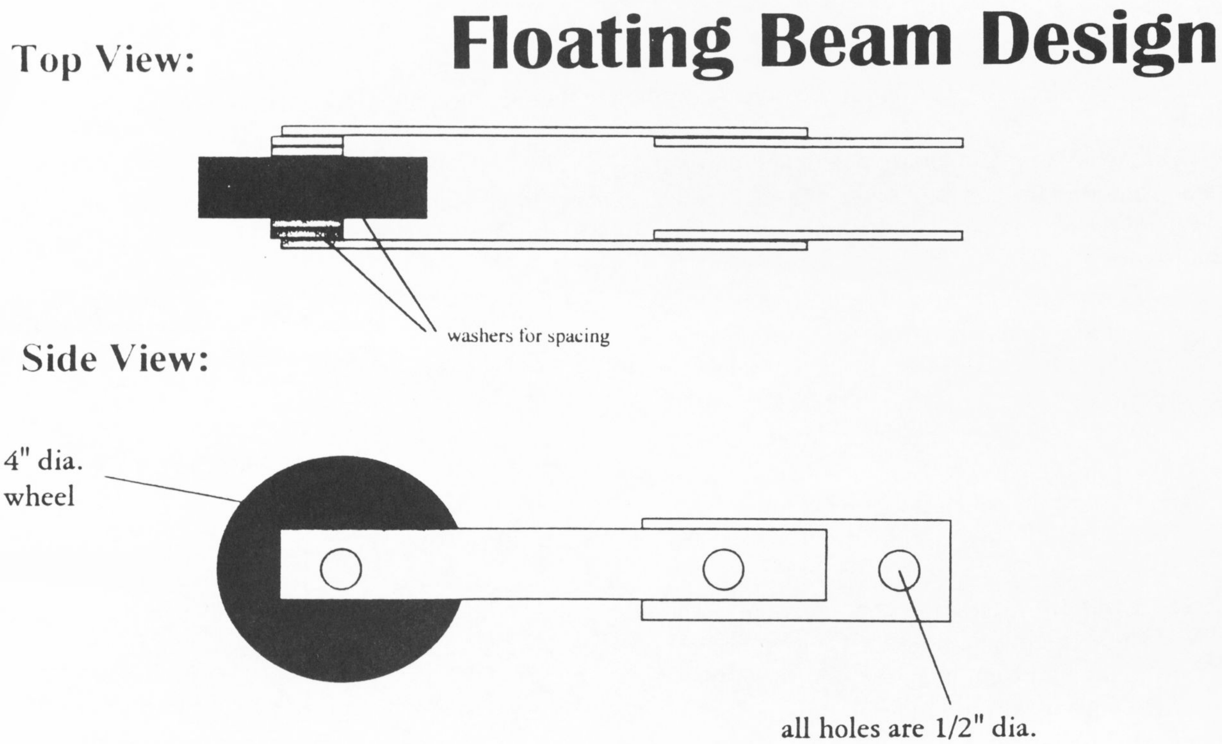
Test Procedure: The first set of tests involved placing a single weight in the center of the stationary conveyor belt. Verified weights of 7, 15 and 18 pounds were used for these tests. Appropriate combinations of these weights allowed calibration of the weighing system in the range 0-51 lb. A second set of test used the same weights, but were conducted with the conveyor running at speeds in the range of 60-120 ft/min. Moving weight tests were also conducted using groups of potatoes of 10, 20, 27, 30, 43 and 50 lb. scattered randomly in a single layer. The results of the walking beam for distributed tubers is illustrated in Table 1.

Table 1. Walking cantilever beam with distributed potatoes.

Test weight, pounds	Measured weight, pounds	Error estimate
10	7.49	-25%
20	20.65	0.03
30	30.26	0.01
43	42.47	-1%
50	59.95	-0%
weighted average		-1.3%

Conclusion: The results of all the cantilever arm design showed positive results proving that a constant weighing system is an obtainable goal. The walking beam showed the most reduction in both amplitude and frequency of noise.

Acknowledgment: Thank you to Bishop Potato Farms, Lenco Mfg. Grand Rapids Scale Co. and MPIC for donation of equipment, supplies, information and monetary support.



