1998
MICHIGAN POTATO RESEARCH REPORT

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Michigan State University
Agricultural Experiment Station

In Cooperation With
The Michigan Potato Industry Commission

THE MICHIGAN POTATO INDUSTRY COMMISSION

February 11, 1999

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 1998 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 1999 season.

The Michigan Potato Industry Commission

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1998 MICHIGAN POTATO RESEARCH REPORT

R.W. Chase, Coordinator

INTRODUCTION AND ACKNOWLEDGMENTS

The 1998 Potato Research Report contains reports of potato research projects conducted by MSU potato researchers at several different locations. The 1998 report is the 30th 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. Kaz will complete his MSU appointment and return to his home in Poland in March 1999. 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. Best wishes to Dr. Maury Vitosh who will be retiring from MSU in June, 1999. He has been a long time member of the MSU potato research team.

WEATHER

The weather during the 1998 growing season was unseasonably warm from April through September. Both average maximum and minimum temperatures in April and May were well above the 15 year average (Table 1), near average in June and July and again higher in August and September. If one compares the 1998 six-month average, it was very similar to 1991, 1988 and 1987. There were five days in which the temperature reached 90F or above and five days in April that the temperature was below 32F.

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
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
1998	60	37	75	51	77	56	82	58	81	60	76	52	75	52
15-YR. AVG.	55	34	68	44	78	54	81	58	78	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
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
1998	2.40	2.21	1.82	0.40	2.22	3.05	12.10
15-YR. AVG.	2.82	2.82	3.21	3.09	4.28	3.90	20.12

Rainfall was well below the 15 year average, 2.04 inches less than the drought year of 1988 and the lowest during the past 15 years. It reflects the droughty conditions which occurred across the West and East Central area of Michigan as well as Northern Michigan. The value of irrigation was well documented in 1998. Irrigation was initiated on June 16, and 14 applications were made with the final irrigation on August 24. The weather during September and October was excellent for harvest.

GROWING DEGREE DAYS

Table 3 summarizes the cumulative, base 50F growing degree days for May through September. Collection of these data were initiated in 1991. Table 3 shows the 1998 season was a close parallel to 1991, the two warmest seasons during the past eight years. Growing degree days for May 1998, were significantly higher than the previous six years which helped the crop get off to a good start.

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
1998	427	932	1545	2180	2616

*1991 and 1992 data calculated from Vestaburg weather station in Montcalm County (Dr. Jeff Andresen, Geography). 1993-1998 data from the weather station at MSU Montcalm Research Farm (Don Smucker, Montcalm County Extension Director).

PREVIOUS CROPS AND FERTILIZERS

The general potato research area was planted to soybeans in 1997, disked in late summer and seeded to rye. The plot area was not fumigated and the following fertilizers were used in the general potato research plot area.

Application	Analysis	Rate	Nutrients ($N-P_2O_5-K_2O$)
Broadcast at plowdown	0-0-60	225 lbs/A	0-0-135
At-planting	18-18-0	10 gal/A	20-20-0
At emergence	46-0-0	200 lbs/A	92-0-0
Sidedress	46-0-0	152 lbs/A	70-0-0
Sidedress (long type and Snowden)	46-0-0	135 lbs/A	62-0-0

SOIL TESTS

Soil tests for the general plot area.

	lbs/A				Cation Exchange
pH	P_2O_5	K_2O	Ca	Mg	Capacity
5.9	434	238	600	210	3.9 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.

INSECT AND DISEASE CONTROL

Imidacloprid (Admire) was used at planting and no foliar insecticides were needed. Fungicide applications were initiated on June 14, and 11 applications of Bravo ZN were made during the growing season.

Funding: Federal Grant/MPIC

MICHIGAN STATE UNIVERSITY POTATO BREEDING PROGRAM 1998 STATUS REPORT

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Department of Crop and Soil Sciences

Cooperators: R.W. Chase, Ray Hammerschmidt, Ed Grafius Willie Kirk, and George Bird

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, utilize transformation techniques to insert economically important genes, 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 and Mexican germplasm as sources of disease resistance and quality traits. In addition, our program integrates genetic engineering to introduce traits. We feel that these in-house capacities (integrating 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, dormancy, 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, Colorado potato beetle, Potato tuber moth, broad-spectrum disease resistance via the glucose oxidase (GO) gene, late blight resistance with the resveratrol synthase (RS) gene and cold/frost resistance (COR15). We also have the glgC16 gene (or starch gene) from Monsanto to modify starch and sugar levels in potato tubers. We have transgenic lines that express the PVYcp, Bt, and GO genes. Transformations with the starch, cryIIIA-Bt, GO, RS, and COR15 genes 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 six species: *S. tuberosum* (adaptation, tuber appearance), *S. phureja* (cold-chipping, specific gravity), *S. tarijense* and *S. berthaultii* (tuber appearance, insect resistance), *S. microdontum* (late blight 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 1998 field season over 500 crosses have been planted and evaluated. Of those 15% of the crosses were between long types, 80% between round whites, and 5% to select red-skinned or yellow-flesh varieties. During the 1998 harvest, approximately 700 single hill selections and 1,200 bulk selections were made from the 32,000 seedlings grown at the Montcalm Research Farm and Lake City Experiment Station. We have been maximizing the seedling population size to emphasize our late blight breeding efforts. In addition to the single hill selections, 400 selections were made from 1,800 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. In 1997 we evaluated about 5,000 seedlings from late blight crosses. Intensive evaluation (specific gravity, tuber appearance, chip-processing, and late blight testing) was made on the 423 selections. In 1998, the selections were planted at the Lake City Experiment Station as 8-hill plots for agronomic evaluation and at the Muck Soils Research Farm for late blight evaluation. We now have identified about 110 selections that have late blight resistance and possess good tuber qualities. In addition, we have learned from this study which late blight resistant parents transmit the best resistance along with agronomic qualities (Zarevo, Tollocan, and B0718-3). We are planning to cross some of the best selections to combine different late blight resistance sources. This strategy may lead to late blight resistance with a more durable and broader genetic base.

Our germplasm enhancement efforts have been focusing on screening wild *Solanum* species for late blight resistance. Numerous plant introductions from Mexico and South America were tested in the greenhouse late blight chamber. The selections that showed the strongest resistance were retested. As a result, we have identified approximately 30 lines with strong resistance that constitute a broad genetic base to work with. These lines have been crossed to our best diploid lines to introgress the late blight resistance. These populations will be screened in 1999.

One of our objectives is also 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 1998, 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, and 3) select more russet lines and introduce the CryIII-Bt gene into Yukon Gold, Norwis, Onaway, MSG274-3 (late blight resistant line), and MSE018-1.

Directed breeding efforts have been made to combine cold-chipping from diverse sources. 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. We are using a 42F storage as our interim screen for cold-chipping prior to 40F storage. This germplasm is advancing through the early selection stages. We now have many selections with 2-3 different sources of cold-chipping in their pedigree. Some of these were agronomically tested at the Montcalm Research Farm in 1998 and more selections are planned for 1999. We have also been using the starch gene (AGPase) to reduce sugar levels in the cold-stored tubers. We have transgenic lines of Atlantic, Onaway, and Snowden. We are in the process of transforming MSE149-5Y.

Performance of 38 and 61 advanced selections was tested in the Adaptation and 2x23 Trials, respectively. The most promising selections are summarized in Tables 1 and 2. The specific gravity of the plots in the trials at Montcalm Research Farm were below average in 1998. The most promising selections from these trials with chip-processing potential are MSH031-5, MSG015-C, MSH095-4, MSG141-3, MSG007-1, and MSG227-2. MSG274-3 has strong resistance to late blight, high yield potential with smooth attractive tubers, and will chip-process out of the field. We also identified a high-yielding blue-fleshed potato (MSG147-3P) that makes a novelty chip (Wolverine chips). Attractive tablestock selections in these trials are MSG050-2, MSG004-3, and MSG145-1Y. The selections MSG050-2 and MSH120-1 have reduced susceptibility to late blight. All promising selections are targeted for tissue culture this winter and seed increase in 1999. The Late Blight and Fusarium dry rot tests, scab trial results, and blackspot bruise tests for these selections are summarized in the 1998 Potato Variety Evaluation Report.