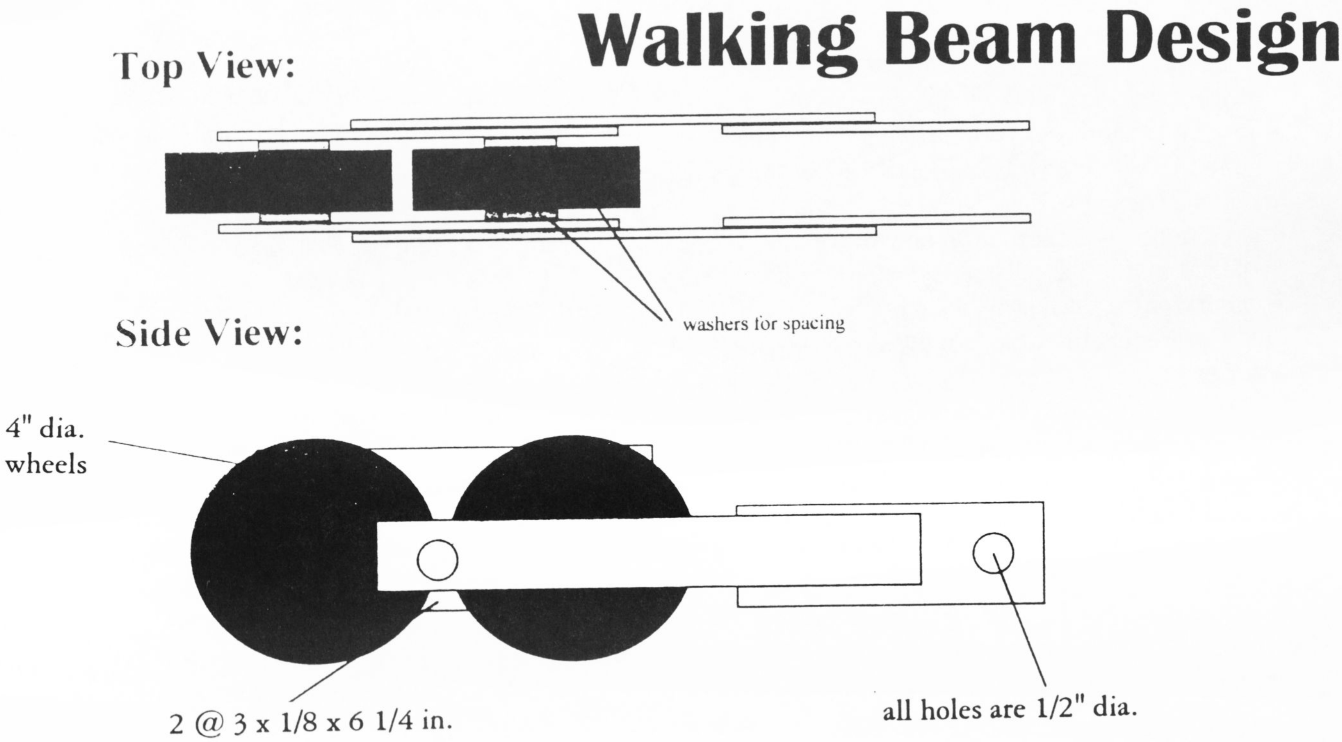


Figure 1. Sketch of the walking cantilever beam design used for continuous weighing tests.

Funding MPIC

Potato Defect and Foreign Material Detection using Light Frequency Analysis and Image Processing

Roger Brook and Daniel Guyer
Agricultural Engineering Department
Michigan State University

Project Objective: To study the combined techniques of spectral reflectance, image processing and pattern recognition for their ability to detect common and grade reducing defects, and to differentiate potatoes and foreign material.

Michigan State University personnel, particularly through the USDA unit formerly housed here, has been promoting proper lighting design that reduces worker fatigue and eye strain and improves sorting efficiency. Design considerations that impact sorting efficiency and overall worker performance include (see Figure 1):

- ***Background Color of sorting surface (belt):*** Reflected light energy from the sorting surface should not be greater than reflected light from the produced. Used belts that are black or dark gray, brown or green, but not glossy in finish.
- ***Surrounding colors:*** Surfaces near sorting areas and the clothing of inspection personnel should not be bright or highly reflective, and should not cause glare.
- ***Placement of fixtures:*** The light source should not shine directly in the sorters' eyes, i.e. unshielded, or too low so as to obstruct the view of the sorting surface. The fixture must also be placed at a height that provides the proper amount of light at the sorting surface. This will depend on the amount and type of light utilized and the considerations mentioned above. Fixture height will vary, depending on whether standard or high output lamps are used. For a standard output SP-30 light, this height will be about 22 to 32 inches above the sorting surface when the 4-tube fixture is centered over a 12- to 30-inch wide belt. Wider belts may require more fixtures to be positioned perpendicular to the belt travel and above head height.
- ***Type of lighting:*** Light type should be appropriate for the sorting task and the colors involved. The quality and quantity of area lighting should also be considered, as it can have negative impacts on color evaluation and on eye strain.

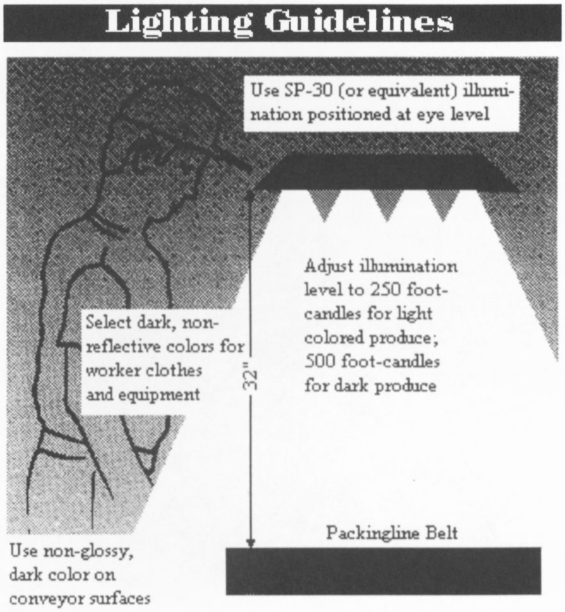


Figure 1. Lighting guidelines for sorting of vegetable and fruit produce.

The scope of this research is to attempt to differentiate desirable tissue from undesirable tissue in the inspection of potatoes using bands of light energy in the visible and near-infrared regions. Specific defects that will be investigated include greening, bruise damage, disease and foreign material.

Progress Report 1997: The equipment for this project arrived and was installed in late summer. During the fall semester, a large sample of green potatoes were obtained from a field in St. Joseph Co. These tubers were imaged at specific light frequencies from 400 nm to 2000 nm. As can be seen from the examples in Figure 2, the light frequency of maximum difference appears to be in the high 800 - low 900nm range. Further testing of these type of tuber defects will be conducted using light in this narrow range of frequencies to develop procedures that can sense the occurrence of "greened" tubers.