In 1999 we plan to field test Yukon Gold, Lemhi Russet, Norwis, and Spunta lines with the CryIII-Bt gene for Colorado potato beetle resistance. We will also test the AGPase-transgenic lines of Snowden, Atlantic, Onaway, and GoldRush. In addition, Snowden, Atlantic, and Spunta lines with the GO gene will be field tested for late blight resistance at the Muck Soils Research Farm.

TABLE 1

ADAPTATION TRIAL

SEPTEMBER 16, 1998 (135 DAYS)

	CWT/A		Percent By Weight[1]							Quality[2]				Total		
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[5]	HH	VD	IBS	BC	Cut	Scab[3]	Maturity[4]
G104-6	521	558	93	5	59	35	2	1.065	1.5	11	4	1	0	40	4.0	5
AF1753-16	474	524	90	4	55	35	5	1.077		1	2	0	0	40	3.0	4
F019-11	433	465	93	7	82	11	0	1.072	1.0	4	1	0	0	40	3.0	3
F059-1	425	452	94	3	50	44	3	1.069	2.5	0	5	0	0	40	3.0	3
ATLANTIC	425	453	94	6	80	14	0	1.082	1.0	6	2	1	0	40	3.0	2
AF1763-2	418	466	90	10	87	2	0	1.050	3.0	1	2	0	0	40	4.0	1
AF1475-20	406	436	93	7	87	6	0	1.068	1.0	1	1	0	0	40	2.0	2
ONAWAY	402	437	92	7	83	9	1	1.063	3.5	0	11	0	0	40	1.5	1
F014-9	394	438	90	9	71	19	1	1.065	1.5	0	0	0	0	40	-	3
G274-3	383	576	66	33	66	0	0	1.077	1.5	0	2	0	0	40	3.0	3
E011-14	375	400	94	5	84	9	1	1.070	1.0	0	3	0	0	40	4.0	1
G049-4	375	422	89	6	62	26	5	1.067	2.5	2	6	0	1	40	3.3	2
F105-10	374	422	89	9	76	13	3	1.084	1.5	8	11	2	0	40	2.0	4
P84-9-8	366	414	88	8	82	6	4	1.075	2.0	1	8	3	3	40	2.0	4
P83-11-5	362	418	87	9	79	8	4	1.074	1.0	3	6	0	0	40	1.5	2
G119-1RD	352	367	96	3	76	20	1	1.064	1.0	0	0	0	0	40	1.2	4
E030-4	347	382	91	9	85	6	0	1.064	2.0	0	2	0	0	40	3.0	1
E033-1RD	346	379	91	8	76	16	1	1.062	2.0	0	0	1	2	40	1.2	1
SNOWDEN	343	407	84	16	81	3	0	1.076	1.0	1	8	0	0	40	3.3	3
G227-2	337	394	85	15	83	2	0	1.075	1.0	2	2	0	0	40	1.0	3
G007-2	327	361	91	9	82	9	1	1.086	1.0	1	4	0	0	40	2.5	2
B094-1	307	339	91	8	82	9	1	1.073	1.5	1	6	0	0	40	2.0	2
ERNTESTOLZ	305	393	77	20	77	1	3	1.086	1.5	3	4	0	0	40	2.0	3
F020-23	303	369	82	16	74	8	2	1.075	1.0	2	4	1	0	40	1.5	4
E080-4	302	340	89	6	65	24	6	1.071	1.5	0	5	0	0	40	2.0	1
F313-3	297	350	85	13	67	18	3	1.071	1.0	1	8	1	0	40	2.0	4
G077-7Y	289	370	78	21	71	7	1	1.069	1.0	6	3	0	0	40	2.5	1
NY119	281	330	85	15	83	2	0	1.081	1.0	0	0	0	5	40	1.0	2
E245-B	266	321	83	15	76	7	2	1.075	1.5	2	5	0	0	40	1.5	2
NY121	265	381	70	30	68	2	0	1.069	1.0	1	1	0	0	40	3.0	1
SUPERIOR	258	306	84	16	84	0	0	1.065	2.0	0	5	0	6	40	1.2	1
B040-3	211	283	75	24	75	0	2	1.063	1.5	2	3	0	0	40	2.0	1
MEAN	352	405						1.071								
$LSD_{0.05}$	64	66						0.004								

[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
1 = VERY RESISTANT
5 = VERY SUSCEPTIBLE

[4]MATURITY
1 = VINE DEAD BY AUGUST 13
5 = 100% GREEN ON AUGUST 13

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

TABLE 2

2X23 BREEDING LINE TRIAL

SEPTEMBER 14, 1998 (133 DAYS)

	CWT/A		Percent By Weight[1]							Quality[2]				Total		
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[5]	HH	VD	IBS	BC	Cut	Scab[3]	Maturity[4]
E028-1	672	729	92	4	68	24	4	1.063	1.0	0	1	11	0	20	2.0	5
H031-5	560	618	91	9	86	4	0	1.075	1.0	0	0	0	0	20	2.0	2
G015-C	536	589	91	9	84	7	0	1.075	1.0	0	0	0	1	20	1.0	3
H095-4	506	570	89	8	56	33	3	1.074	1.0	3	0	0	0	20	1.8	4
ATLANTIC	494	519	95	5	66	30	0	1.082	1.0	7	1	0	0	20	3.0	3
H110-2	491	611	80	19	72	8	1	1.077		0	0	0	0	20	3.0	2
G147-3P	486	528	92	6	51	41	2	1.056	1.5	0	0	0	0	20	2.5	5
H098-2	485	511	95	5	71	23	0	1.076	1.0	0	1	0	0	20	1.8	3
H419-1	475	553	86	12	77	9	2	1.078		0	0	0	1	20		3
G034-2	475	509	93	5	55	38	2	1.064	1.0	0	0	0	0	20	1.3	2
G257-7	466	535	87	9	74	13	4	1.076	1.0	11	0	0	0	20		4
H321-1	463	586	79	13	76	3	8	1.075	1.0	0	2	0	0	20		2
H311-4	463	491	94	5	82	13	0	1.071	1.0	2	0	0	0	20	3.0	3
H106-2	452	510	89	11	74	14	1	1.084	1.0	0	0	6	3	20	1.0	5
G297-4Y	439	501	88	10	73	14	2	1.079	1.5	4	0	1	0	20		3
SNOWDEN	425	501	85	13	73	12	2	1.075	1.0	1	0	0	0	20	3.3	3
H101-2Y	418	481	87	13	65	22	0	1.070	1.0	0	0	0	0	20	3.5	1
H067-3	417	455	92	7	76	16	2	1.079	1.0	2	0	0	0	20	2.5	1
G050-2	415	483	86	13	72	14	1	1.072	1.5	0	0	0	0	20		1
H308-2	411	484	85	11	64	21	4	1.074	1.5	1	0	0	0	20	2.5	2
F001-2	411	444	93	7	78	14	1	1.082	1.0	3	0	2	0	20	4.0	2
ONAWAY	394	434	91	7	80	10	2	1.063	3.0	0	2	0	0	20	1.5	1
G004-3	385	398	97	3	74	23	0	1.058	1.0	0	0	0	0	20	1.0	3
F060-6	377	401	94	5	64	30	1	1.074	1.0	1	0	0	0	20	1.5	4
G145-1	377	414	91	7	72	19	2	1.067	1.5	6	0	0	0	20	3.0	2
H136-2	367	430	85	11	75	10	3	1.069	1.0	0	0	0	0	20	3.3	2
H392-1	364	429	85	11	56	29	4	1.078	1.5	12	0	0	0	20	2.0	3
F090-9	362	421	86	10	69	17	4	1.068	1.0	0	0	0	0	20	1.2	2
H120-1	355	440	81	19	74	7	0	1.077	1.0	0	0	0	2	20	2.5	2
E074-1	350	380	92	8	71	21	0	1.074	1.0	0	0	1	0	20	3.3	1
H130-2	343	477	72	27	71	1	1	1.065	1.0	2	0	0	0	20	1.3	1
G141-3	339	427	79	20	78	2	1	1.079	1.0	0	1	0	0	20	3.0	1
H351-6	327	370	88	8	63	25	3	1.080	1.0	1	0	0	0	20	3.0	3
H139-4	320	480	67	17	52	14	16	1.079		9	0	0	1	20	2.0	5
AF1552-5	318	368	86	5	30	57	9	1.076		10	0	0	0	20	1.0	4
G301-9	315	402	78	21	76	3	1	1.068	1.0	0	0	0	0	20	2.0	1
E040-6RY	311	426	73	24	67	6	3	1.066	1.5	1	1	0	0	20	3.0	1
E274-A	277	305	91	7	78	13	3	1.075	1.0	0	0	0	0	20	1.2	2
AF1808-18	262	321	82	18	65	17	0	1.067		1	1	0	0	20	3.0	1
H369-2	251	280	90	7	56	34	3	1.073	1.0	0	0	0	0	20	3.0	3
E026-A	250	285	88	12	75	13	1	1.072	1.0	0	3	0	0	20	1.5	1
F369-1RY	237	332	71	28	69	3	1	1.061	1.5	0	0	0	0	20	2.0	2
F420-1	222	260	85	9	77	8	6	1.069	1.0	1	0	0	0	20	1.0	4
H018-3	169	315	54	46	54	0	0	1.068	1.0	0	1	0	0	20		1
MEAN	392	455						1.072								
$LSD_{0.05}$	111	114						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
1 = VERY RESISTANT
5 = VERY SUSCEPTIBLE