In another test with the sample of "greened" tubers, we tested their response to a phenomenon called chlorophyll fluorescence. This test involves brief exposure to light of around 670 nm, followed immediately by an analysis of light emitted at 710 nm. This phenomenon is a particular characteristic of chlorophyll containing tissues. Further testing of these type of tuber defects will be conducted using a filter that blocks light source frequencies above 700 nm, and another filter that blocks light detection for frequencies below 700 nm. to develop procedures that can sense the occurrence of "greened" tubers.

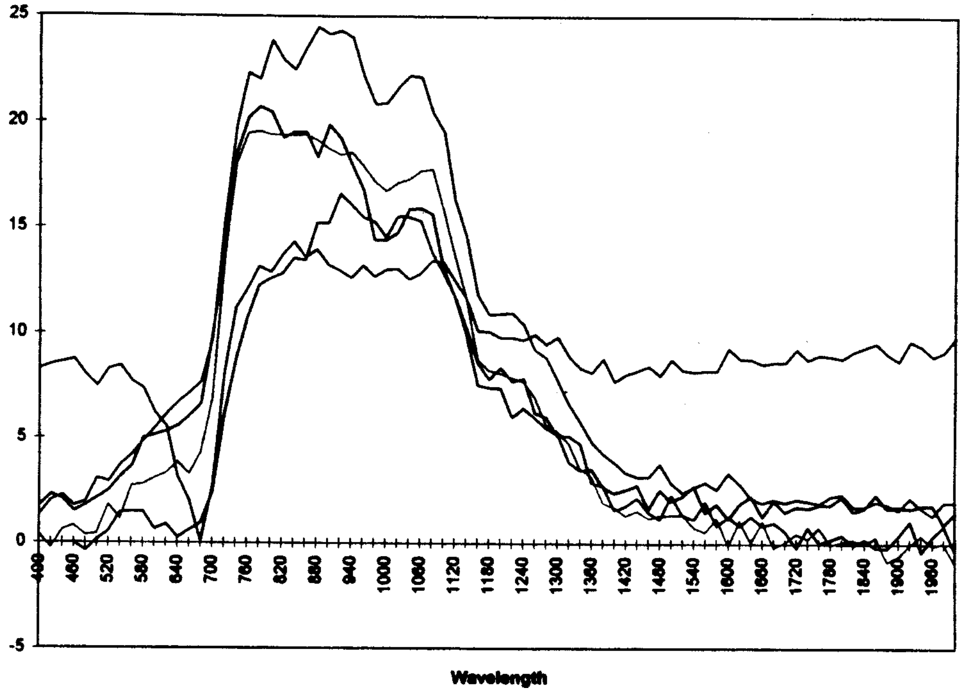


Figure 2. Light reflectance differences between normal and "greened" potato tuber surface.

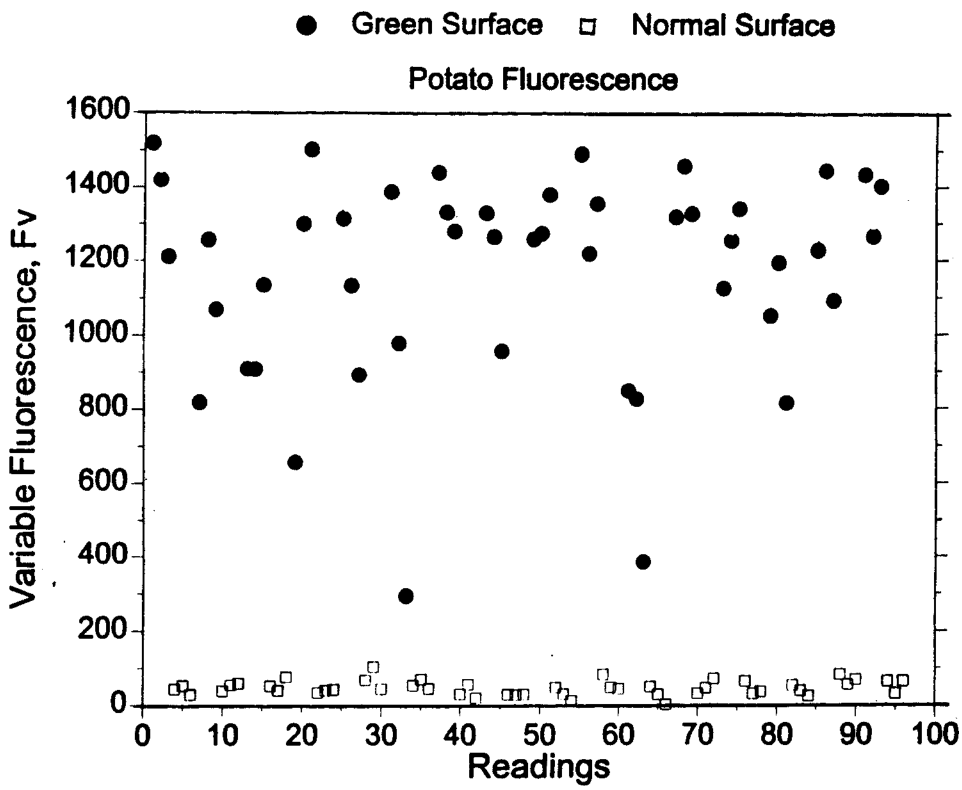


Figure 3. Response of "greened" potato tubers to chlorophyll fluorescence test.

Further testing during 1998, using grant money remaining, will begin imaging of diseased potato tubers and imaging of foreign material common in seed cutting operations.