[4]MATURITY
1 = VINE DEAD BY AUGUST 13
5 = 100% GREEN ON AUGUST 13

[5]SNACK FOOD ASSOCIATION CHIP SCORE

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1998 POTATO VARIETY EVALUATIONS

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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.

The round white tuber types were harvested at two dates (Date-of-Harvest trial). The other field experiments were the Long, North Central Regional, Robinson 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 and 50°F for chip-processing out of storage in January and March.

Results

A. Round White Varieties

Three varieties and 22 breeding lines were compared at two harvest dates. Atlantic, Snowden and Onaway were used as checks. The trials were subject to early growth due to the warm spring with subsequent earlier maturity. The plot yields were high in the early harvest (98 days), however, little yield increase was observed for the second harvest date (133 days). It was also a below average year for specific gravity. The results are presented in Tables 1 and 2. In the early harvest trial NY112, MSE221-1, MSF373-8, MSF099-3, MSE228-1 and E018-1 had the highest yields of the 25 entries. At the later harvest NY112, MSF373-8, MSE018-1, MSE221-1, MSF099-3 were still the top yielders along with MSE149-5Y and Atlantic. MSE149-5Y and MSE018-1 were also top yielders in the on-farm processing trials, while MSE228-1 was the top yielder in the on-farm tablestock trial. Internal brown spot and hollow heart incidence were low within the trial, however vascular discoloration was more prevalent as in 1997.

Variety Characteristics

MSA091-1 - an MSU selection for chip-processing with scab resistance. Yields in 1998 were below average, but it has performed well in other states and the late blight trials indicate a reduced susceptibility to late blight. It is a candidate for the 1999 SFA Trials.

MSB076-2 - this MSU selection has high yield potential, has very high specific gravity, and resistant to scab, but the chip-processing tends to be variable. 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 1996-1998.

MSE018-1 - an MSU chip-processing selection with high yield potential. It was an outstanding yielder in the 1997 and 1998 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 was in the 1998 SFA Trials. Chip-processing was variable in the 1998 on-farm trials.

MSE149-5Y – an MSU tablestock/chip-processing selection. It has high yield potential and produces attractive round tubers with a bright skin and light yellow flesh. It was the top yielder in the 1998 on-farm chip-processing trials. It chips out of 45F cold storage, but has a low specific gravity. It is a candidate for the transformation with the starch gene to raise the specific gravity.

MSE221-1 - an MSU tablestock selection. It has high yield potential as seen in the MSU and on-farm trials. General appearance is good, but it has a netted appearance similar to Superior. It has strong resistance to scab.

MSE228-1 – an MSU tablestock selection. It has high yield potential as seen in the MSU trial. It was the top yielder in the on-farm tablestock trials. We now have tissue culture-derived seed for the 1999 field season.

MSE228-11 - an MSU selection for the tablestock/chip-processing market. It has high yield potential with a high tuber set. It has a mid-season maturity. It will chip-process out of the field and also has a bright skin with an attractive general appearance. In the 1998 on-farm trials it performed well.

MSE246-5 – an MSU chip-processing selection. It produces round tubers, has some scab tolerance along with reduced susceptibility to late blight. It also chip-processes from 45 F cold storage. A candidate for the 1999 grower trials.

MSF373-8 – an MSU tablestock selection. It produces large tuber with excellent internal quality. Tuber set is low and it sizes early. The tubers have medium deep eyes.

MSF099-3 – an MSU chip-processing selection. It has high specific gravity, smooth attractive tubers, excellent chip quality and will chip-process from 45 F cold storage. It is a candidate for the 1999 grower trials.

MSNT-1 - an MSU chip-processing selection. It has above average yield potential, excellent chip quality and strong resistance to scab. Yield was below average in the 1998 MSU trial. It was in the 1998 SFA trials.

B. Long Varieties

Six varieties and five breeding lines were tested in 1998. Russet Burbank, Russet Norkotah and Shepody were grown as check varieties. The trial was dug at 127 days from planting and results are shown in Table 3. Early die was present in the trial resulting in moderate yield and lower specific gravity. Within the 11 entries, MSG088-6Rus, A7961-1,Umatilla Russet (AO82611-7) and Shepody produced the highest yields, however pickouts were high in MSG088-6Rus and Shepody.

Variety Characteristics

A7961-1 - is an USDA-Aberdeen entry with good performance. It has uniform appearance, heavier russeting than Russet Burbank and minimal internal defects. It can be used for frozen-processing. It will be named in the Northwest.

A8495-1 - is an USDA-Aberdeen entry with average performance in Michigan. It has similar yield as Russet Burbank, but a more desirable size distribution. It will be named in the Northwest.

Innovator - a European selection that has attractive russetting and produces excellent fry color, but has a low specific gravity.

MSB106-7 - a MSU tablestock selection. It has high yield potential as seen in the on-farm trials, but performed poorly at MSU. Tubers are oblong-long with a light netting.

MSE192-8RUS - a MSU tablestock selection. The tubers have an attractive russeting and shape. The yield in on-farm trials have been dissappointing. The vine is small which may make this line uncompetitive in small plot trials.

Umatilla Russet (AO82611-7) - this selection was the top performing line in 1997 and performed well in 1998. It is suitable for the frozen processing market. It is reported to have some resistance to early dying. Tuber shape is long but tuber width is narrow.

C. North Central Regional Trial

The North Central Trial is conducted in a wide range of environments (10 states) to provide adaptability data for the release of new varieties from North Dakota, Minnesota, Wisconsin, Michigan and Canada. Eighteen breeding lines and seven varieties were tested in Michigan. The results are presented in Table 4. The range of yields was wide and the specific gravity was low. The MSU selection MSA091-1 performed well in 1998. The line with the highest overall merit was the red-skinned selection MN17922, followed by Atlantic. MSE192-8RUS had a nice russeting and good tuber type, but an average yield. W1313, a Wisconsin seedling, had yield, but was one of the most bruise susceptible lines in all the trials. 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 and Robinson Trials

Nine European varieties and advanced selections were tested along with eight yellow-fleshed MSU seedlings. Yukon Gold and Saginaw Gold were used as checks. The results are summarized in Table 5. Typically, most of the European selections and varieties are late to very-late in maturity, but in 1998, the vines died early and we observed low specific gravity and a high percentage of 'B' size tubers. The yields varied considerably. The best performing lines in 1998 were A097-1Y, MSE048-2Y and Caesar. Lady Rosetta, a chip-processing line, had high specific gravity, but IBS in the tubers. Pickouts were high in Latona, Turbo and Dali. Obelix has nice tuber appearance along with Caesar, but scab susceptibility is high in Obelix. The Robinson trial tested four varieties (Table 6). The trial was subject to early die and below average yields were observed with few oversized tubers. Atlantic was the highest yielding variety in the trial. Navan was the most promising line from Robinson with chip-processing characteristics. Rocket and Saxon are bright-skinned tubers with good general appearance.

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 five 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 in 1998 at the MSU Soils Farm Scab Nursery. This disease trial is a severe test. The varieties and lines are placed into four arbitrary categories based upon scab infection level and lesion severity. A rating of 1.0 indicates zero to a trace amount of infection. A moderate resistance (1.2 – 1.8) correlates with <10% infection. Susceptible lines have greater than 25% infection with pitted lesions. Scores of 4.0 or greater are found on lines with >50% infection and severe pitted lesions. The check varieties Russet Burbank, Superior, Norchip, Atlantic and Snowden can be used as references. Scab results are also found in the Trial Summaries (Tables 2,3,4 and 5). Table 7B summarizes the 1996-8 scab trial results for the varieties and lines that have been tested at least two years in the past four years. These multi-year results give a more stable rating score for the clones tested in these trials.

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, placed in 50F storage overnight and then 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 greater than Atlantic are approaching the bruise-susceptible rating. In addition, the data is grouped by trial, since the bruise levels can vary between trials. We are also hoping the uniform tuber temperature prior to bruising may help reduce variability observed in previous years. These results become more meaningful when evaluated over 3 years which reflects different growing seasons and harvest conditions. Bruising was more severe in 1996 and 1998 than in 1997 and 1995.

G. Late Blight Trial

In 1998 a late blight trial was conducted at the Muck Soils Research Farm. Over 175 entries were evaluated in replicated plots. The field was inoculated mid-July 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, B0692-4, B0718-3 NY121 (Q237-25) and MSG274-3. The good agronomic qualities of MSG274-3 (see Table 1 of Breeding Report) make this selection the strongest candidate for commercialization. Lines with reduced susceptibility to late blight are Umatilla Russet, NorDonna, MSA091-1, Pike, MSH120-1, MSG050-2 and MSE246-5. 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 ranked according to infection depth. Infection levels within a clone can vary as seen by the multiple tests of the check varieties. Snowden, which has tolerance to fusarium, had infections from 4.4-12.3 mm in depth. Russet Burbank infections ranged from 9.7-12.2 mm, while Atlantic infections were from 16.2-26.8 mm. Few clones have low levels of infection. The best lines identified in this experiment were P83-11-5, A091-1, G034-2, G049-4, E263-10, F165-6RY, E080-4, G088-6RUS, H067-3, and E030-4. The results from this study support the tolerance observed for Snowden, A091-1, Superior, E030-4 and GoldRush in 1997.

TABLE 1

ROUND WHITES: EARLY HARVEST

AUGUST 10, 1998 (98 DAYS)

	CWT/A		Percent by Weight[1]							QUALITY[2]				Total	CWT/A
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[3]	HH	VD	IBS	BC	Cut	3-Year Avg.
NY112	539	570	95	5	83	11	0	1.075	1.0	1	0	0	0	40	-
MSE221-1	462	495	93	5	68	25	2	1.066	-	1	0	0	0	40	297*
MSF373-8	430	453	95	2	43	52	3	1.071	1.0	3	0	0	0	40	-
MSF099-3	407	444	92	8	82	10	1	1.081	1.0	1	0	0	1	40	-
MSE228-1	383	442	87	10	73	13	3	1.064	-	2	1	0	0	40	-
MSE018-1	370	412	90	10	81	9	0	1.074	1.0	2	0	0	0	40	226
ATLANTIC	350	395	89	9	81	8	2	1.081	1.0	6	0	0	0	40	259
MSE149-5Y	337	401	84	15	77	7	1	1.065	1.0	0	0	0	0	40	-
MSB107-1	330	355	93	5	67	26	2	1.068	-	0	0	0	0	40	205
NY115	328	382	86	14	82	3	0	1.068	1.0	0	1	0	0	40	-
MSA091-1	312	373	84	8	75	8	8	1.078	1.0	1	0	0	2	40	195
MSB073-2	309	401	77	22	77	0	1	1.079	1.0	0	0	0	0	40	170*
MSB076-2	308	353	87	11	82	5	2	1.083	1.5	7	0	0	0	40	201
SNOWDEN	298	355	84	14	77	7	2	1.077	1.0	2	0	0	0	40	190
ONAWAY	296	349	85	11	81	4	4	1.063	-	1	4	1	0	40	247
MSF015-1	289	356	81	18	79	2	0	1.066	1.0	0	0	0	0	40	-
MSNT-1	278	365	76	23	74	2	1	1.079	1.0	0	0	0	0	40	198*
MSE246-5	264	322	82	17	79	3	1	1.088	1.0	8	0	0	0	40	-
MSE263-10	258	315	82	17	80	2	1	1.071	1.0	0	0	0	0	40	-
MSE230-6	258	468	55	41	55	0	4	1.082	1.0	0	0	0	0	40	-
MSC148-A	237	331	72	24	69	2	4	1.071	1.0	1	1	0	0	40	156*
MSE228-9	234	317	74	24	72	1	2	1.076	1.0	0	0	0	0	40	192*
MSC103-2	203	231	88	7	71	16	6	1.063	-	1	0	0	0	40	148*
MSE250-2	196	313	63	37	63	0	1	1.083	1.0	0	0	0	0	40	-
MSE228-11	173	344	50	50	50	0	0	1.079	1.0	0	2	0	0	40	156*
MEAN	314	382						1.074							
$LSD_{0.05}$	60	60						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]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD RATINGS: 1 - 5
1: EXCELLENT
5: POOR

* 2-YEAR AVERAGE

TABLE 2

ROUND WHITES: LATE HARVEST

SEPTEMBER 14, 1998 (133 DAYS)