Funding: MAES

Major Factors Affecting Demand and Supply for Frozen Potato Products from Michigan[1]

Dr. Chris Peterson, Dr. David Schweikhardt, Michael Masterovsky, Jon Phillips, and Mary Schulz
Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824.

This report presents a general assessment of the demand and supply conditions affecting the Michigan frozen potato industry. The information has been drawn from various secondary sources and interviews with key industry informants. This analysis was necessitated by the 80% reduction in Michigan frozen processing potato acreage by Simplot in 1997. This reduction of 5,000 acres for the Grand Rapids processing facility has created both short-term and long-term concerns for the Michigan potato industry. This assessment provides broad background information relevant to why this cutback occurred.

The report begins with a consideration of demand conditions, emphasizing domestic demand trends for consumption and consumer preferences. The report then discusses supply issues, including current North American production capacity, international sourcing trends, competition from Canadian imports, cost considerations, processing innovation, and industry consolidation. The report concludes with a section addressing key strategic issues suggested by the demand and supply trends.

Frozen Potato Demand

Frozen Potato Product Consumption Domestic demand for frozen potato products steadily rose between 1976 and 1994, and continues to be dominated by frozen french fries. In 1996, however, french fry consumption in the U.S. market experienced its slowest growth in a decade and is not expected to realize significant gains in the near future. The food service (quick-service restaurant) sector, which has spurred much of the growth in fry markets since the late 1950's, continues to account for the majority of frozen processor sales. However, demand in this segment has now reached a saturation point and growth is stagnant. Almost all growth in domestic french fry markets in 1996 came from the retail sector, but the relatively small scale of this market indicates only limited total consumption growth outside of quick-service restaurants.

Domestically, consumer preferences continue to grow increasingly sophisticated as incomes rise due largely to the increasing number of dual income households. One of the most notable conclusions of proprietary consumer taste tests has been the realization that consumers prefer frozen

[1] A more detailed presentation of the information contained in this article is given in "Demand and Supply Assessment for the Michigan Frozen Potato Industry," M.S.U. Agricultural Economics Staff Paper 97-47, by the authors listed above.

potato products made from Western grown potatoes. Changes in consumer tastes present opportunities for the development of new frozen potato products, e.g. flavored fries.

Though domestic frozen potato consumption appears to be lagging, especially for french fries, foreign markets provide sizable opportunities for frozen processors. International consumption, particularly in Pacific Rim markets, is still growing. Nearly all of U.S. exports of frozen potato products to the Pacific Rim are produced by plants in the Northwest, however. Since international demand is somewhat inaccessible to processors in the Central States, it will not be examined in detail in this report.

Per capita consumption of frozen potato products in 1996 equaled 60.0 lbs. compared to 58.4 pounds a year earlier, an increase of 1.6 pounds per consumer. However, of the four major processed potato categories, per capita consumption of frozen potatoes is the only one forecasted to decline in 1997, dropping 2.7 lbs. per person to 57.3 lbs. Including the 1997 forecast, frozen potato per capita demand has now been stagnant or declining since 1994. *(See Exhibit 1 for per capita consumption of all potatoes, 1976-97).*

French fries continue to dominate all frozen potato market segments, accounting for approximately 86% of frozen potatoes packaged by processors. Domestic frozen french fry markets, which generate roughly $3 billion in sales annually, expanded by 2.5% in 1996, the smallest gain since 1987. In 1996, the growth rate for french fries packed by processors grew 0.6%, the slowest rate in a decade. This compares to 9.4% and 5.4% in 1994 and 1995, respectively. Domestic french fry consumption is not expected to experience much more growth in the foreseeable future (Huffacker, 1997). This is consistent with predictions by other industry experts.

Nearly 90% of US fries are sold (consumed) in domestic and foreign foodservice outlets. However, this segment was unchanged between 1995 and 1996 at about 6.54 billion pounds. The volume of frozen french fries sold in domestic retail markets increased by 12.1%, which accounted for almost all of the growth in fry production during 1996.

Regional Market Volume The total market volume for frozen potato products within 100/200/300 miles of the Grand Rapids plant was estimated to be roughly 2.1 billion lbs. in 1996. Holding population constant and adjusting for the forecasted drop in per capita consumption in 1997, the total market volume in a 300 mile radius of Grand Rapids is estimated to be 2.0 billion lbs. of finished frozen potato products.

The Simplot plant in Grand Rapids generates approximately 175 million lbs. of finished product annually.[2] If the 1996 market volume calculations are correct, then roughly 1.9 billion lbs. of finished product is being supplied to this market by other frozen processors, possibly including other Simplot operations. If the Grand Rapids output were totally consumed within the region, it would have an 8.8% market share. *(See Exhibit 2 for the volume of frozen potato markets within in 100/200/300 miles of Grand Rapids and a map of these markets.)*

---

[2] The anticipated decline in regional consumption of 100 million lbs. represents 57% of the Grand Rapids plant's capacity.

Consumer Preferences The trend toward healthier eating and a more balanced diet continues. Even so, health conscious consumers cannot resist the appeal of the french fry and the convenience of take-out foods. Fries are often sold through the take out window of quick service restaurants. Due to the buildup of steam in the bag, they often become soggy once the bag is opened. One way to address this problem is to coat the fry. More information about coating is provided in the supply section of this report.

In recent years, french fry demand has mirrored an upward trend in Away-From-Home (AFH) dining. Private surveys indicate that end-user consumers purchase about one-half of their AFH meals at fast food restaurants. Supersizing, which caused much of the rapid growth of consumption in fry markets in the early 1990's, appears to have run its course. This may be due to consumers placing more emphasis on smaller serving sizes that reduce waste and calorie intake.