	CWT/A		Percent by Weight[1]							QUALITY[2]				Total			CWT/A
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[3]	HH	VD	IBS	BC	Cut	Scab[4]	Maturity[5]	3-Year Avg.
NY112	512	556	92	8	84	8	0	1.072	1.0	0	0	0	0	40	1.8	3	-
F373-8	463	482	96	2	37	59	2	1.073	1.0	4	1	0	0	40	2.3	5	412
E018-1	456	501	91	8	73	18	1	1.075	1.0	3	1	0	0	40	3.0	5	423
E221-1	417	455	92	6	71	20	2	1.062	1.0	0	4	0	0	40	1.5	1	328
ATLANTIC	402	443	91	8	77	13	1	1.081	1.0	5	1	0	0	40	3.3	2	339
F099-3	384	429	90	10	82	7	0	1.079	1.0	0	1	0	0	40	3.7	2	284
E149-5Y	368	408	90	10	78	12	0	1.063	1.0	0	1	0	0	40	1.8	2	303
E228-1	358	431	83	11	66	17	5	1.063	1.5	0	1	0	0	40	2.8	3	352
NY115	358	428	84	16	77	7	0	1.067	1.0	0	1	1	0	40	4.0	1	-
B107-1	345	378	91	6	61	31	2	1.068	1.0	2	1	0	0	40	1.0	4	340
SNOWDEN	335	391	86	14	80	6	1	1.075	1.0	2	0	0	0	40	3.5	3	278
B073-2	322	415	78	22	77	0	0	1.077	1.0	0	1	0	1	40	1.7	3	268
E246-5	307	376	82	17	78	3	1	1.087	1.0	4	1	0	0	40	1.0	4	229*
B076-2	296	365	81	16	78	3	3	1.079	1.0	3	1	0	0	40	1.2	2	259
E263-10	291	350	83	16	83	0	0	1.070	1.0	0	0	0	0	40	3.0	1	256*
A091-1	287	347	83	9	64	18	8	1.075	1.0	0	4	0	2	40	1.5	3	261
E228-9	277	369	75	24	74	1	1	1.073	1.0	0	3	0	0	40	3.0	1	247
ONAWAY	270	338	80	18	79	1	2	1.060	3.0	0	4	0	0	40	1.5	1	267
F015-1	262	352	74	25	72	2	0	1.063	1.0	0	1	1	0	40	1.0	1	266*
C103-2	260	284	92	6	63	28	2	1.067	2.0	1	1	0	0	40	3.7	5	262
NT-1	234	346	68	31	66	2	1	1.077	1.0	3	0	1	0	40	1.8	3	246
E250-2	228	325	70	28	69	1	2	1.081	1.0	0	0	0	0	40	4.0	4	202*
E230-6	224	437	51	45	51	0	3	1.079	1.0	0	0	0	0	40	2.3	2	250
E228-11	204	410	50	49	50	0	1	1.075	1.0	0	2	0	0	40	3.2	2	253
C148-A	183	290	63	35	62	1	1	1.070	1.0	0	2	0	0	40	3.3	1	158
MEAN	322	396						1.072									
$LSD_{0.05}$	60	60						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]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD RATINGS: 1 - 5
1: EXCELLENT
5: POOR

[4]SCAB
1 = VERY RESISTANT
5 = VERY SUSCEPTIBLE

[5]MATURITY
1 = VINE DEAD BY AUGUST 13
5 = 100% GREEN ON AUGUST 13

* 2-YEAR AVERAGE

TABLE 3

LONG WHITES/RUSSETS

SEPTEMBER 10, 1998 (129 DAYS)

	CWT/A		Percent by Weight[1]							QUALITY[2]				Total		CWT/A
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	FF[3]	HH	VD	IBS	BC	Cut	Scab[4]	3-Year Avg.
G088-6RUS	410	570	72	9	57	15	19	1.079	1.5	3	1	0	0	40	1.8	-
A7961-1	381	476	80	18	65	15	2	1.075	1.5	4	5	0	1	40	1.0	261
UMATILLA R	332	490	68	27	62	6	6	1.075	1.0	1	3	0	0	40	1.0	273
SHEPODY	324	421	77	12	59	18	11	1.074	1.5	2	15	0	0	40	3.3	273
A8495-1	296	352	84	14	70	14	2	1.075	1.0	8	1	0	0	40	1.0	207*
R BURBANK	293	448	65	29	58	8	6	1.072	2.0	1	1	0	0	40	1.0	230
INNOVATOR	291	397	73	21	64	9	5	1.067	1.0	0	4	0	0	40	3.8	-
E192-8RUS	225	304	74	23	63	11	3	1.067	1.0	0	3	0	0	40	1.0	195
GOLDRUSH	223	299	75	24	60	15	1	1.064	2.0	0	5	0	0	40	1.0	254*
B106-7	212	327	65	30	61	3	6	1.060	2.0	0	7	0	0	40	2.3	250
R NORKOTAH	207	311	67	32	65	2	1	1.065	1.5	2	3	0	0	40	2.0	161
MEAN	290	400						1.070								
$LSD_{0.05}$	83	88						0.011								

[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]FRENCH FRY COLOR SCORE
1: LIGHT
5: DARK

[4]SCAB
1 = VERY RESISTANT
5 = VERY SUSCEPTIBLE

* 2-YEAR AVERAGE

TABLE 4

NORTH CENTRAL TRIAL

SEPTEMBER 8, 1998 (127 DAYS)

	CWT/A		Percent by Weight[1]							QUALITY[2]				Total	
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[3]	HH	VD	IBS	BC	Cut	Scab[4]
R PONTIAC	475	518	92	6	70	21	2	1.055	3.0	5	2	0	0	40	3.3
ND5084-3R	471	513	92	7	75	17	1	1.053	3.0	0	3	1	0	40	2.5
MN16966	383	487	79	19	76	2	2	1.072	1.0	0	9	0	0	40	3.0
MN17922	372	387	96	3	65	31	0	1.056	2.0	1	7	0	0	40	1.7
A091-1	363	397	91	8	73	18	0	1.078	1.5	2	5	1	0	40	1.5
W1313	355	403	88	12	86	2	0	1.087	1.0	5	2	4	0	40	2.7
ATLANTIC	344	378	91	9	72	19	0	1.078	1.0	9	1	1	0	40	3.3
B073-2	317	377	84	15	79	5	1	1.075	2.0	0	4	0	0	40	1.7
W1355-1	315	435	73	27	72	1	0	1.080	1.0	0	1	0	0	40	3.0
SNOWDEN	313	366	86	14	80	6	0	1.076	1.0	2	8	0	0	40	3.5
NORCHIP	291	358	81	17	79	2	2	1.070	2.0	0	3	0	0	40	2.0
MN17572	287	389	74	26	71	3	0	1.052	2.0	0	2	1	0	40	1.0
W1151RUS	287	364	79	21	72	6	0	1.057	1.5	2	6	0	0	40	1.0
NORLAND	286	329	87	12	81	6	1	1.052	3.0	1	1	0	1	40	1.0
E230-6	276	376	73	24	73	0	2	1.078	1.5	1	1	0	0	40	2.3
ND2676-10	275	364	75	24	75	1	0	1.071	1.0	0	10	0	0	40	1.5
WIS75-30	274	385	71	28	70	1	0	1.074	1.5	1	2	0	0	40	2.0
E192-8RUS	251	332	75	22	54	21	2	1.066	-	1	4	0	0	40	1.0
FV8957-10	243	285	85	14	74	11	0	1.063	1.5	4	0	0	0	40	-
R BURBANK	229	352	65	19	60	5	16	1.069	1.5	3	7	0	0	40	1.0
ND2470-27	215	238	90	10	74	16	0	1.065	1.0	1	5	0	0	40	2.3
MN16478	159	198	80	19	79	1	1	1.075	2.0	0	7	0	0	40	2.3
W1348RUS	146	292	50	50	49	1	0	1.070	1.5	1	0	0	0	40	1.0
ND4093-4RUS	129	251	52	48	51	0	0	1.063	2.0	0	0	0	0	40	1.0
R NORKOTAH	127	215	59	41	53	6	0	1.060	2.5	1	5	0	0	40	2.0
MEAN	287	360						1.068							
$LSD_{0.05}$	80	80						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]SNACK FOOD ASSOCIATION CHIP SCORE
OUT OF THE FIELD RATINGS: 1-5
1: EXCELLENT
5: POOR

[4]SCAB
1 = VERY RESISTANT
5 = VERY SUSCEPTIBLE

TABLE 5

EURO/YELLOW TRIAL

SEPTEMBER 30, 1998 (149 DAYS)