Related to the AFH trend is the movement toward Home Replacement Meals (HRM), which are prepared meals that consumers can pick up on their way home. These meal solutions differ from fast food take-out in that they provide a sense of fresh, homemade dining without the hassles of cooking. HRM provides new frozen potato product opportunities, such as better tasting mashed potatoes. However, this trend probably threatens frozen french fry consumption given the short life, even with coatings, of french fries as a take home item.

Frozen Potato Supply

North American Production Capacity

Large scale frozen potato processing has been developing in the U.S. over the past four decades. Exhibit 3 lists the location, ownership, and capacity of plants in the North American frozen potato industry. The U.S. Northwest (Washington, Oregon, and Idaho) has 172.5 million cwt. of capacity (in terms of raw product), or 70% of the total North American capacity. All other U.S. plants represent 16% of capacity while Canadian plants are 14% of capacity. The top three processors, Lamb-Weston, McCain, and Simplot, control 74.5% of total capacity. Leading processors in order of capacity are:

Company	Raw Capacity	Percent Capacity
Lamb-Weston	73.0 m cwt.	29.5%
McCain	58.8	23.9
Simplot	52.0	21.1
Nestle	14.5	5.9
Ore-Ida	12.0	4.9
Cavendish	9.0	3.7
All others	27.1	11
TOTAL	246.4	100%

The raw processing capacity of 246.4 million cwt. translates at a 50% yield rate into approximately 12.3 billion lbs. of finished product. At 1996 U.S. frozen product demand levels (and taking into account rough estimates of U.S. exports, U.S. imports and Canadian consumption), the North American industry is likely to be operating at approximately 75% of capacity, but could be operating at as little as 70% or as much as 80%. Whatever the specific number in this range, the industry clearly suffers from excess capacity at this point in time.

International Sourcing Issues and Trade

Global supply and demand conditions also impact the North American frozen french fry industry. Western Europe is another major frozen potato processing region. However, frozen processors in this region are also experiencing the effects of maturing European frozen potato markets and are expanding sales in other foreign markets. North and South America and Asia are potential new markets for these potential competitors. The establishment in 1996 of a new processing plant in North Dakota by the Dutch firm AVIKO provides an example of such an expansion strategy.

Conditions were uniformly favorable for growing potatoes in 1996 worldwide. A record U.S. crop of 48.8 billion pounds was produced. This sent prices plummeting, from about $8/cwt. to about $2/cwt. during the 1995-1996 marketing season. This is only about a third of what it costs U.S. farmers to grow potatoes.

Challenge of Canadian Supply Potato acreage and processing capacity have been expanding in Canada recently, also. This development, combined with a relatively weak Canadian dollar, has caused a large influx of frozen potato products from the north. Canadian processors such as McCain Foods and Cavendish Farms exported 450 million lbs. of frozen french fries to the U.S. last year at low prices (Stuebner, 1997). In 1997, McCain purchased two of Ore-Ida's three frozen french fry processing plants and the right to use the Ore-Ida name in the food service market. According to industry sources, this action may have been an attempt to counteract political reaction to their huge increase in exports from Canadian processing plants to the U.S.

In 1998, the tenth year anniversary of the enactment of the United States/Canadian Free Trade Agreement (USCFTA), the U.S. and Canadian tariffs on all fresh and processed potatoes will be eliminated. Prior to 1989, both the U.S. and Canadian tariff on frozen french fries was 10%. But USCFTA has not fully opened the Canadian potato market because Canada instituted non-tariff barriers to restrict imports of U.S. french fries and fresh potatoes. Almost 100% of U.S. frozen potato imports come from Canada (predominantly french fries). Total frozen french fry imports from Canada have steadily increased since USCFTA was enacted.

The International Trade Commission (ITC) issued a report in late July 1997 concerning Canadian dumping of frozen potato products into the U.S., but did not conclude as to whether or not dumping has occurred. Much of the information contained in the ITC report confirms the findings of our assessment of the frozen processed potato subsector. There was, however, a mild discrepancy regarding the issue of processing capacity. When questioned about this matter, ITC officials explained that many different published measurements of capacity exist and there is no agreed upon figure.

Cost Components

The primary cost components of frozen french fries tend to determine the location of processing plants. The most important element is the cost of raw potatoes. Processors are generally seeking to source their potatoes within a smaller radius (less than 25 miles) of their plants. Factors such as quality and production costs appear to be more important than the cost of transporting finished product in determining sourcing location and market shares.

The cost of raw product being "out of condition"[3] is also important. This presents an opportunity for cost reduction by implementing quality improvement programs involving suppliers. In fact, material handling is an essential management task for potato processors. Storing potatoes involves minimizing the risk that they go out of condition. If the processor is responsible for storing the potatoes, growers have less incentive to take care of them in harvest to assure their storage quality.

One final aspect of raw product storage is that the climate of the location will impact the storage technology. For example, the potato-growing region of Idaho is quite dry. Since this reduces the risk of rot, potatoes may be stored in larger warehouses. In a humid state like Michigan, a warehouse must be divided into smaller bins so that pockets of degradation may be easily accessed and isolated. Since partitioned storage costs about twice as much as non-partitioned, storage costs less in a dry region.

The second largest component of processing cost is labor. Although cost per labor hour is important, cost per pound of finished product is a more appropriate measure of competitiveness. This measure also takes into account the efficiency of the plant. Another major consideration is the cost of waste disposal. One plant that was built in the 1980's is reported to have waste disposal costs three to four times higher than planned. In fact, objections about the environmental impact of processing plants have made it impossible to get a new plant sited in Oregon and Washington. These environmental limits to capacity expansion in the Northwest may provide an opportunity for capacity expansion in other areas, including Michigan.