	CWT/A		Percent by Weight[1]							QUALITY[2]				Total		CWT/A
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[3]	HH	VD	IBS	BC	Cut	Scab[4]	3-Year Avg.
A097-1Y	479	568	84	13	68	16	3	1.074	-	1	6	0	0	40	2.0	340
E048-2Y	478	530	90	9	73	17	1	1.073	-	8	0	0	0	40	1.0	390
CAESAR	468	531	88	10	84	4	1	1.068	1.5	0	2	3	0	40	1.3	-
F349-1YROSE	440	512	86	12	80	6	2	1.078	1.5	0	2	0	0	40	3.7	452*
OBELIX	366	516	71	26	71	0	3	1.056	2.5	0	1	0	0	40	4.8	267*
E222-5Y	334	419	80	17	77	3	3	1.072	2.0	9	3	0	0	40	2.0	281*
ACCENT	325	461	70	27	70	0	3	1.060	3.0	0	10	0	0	40	2.0	-
E226-4Y	311	359	86	12	77	9	1	1.059	2.0	1	0	0	0	40	2.3	298
MS401-1	286	362	79	19	77	2	2	1.075	1.0	2	0	0	0	40	3.0	-
YUKON GOLD	280	317	88	10	80	8	2	1.071	2.0	0	1	1	0	40	2.7	251
LATONA	275	471	58	34	58	0	8	1.075	2.0	0	10	3	0	40	3.8	328
FAMBO	273	377	72	25	68	4	3	1.064	1.5	0	8	1	0	40	3.0	-
SAG GOLD	260	365	71	28	70	1	1	1.068	1.0	0	1	0	0	40	2.0	246
LADY ROSETTA	252	407	62	33	61	1	5	1.085	1.0	11	1	6	0	40	2.5	-
F165-6RY	240	319	75	18	66	9	7	1.062	2.5	6	6	0	0	40	4.0	237
TURBO	216	457	47	31	47	0	21	1.063	2.0	0	12	2	0	40	2.5	-
C120-1Y	187	268	70	27	70	0	3	1.061	1.5	0	0	0	0	40	1.0	172
MIRAKEL	187	382	49	49	49	0	2	1.070	2.5	0	1	14	0	40	3.0	-
DALI	124	343	36	52	36	0	11	1.059	2.5	0	4	0	0	40	3.0	100*
MEAN	304	419						1.068								
$LSD_{0.05}$	79	81						0.0055								

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

[4]SCAB
1 = VERY RESISTANT
5 = VERY SUSCEPTIBLE

* 2-YEAR AVERAGE

TABLE 6

ROBINSON STUDY

SEPTEMBER 29, 1998 (145 DAYS)

	CWT/A		Percent by Weight[1]							QUALITY[2]				Total
	US#1	TOTAL	US#1	Bs	As	OV	PO	SP GR	SFA[3]	HH	VD	IBS	BC	Cut
ATLANTIC	300	348	86	13	81	5	1	1.082	1.0	3	4	0	1	40
NAVAN	242	354	68	31	67	2	0	1.079	1.5	0	2	0	0	40
SNOWDEN	210	301	70	30	67	2	0	1.077	1.0	0	15	0	0	40
ROCKET	204	370	55	42	55	0	3	1.072	-	0	11	0	0	40
MARIS BARD	180	273	66	31	66	0	3	1.066	2.0	2	5	0	0	40
YUKON GOLD	172	202	85	14	76	9	1	1.071	2.0	0	8	0	0	40
SAXON	151	301	50	49	50	0	0	1.061	-	0	4	0	0	40
SUPERIOR	128	226	56	43	56	0	1	1.065	-	0	6	1	5	40
MEAN	198	297						1.072						
$LSD_{0.05}$	56	63						0.0038						

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

TABLE 7A

1998 SCAB RESULTS

Strong Resistance		**Moderate Resistance**		**Intermediate Infection**		**Susceptible**	
A7961-1	1.0	MSB076-2	1.2	ACCENT	2.0	DALI	3.0
A8495-1	1.0	MSF090-9	1.2	AF1475-20	2.0	FAMBO	3.0
AF1552-5	1.0	MSG119-1RD	1.2	MSA097-1Y	2.0	MIRAKEL	3.0
AO82611-7	1.0	PICASSO	1.2	MSB094-1	2.0	MN16966	3.0
GOLDRUSH	1.0	**SUPERIOR**	**1.2**	MSE222-5Y	2.0	MS401-1	3.0
MN17572	1.0	CAESAR	1.3	MSH031-5	2.0	MSE018-1	3.0
MSB107-1	1.0	MSE033-1RD	1.3	MSH311-4	2.0	MSE226-5	3.0
MSC120-1Y	1.0	MSE245-B	1.3	**NORCHIP**	**2.0**	MSE263-10	3.0
MSE048-2Y	1.0	MSH098-2	1.3	P83-11-5	2.0	MSF369-1RY	3.0
MSE192-8RUS	1.0	MSA091-1	1.5	R NORKOTAH	2.0	MSG130-1	3.0
MSE246-5	1.0	MSC122-1	1.5	SAG GOLD	2.0	MSG141-3	3.0
MSF015-1	1.0	MSE026-A	1.5	WIS75-30	2.0	MSG145-1Y	3.0
MSF420-1	1.0	MSE221-1	1.5	MN16478	2.3	MSG147-3P	3.0
MSG004-3	1.0	MSE274-A	1.5	MSB106-7	2.3	MSG297-4	3.0
MSG015-C	1.0	MSF060-6	1.5	MSE080-4	2.3	MSH351-6	3.0
MSG034-2	1.0	MSH130-2	1.5	MSE226-4Y	2.3	MSH369-2	3.0
MSG227-2	1.0	ND2676-10	1.5	MSE230-6	2.3	MSH392-1ROSE	3.0
MSH106-2	1.0	**ONAWAY**	**1.5**	MSF373-8	2.3	NY121	3.0
MSH361-1	1.0	MN17922	1.7	ND2470-27	2.3	W1355-1	3.0
ND4093-4RUS	1.0	MSB040-3	1.7	ERNTESTOLZ	2.5	MSE228-11	3.2
NY119	1.0	MSB073-2	1.7	LADY ROSETTA	2.5	AF1808-18	3.3
PIKE	**1.0**	MSG124-8P	1.7	MATILDA	2.5	**ATLANTIC**	**3.3**
R NORLAND	1.0	MSH139-4	1.7	MSE040-6RY	2.5	MSC148-A	3.3
R BURBANK	**1.0**	LILY	1.8	MSF105-10	2.5	MSF019-11	3.3
W1151RUS	1.0	MSE028-1	1.8	MSG265-1	2.5	MSF059-1	3.3
W1348RUS	1.0	MSE149-5Y	1.8	MSH110-2	2.5	MSG274-3	3.3
		MSF020-23	1.8	ND5084-3R	2.5	MSH061-1	3.3
		MSG088-6RUS	1.8	TURBO	2.5	RED PONTIAC	3.3
		MSG261-3	1.8	MSE030-4	2.7	**SHEPODY**	**3.3**
		MSH095-4	1.8	MSF313-3	2.7	MSH101-2Y	3.5
		MSNT-1	1.8	MSH067-3	2.7	**SNOWDEN**	**3.5**
		NY112	1.8	MSH120-1	2.7	AF1763-2	3.7
		P84-9-8	1.8	W1313	2.7	MSF099-3	3.7
				YUKON GOLD	2.7	MSH127-4	3.7
				MSE228-1	2.8	INNOVATOR	3.8
				MSF165-6RY	2.8	LATONA	3.8
				MSG007-1	2.8	MSE011-14	4.0
						MSE250-2	4.0
						MSF001-2	4.0
						MSG050-2	4.0
						MSH034-1	4.0
						MSH136-2	4.0
						MSNT-2	4.0
						NY115	4.0
						OBELIX	4.8

SCAB RATING:
1 = practically no infection
2 = low infection
3 = avg. susceptibility (e.g. Atlantic)
4 = high susceptibility
5 = severe susceptibility

TABLE 7B

1996-98 MICHIGAN SCAB TRIAL

Line	1996 Rating	1997 Rating	1998 Rating	Avg.
A082611-7	1.0	1.0	1.0	1.0
A7961-1	1.0	1.0	1.0	1.0
A84118-3	1.0	1.0	---	1.0
A8495-1	---	1.0	1.0	1.0
AF1433-4	3.0	1.8	---	2.4
ATLANTIC	3.5	3.3	3.3	3.4
ATX 85404-8	3.0	1.6	---	2.3
BC0894-2	2.0	1.3	---	1.7
CENTURY RUS	3.5	3.1	---	3.3
FL1833	1.5	1.7	---	1.6
FL1867	2.0	1.3	---	1.7
GOLDRUSH	1.0	---	1.0	1.0
JS111-28	1.0	1.0	---	1.0
MATILDA	2.0	2.3	2.5	2.3
MICHIGOLD	4.0	2.8	---	3.4
MN16180	3.0	2.3	---	2.6
MN16489	2.0	1.9	---	2.0
MSA091-1	1.0	1.8	1.5	1.4
MSA097-1Y	2.0	1.7	2.0	1.9
MSB040-3	1.0	1.8	1.7	1.5
MSB073-2	1.5	1.8	1.7	1.7
MSB076-2	1.5	1.8	1.2	1.5
MSB094-1	3.0	3.0	2.0	2.7
MSB106-7	3.0	1.3	2.3	2.2
MSB107-1	2.5	1.8	1.0	1.8
MSC103-2	2.0	---	3.7	2.9
MSC120-1Y	2.5	1.5	1.0	1.7
MSC122-1	1.5	---	1.5	1.5
MSC148-A	2.5	2.4	3.3	2.7
MSE018-1	3.0	2.6	3.0	2.9
MSE033-1RD	---	1.0	1.3	1.2
MSE048-2Y	2.0	2.1	1.0	1.7
MSE080-4	---	1.8	2.3	2.1
MSE149-5Y	2.0	2.0	1.8	1.9
MSE192-8	---	1.3	1.0	1.2
MSE202-3	2.0	1.0	---	1.5
MSE221-1	1.0	1.0	1.5	1.2
MSE222-5Y	---	3.0	2.0	2.5
MSE226-4Y	1.5	1.9	2.3	1.9
MSE228-1	---	2.7	2.8	2.8
MSE228-9	1.5	1.8	3.0	2.1
MSE228-11	3.0	1.5	3.2	2.6
MSE230-6	1.5	1.5	2.3	1.8
MSE245-B	---	1.5	1.3	1.4
MSE246-5	---	1.4	1.0	1.2
MSE250-2	---	3.2	4.0	3.6
MSE263-10	---	1.3	3.0	2.2
MSF001-2	---	2.0	4.0	3.0
MSF019-11	---	2.8	3.3	3.1
MSF099-3	---	2.5	3.7	3.1
MSF165-6RY	---	3.5	2.8	3.2
MSF313-3	---	1.8	2.7	2.3
MSF373-8	---	3.0	2.3	2.7
MSG050-2	---	2.0	4.0	3.0
MSG077-7Y	---	2.5	3.5	3.0
MSG104-6	---	3.3	3.5	3.4
MSG119-1RD	---	2.0	1.2	1.6
MSG124-8P	---	1.5	1.7	1.6
MSG227-2	---	1.0	1.0	1.0
MSG261-3	---	3.0	1.8	2.4
MSNT-1	1.0	1.0	1.8	1.3
ND2225-1R	2.0	3.3	---	2.7
ND2676-10	1.5	1.5	1.5	1.5
ND860-2	3.0	3.0	---	3.0
NORCHIP	3.0	1.8	2.0	2.3
NY101	1.0	1.0	---	1.0
NY103	3.0	2.5	---	2.8
ONAWAY	1.5	1.0	1.5	1.3
PICASSO	1.5	---	1.2	1.4
PIKE	1.5	1.7	1.0	1.4
R. BURBANK	1.0	1.0	1.0	1.0
R. NORKOTAH	---	1.8	2.0	1.9
RED NORLAND	2.0	1.0	1.0	1.3
RED PONTIAC	4.0	2.6	3.3	3.3
SAGINAW GOLD	2.5	1.5	2.0	2.0
SHEPODY	4.0	3.8	3.3	3.7
SNOWDEN	3.0	2.5	3.5	3.0
W1151	1.5	1.3	1.0	1.3
W1313	2.5	3.0	2.7	2.7
YUKON GOLD	2.0	3.0	2.7	2.6

SCAB RATING:
1 = practically no infection
2 = low infection
3 = avg. susceptibility (e.g. Atlantic)
4 = high susceptibility
5 = severe susceptibility

Table 8A 1998 BLACKSPOT BRUISE SUSCEPTIBILITY TEST

A. SIMULATED BRUISE SAMPLES*

	NUMBER OF SPOT PER TUBER						PERCENT (%)		
VARIETY	0	1	2	3	4	5+	TOTAL TUBERS	BRUISE FREE	AVERAGE SPOTS/TUBER
DATE OF HARVEST: LONG									
RUSSET NORKOTAH	21	5	2	0	0	0	28	75	0.32
RUSSET BURBANK	20	8	2	0	0	0	30	67	0.40
MSE192-8RUS	11	15	2	0	0	0	28	39	0.68
GOLDRUSH	12	9	7	0	0	0	28	43	0.82
A7961-1	13	6	6	2	1	0	28	46	1.00
A8495-1	10	9	7	1	1	0	28	36	1.07
SHEPODY	6	8	13	2	0	0	29	21	1.38
MSB106-7	5	7	11	3	2	1	29	17	1.76
INNOVATOR	4	6	7	9	1	1	28	14	2.00
UMATILLA	0	2	13	11	5	1	32	0	2.69
MSG088-6RUS	2	1	4	8	5	4	24	8	3.04
DATE OF HARVEST: ROUND WHITES-LATE									
MSE228-1	27	1	0	0	0	0	28	96	0.04
MSE228-9	26	2	0	0	0	0	28	93	0.07
NY115	24	5	0	0	0	0	29	83	0.17
MSB073-2	22	6	0	0	0	0	28	79	0.21
MSE149-5Y	23	4	1	0	0	0	28	82	0.21
ONAWAY	23	3	2	0	0	0	28	82	0.25
MSF015-1	18	8	2	0	0	0	28	64	0.43
MSC148-A	19	5	2	1	0	0	27	70	0.44
SNOWDEN	19	6	2	1	0	0	28	68	0.46
ATLANTIC	16	9	2	1	0	0	28	57	0.57
MSE221-1	15	10	3	0	0	0	28	54	0.57
MSE228-11	14	11	3	0	0	0	28	50	0.61
MSF099-3	17	7	4	1	0	0	29	59	0.62
MSC103-2	15	11	1	2	0	0	29	52	0.66
MSF373-8	16	6	2	3	0	0	27	59	0.70
MSA091-1	14	9	4	1	0	0	28	50	0.71
NY112	16	6	3	3	0	0	28	57	0.75
MSB107-1	9	16	3	0	0	0	28	32	0.79
MSE230-6	12	9	5	1	0	0	27	44	0.81
MSB076-2	12	8	7	1	0	0	28	43	0.89
MSE018-1	13	9	4	0	2	0	28	46	0.89
MSE263-10	11	8	5	1	1	0	26	42	0.96
MSNT-1	9	10	6	0	0	1	26	35	1.04
MSE250-2	10	6	9	2	1	0	28	36	1.21
MSE246-5	3	9	9	3	2	1	27	11	1.81

* 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 20, 1998. Table is presented in descending order of average number of spots per tuber.