Technological Considerations in Processing

The technology of frozen french fry processing has seen relatively few changes. The basic method of cutting fries using a water gun cutter has changed little over the past twenty years. Likewise, the "Individually Quick" freezing technique has also remained relatively consistent in recent years.

One of the few recent technological developments in frozen potato processing involves automatic defect detection and removal. The technology provides benefits related to efficiency in addition to quality. It reduces waste by removing only the defect instead of the entire defective fry. Raw product handling labor is also substantially reduced. Plants with the most up to date equipment are more efficient and profitable, therefore.

---

[3]This means that the raw potato has deteriorated so that its quality is no longer acceptable.

Another important technological development in the frozen french fry processing industry is the introduction of a technique called "coating." The coating is made of a liquid mixture that contains potato flour, wheat starch and dairy protein. The coating on fries provides two benefits to the food service operator. First, it provides a medium for adding flavors to the fries. The second advantage that coated fries provide to the food service operator is that it increases the salable life of the fries after cooking about four fold. So coating provides the operator the opportunity to differentiate his french fries and to obtain a huge cost savings through waste reduction.

Due to these advantages, there has been a tremendous demand for the output of plants which have the capacity to produce coated fries. Producers with a great deal of standard capacity are at somewhat of a disadvantage, therefore. There is a significant advantage to building a new plant that includes this technology. Unique difficulties are encountered when retrofitting an existing factory. It may be necessary to knock down walls, and pipelines must be installed in circuitous routes around immovable equipment. The bottom line is that it costs about ten times as much to retrofit an existing plant for coated fry production as it does to include it in a new facility.
Some of the fast food companies have switched to selling coated fries. Frozen fry processors are currently scrambling to either convert existing capacity to coated or to add coated capacity. Lamb Weston Inc. and McCain, through its 1997 acquisition of Ore-Ida Foods Inc., both currently have coated capacity.

Industry Consolidation

As mentioned above,, about 90% of the output of the french fry industry is sold to the food service segment. Most of this segment is fast food which has a high level of power. This is evident by the huge volume purchased fast food companies. As in the retail segment, fast food fries are more or less an undifferentiated commodity. Probably very few customers know where McDonald's fries are produced.[4]

Until recently, per capita consumption of french fries in the United States has been increasing and exports have been expanding. In 1995 and 1996, plants were running at about 95% capacity. Plants that processed for 300 days per year in the past were kept in operation for 325 days per year. Processors have reacted by adding capacity. Last year, the change in demand was negligible while capacity increased. This has created the existing excess capacity in the industry. Simplot closed one of its Caldwell, Idaho plants. This was a sobering moment for the company, because decades ago it was in this very plant that the method of freezing potatoes was perfected. The changes in supply and demand in the frozen potato market actually exacerbated a trend of consolidation that is being observed throughout the agri-food sector. The smaller, family-owned food processors are either going out of business or are being acquired by global giants.

Smaller processors have been unable to compete in such a price-driven environment. One by one, family-owned suppliers have been exiting the business. In March, for example, Northern Star in

---

[4] And if they are satisfactory, it is unlikely that they would be concerned with the identity of the source.

Minneapolis shut down its fry line. The plant, owned by Michael Foods, has a capacity of 2.5 million cwt. and is currently for sale.

IMPLICATIONS AND CONCLUSIONS

The industry profile that emerges from this assessment of demand and supply in the frozen potato industry is a rather negative one from the perspective of U.S. industry profitability for the foreseeable future. On the demand side, U.S. demand has probably peaked on a per capita basis. As a result, total demand will not grow faster than the population as a whole--a 1-2% per annum growth rate. The industry should thus be considered mature. There may be some growth of frozen product at the retail level, but Michigan's frozen potato processing subsector in its current state is not positioned to take advantage of this growth. International demand is growing rapidly, but it will likely be supplied by locally sited processing facilities owned by mostly large international firms. On the supply side, the industry is in an over capacity situation that will not be relieved any time soon by demand expansion. Profits will be squeezed. Market share gains will go to those firms that invest in the most modern plant technology in regard to defect sensing and fry coating. As quality becomes an even more important issue to consumers, older, ineffective plants will be a major disadvantage in the competitive environment on that is likely to characterize the frozen potato industry. Though Michigan's frozen potato processing sector has experienced serious raw potato storage problems, the analysis in this report suggests that the causes of the acreage cutback are far more extensive and complex than raw potato quality alone.

References

Huffacker, Bruce, **North American Potato Market News**, Volume 5, No. 29, May 29, 1997.

Michigan Department of Agriculture and USDA/AMS Fruit and Vegetable Division, **Marketing Michigan Vegetables, 1994 Crop**, 1995, p. 79.

National Potato Council, **Potato Statistical Yearbook**, 1996, Englewood, CA, various pages.

Stuebner, Stephen, **Competitive Forces Bring Anxious Days to Idaho**, New York Times Article, April 1997.

U.S. Bureau of the Census, **City and County Data Book 12th Edition**, Washington, DC, 1994.

U.S. International Trade Commission, **Fresh and Processed Potatoes: Competitive Conditions Affecting the U.S. and Canadian Industries**, Investigation Number 332-378, Publication 3050, July 1997.

USDA/ERS, **Review of Canadian Support Programs for the Potato Sector**, FAS staff paper I-96, July 1996.

Exhibit 1. Per Capita Consumption of all Potatoes (pounds), 1976-97.

Year	Total Fresh and Processed	Fresh	Processed				
			Total	Frozen	Chips and Shoestrings	Dehydrated	Canned
1976	125.20	49.40	75.80	41.80	15.80	16.30	1.90
1977	122.10	50.10	72.00	42.20	16.20	11.40	2.20
1978	119.60	46.00	73.60	42.60	16.60	12.10	2.30
1979	117.80	49.30	68.50	38.50	16.70	11.20	2.10
1980	114.70	51.10	63.60	35.40	16.50	9.80	1.90
1981	116.50	45.80	70.70	41.50	16.60	10.80	1.80
1982	115.10	47.10	68.00	38.60	17.10	10.40	1.90
1983	118.70	49.80	68.90	39.20	17.80	10.00	1.90
1984	122.10	48.30	73.80	43.70	18.00	10.30	1.80
1985	122.40	46.30	76.10	45.40	17.60	11.20	1.90
1986	126.00	48.80	77.20	46.30	18.20	10.90	1.80
1987	126.00	47.90	78.10	47.90	17.60	10.80	1.80
1988	122.40	49.60	72.80	43.30	17.20	10.40	1.90
1989	127.10	50.00	77.10	46.80	17.50	10.80	2.00
1990	127.70	45.80	81.90	50.20	17.00	12.80	1.90
1991	130.40	46.40	84.00	51.30	17.30	13.70	1.70
1992	132.40	48.90	83.50	51.00	17.50	13.20	1.80
1993	136.90	49.70	87.20	54.50	17.60	13.40	1.70
1994	140.80	49.10	91.70	59.40	17.10	13.50	1.70
1995	140.20	49.80	90.40	58.40	17.00	13.30	1.70
1996 1/	140.40	48.50	91.90	60.00	16.80	13.50	1.60
1997 f	143.30	52.30	91.00	57.30	16.80	14.90	2.00

Source: Potato Statistical Yearbook, National Potato Council, 1996, p. 36.
1/ Source: ERS/USDA.
f = forcasted

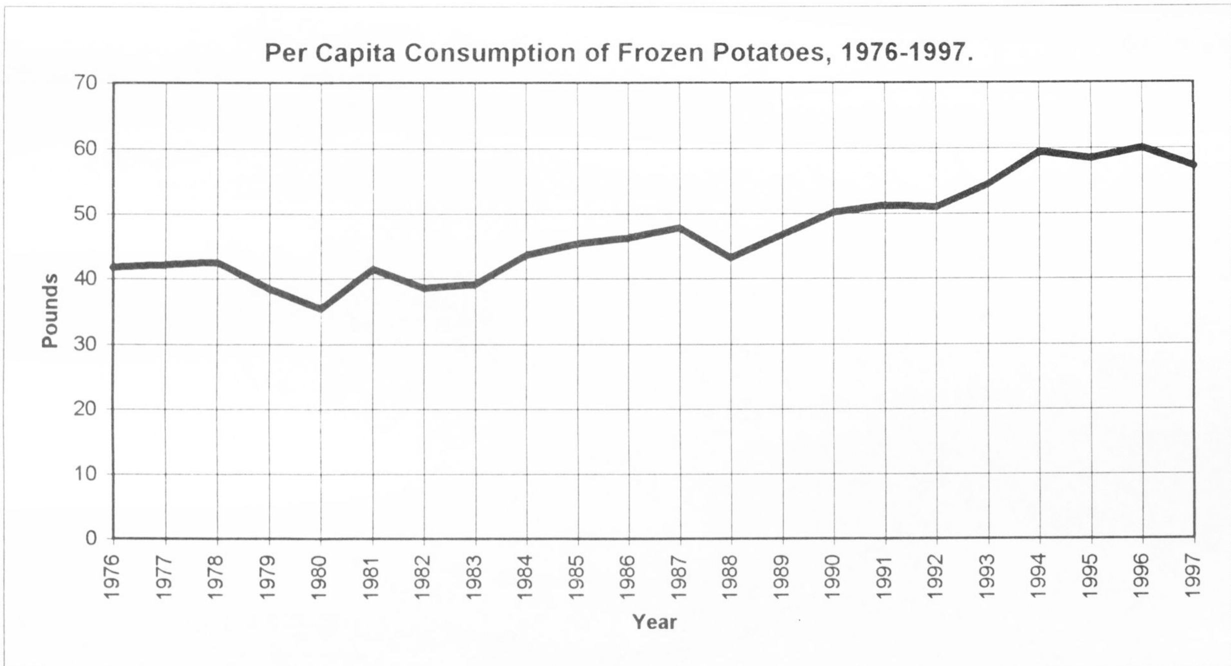


Exhibit 2. Estimated Volume of Frozen Potato Market Within 100/200/300 Miles of the Grand Rapids Plant

Miles from Plant	Total Population /1	1996 per capita Consumption (pounds) / 2	Total Market Volume (pounds)	Total Market Volume (cwt.)
0-100	4,482,082	60	268,924,920	2,689,249
100-200	17,746,705	60	1,048,023,000	10,480,230
200-300	12,728,032	60	763,681,920	7,636,819
1996 Total Market Volume Within 300 Miles	34,956,819	60	2,097,409,100	20,974,091
1997 Forecasted Market Volume Within 300 Miles	34,956,819	57.3	2,003,025,729	20,030,257

1/ Source: County and City Data Book, 1994, 12th Edition.

2/ Source: Potato Statistical Yearbook, National Potato Council, 1996, p. 36.

Volume Calculations: Refer to Michigan State University, Department of Agricultural Economics, Staff Paper #97-47, Sept. 1997.

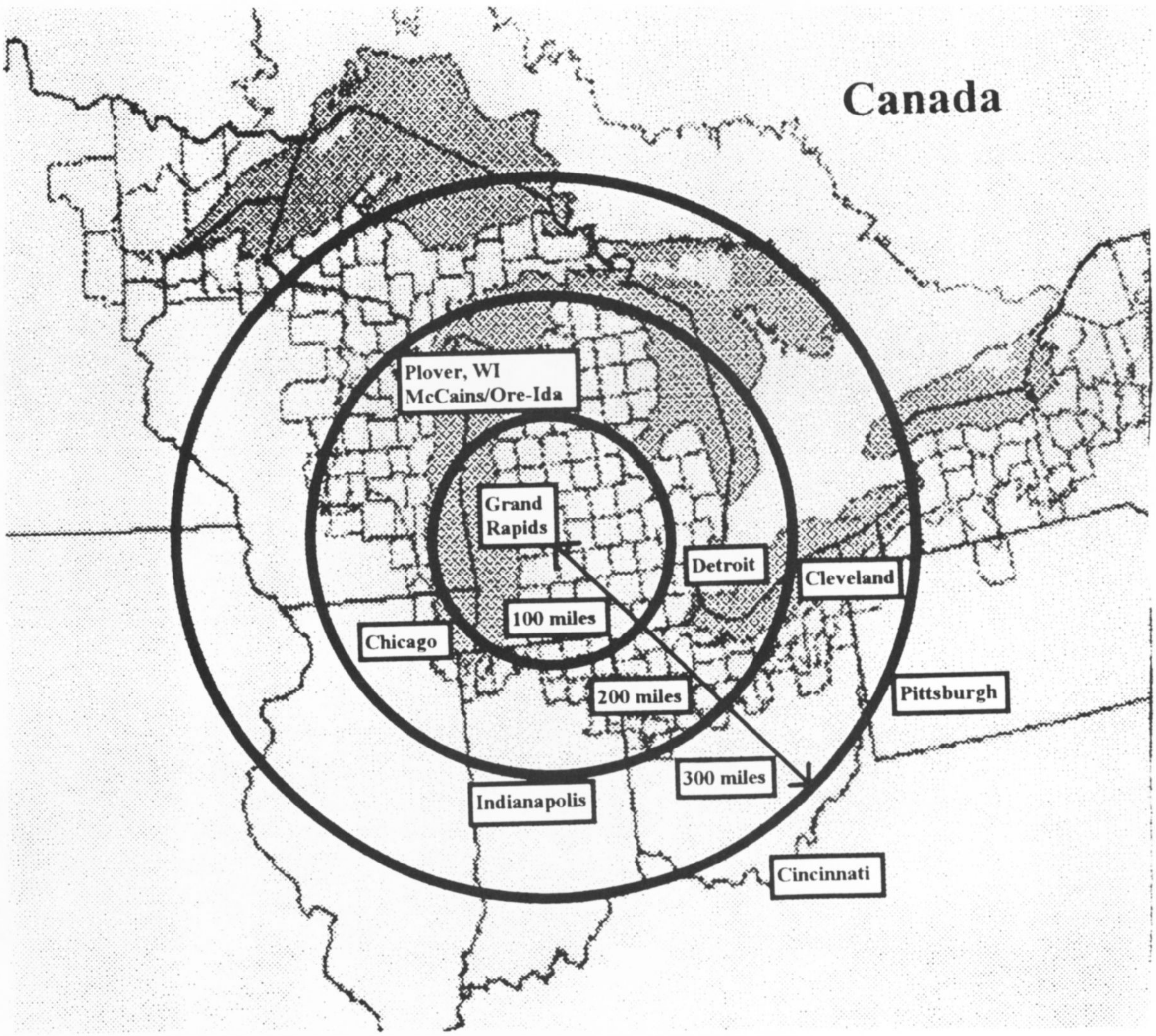


Exhibit 3. Potato Processing Plants in North America

Company	Plant Locations	Capacity (raw product, million cwt.)	Comments
McCain Foods	Othello, WA	11.5	
	Clark, SD	2.0	
	Portage La Pr., Man.	7.0	
	Grand falls, NB	3.5	
	Carleton, P.E.I	3.3	
	Florenceville, NB	3.0	
	Burley, ID	11.0	Recently bought from Ore-Ida
	Plover, Wis.	11.5	Recently bought from Ore-Ida
	Easton, ME	6.0	
Ore-Ida	Ontario, OR	12.0	
Nestle	Moses Lake, WA	5.5	
	Othello, WA	5.5	
	Nampa, ID	3.5	
	Prosser, WA	7.5	
	Hermiston, OR	10.0	
	Boardman, OR	7.0	
	Connell, WA	8.0	
	Pasco, WA	9.5	
	Quincy, WA	9.5	
	Richland, WA	6.0	
	American Falls, ID	12.0	
	Twin Falls, ID	11.0	
Lamb/RDO	Park Rapids, MN	5.0	
Simplot	Hermiston, OR	12.0	
	Caldwell, ID	14.0	
	Heyburn, ID	10.0	
	Abderdeen, ID	5.0	
	Grand Forks, ND	7.5	
	Grand Rapids, MI	3.5	
Amer. Prarie (AVIKO USA)	Jamestown, ND	4.3	
Cavendish Farms	New Annan, P.E.I	9.0	
York Farms	Lethbridge, Alberta	1.5	
Nestle-Simplot	Carberry, Man.	6.8	
Western Idaho Proc'g	Nampa, ID	2.0	