		NUMBER OF SPOT PER TUBER					TOTAL	PERCENT (%) BRUISE	AVERAGE
VARIETY	0	1	2	3	4	5+	TUBERS	FREE	SPOTS/TUBER
NORTH CENTRAL REGIONAL TRIAL									
NORLAND	26	2	0	0	0	0	28	93	0.07
FV8957-10	23	5	0	0	0	0	28	82	0.18
MN17572	23	4	1	0	0	0	28	82	0.21
ND2676-10	22	6	0	0	0	0	28	79	0.21
RUSSET NORKOTAH	23	5	1	0	0	0	29	79	0.24
MSE192-8RUS	22	4	2	0	0	0	28	79	0.29
W1151RUS	21	5	2	0	0	0	28	75	0.32
MN17922	22	4	3	0	0	0	29	76	0.34
MSE230-6	20	7	2	0	0	0	29	69	0.38
RUSSET BURBANK	19	6	2	1	0	0	28	68	0.46
MSB073-2	16	6	4	0	0	0	26	62	0.54
RED PONTIAC	16	9	2	1	0	0	28	57	0.57
ND5084-3R	17	4	4	1	1	0	27	63	0.70
ND2470-27	10	17	2	0	0	0	29	34	0.72
NORCHIP	15	15	1	0	1	1	33	45	0.79
SNOWDEN	8	14	4	1	0	0	27	30	0.93
MSA091-1	10	10	5	2	0	0	27	37	0.96
ND4093-4RUS	10	9	7	1	0	0	27	37	0.96
W75-30	12	9	4	2	1	0	28	43	0.96
MN16478	9	9	7	2	0	0	27	33	1.07
ATLANTIC	13	7	1	3	1	2	27	48	1.19
MN16966	7	11	5	4	0	2	29	24	1.48
W1348RUS	7	9	6	2	1	3	28	25	1.64
W1355-1	1	7	9	6	2	1	26	4	2.15
W1313	1	2	11	7	6	1	28	4	2.64
YELLOW FLESH & EUROPEAN TRIAL									
DALI	27	1	0	0	0	0	28	96	0.04
TURBO	27	1	0	0	0	0	28	96	0.04
MSF165-6RY	25	3	1	0	0	0	29	86	0.17
MS401-1	23	6	0	0	0	0	29	79	0.21
FAMBO	19	4	0	1	0	0	24	79	0.29
ACCENT	20	4	2	0	1	0	27	74	0.44
YUKON GOLD	16	9	0	1	0	0	26	62	0.46
OBELIX	14	8	2	0	0	0	24	58	0.50
SAGINAW GOLD	14	7	3	1	0	0	25	56	0.64
LATONA	17	7	3	1	1	0	29	59	0.69
MSE226-4Y	12	10	6	1	0	0	29	41	0.86
MATILDA	13	7	1	3	0	1	25	52	0.92
MSA097-1Y	10	12	3	3	0	0	28	36	0.96
LILY	11	8	4	4	0	0	27	41	1.04
PICASSO	9	6	4	2	1	0	22	41	1.09
MSE048-2Y	8	8	8	1	1	2	28	29	1.46
MSC120-1Y	7	6	9	4	4	0	30	23	1.73
MIRAKEL	5	5		10	2	0	22	23	1.95

VARIETY	0	1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
	NUMBER OF SPOT PER TUBER								
MSF349-1YROSE	5	6	6	2	5	1	25	20	1.96
CAESAR	3	5	10	2	4	1	25	12	2.08
LADY ROSETTA	4	7	7	3	5	2	28	14	2.14
MSE222-5Y	1	1	3	8	10	5	28	4	3.43
MSU BREEDING LINES 2 X 23 TRIAL									
MSH098-2	19	1	0	0	0	0	20	95	0.05
MSG147-3P	18	2	0	0	0	0	20	90	0.10
MSH120-1	19	1	1	0	0	0	21	90	0.14
MSF369-1RY	16	4	0	0	0	0	20	80	0.20
MSH018-3	15	5	0	0	0	0	20	75	0.25
MSG004-3	14	6	0	0	0	0	20	70	0.30
ONAWAY	12	6	0	0	0	0	18	67	0.33
MSE028-1	13	5	1	0	0	0	19	68	0.37
MSE040-6RY	12	7	0	0	0	0	19	63	0.37
MSG145-1	14	5	0	1	0	0	20	70	0.40
MSH031-5	12	8	0	0	0	0	20	60	0.40
MSH130-2	12	8	0	0	0	0	20	60	0.40
MSG034-2	14	3	1	1	0	0	19	74	0.42
MSH101-2Y	13	4	2	0	0	0	19	68	0.42
MSE026-A	13	6	0	1	0	0	20	65	0.45
MSG130-1	13	5	2	0	0	0	20	65	0.45
MSE084-5	14	3	2	1	0	0	20	70	0.50
MSG141-3	10	8	1	0	0	0	19	53	0.53
MSH067-3	13	3	3	1	0	0	20	65	0.60
MSF090-9	10	7	3	0	0	0	20	50	0.65
MSG301-9	10	7	2	1	0	0	20	50	0.70
MSH321-1	10	6	4	0	0	0	20	50	0.70
MSH361-1	11	6	1	2	0	0	20	55	0.70
MSH136-2	10	6	3	1	0	0	20	50	0.75
MSH308-2	10	6	3	0	1	0	20	50	0.80
MSH061-1	6	10	5	0	0	0	21	29	0.95
MSF001-2	8	6	4	2	0	0	20	40	1.00
MSG017-4	6	9	4	1	0	0	20	30	1.00
MSH142-2	4	12	4	0	0	0	20	20	1.00
MSE074-1	6	5	6	2	0	0	19	32	1.21
MSF420-1	4	11	3	3	0	0	21	19	1.24
MSG257-7	7	8	0	3	2	0	20	35	1.25
MSE74-A	5	6	7	1	1	0	20	25	1.35
MSH311-4	3	8	8	1	0	0	20	15	1.35
MSH351-6	7	5	4	2	2	0	20	35	1.35
MSG261-3	5	8	5	4	0	0	22	23	1.36
AF1552-5	4	8	4	4	0	0	20	20	1.40
AF1808-18	2	9	1	4	0	0	16	13	1.44
MSH369-2	3	6	9	2	0	0	20	15	1.50
MSH106-2	0	9	9	2	0	0	20	0	1.65
MSH086-3	3	7	4	3	2	0	19	16	1.68

	NUMBER OF SPOT PER TUBER							PERCENT (%)	
							TOTAL	BRUISE	AVERAGE
VARIETY	0	1	2	3	4	5+	TUBERS	FREE	SPOTS/TUBER
MSG050-2	1	9	6	2	2	0	20	5	1.75
MSG139-1	5	3	6	4	0	2	20	25	1.85
MS392-1	2	7	6	4	2	0	21	10	1.86
SNOWDEN	2	5	4	5	2	0	18	11	2.00
MSG297-4	1	5	5	6	2	0	19	5	2.16
MSH095-4	3	4	6	1	2	4	20	15	2.35
MSH419-1	2	2	8	3	2	3	20	10	2.50
MSG015-C	0	3	6	7	4	0	20	0	2.60
ATLANTIC	2	2	2	6	3	3	18	11	2.83
MSF060-6	1	2	3	4	5	4	19	5	3.16
ADAPTATION TRIAL									
NY121	27	1	0	0	0	0	28	96	0.04
SUPERIOR	26	2	0	0	0	0	28	93	0.07
MSE033-1RD	24	3	0	0	0	0	27	89	0.11
MSG119-1RD	22	4	0	0	0	0	26	85	0.15
AF1763-2	20	6	0	0	0	0	26	77	0.23
MSB040-3	16	11	1	0	0	0	28	57	0.46
MSE030-4	16	7	3	0	0	0	26	62	0.50
NY119	17	8	4	0	0	0	29	59	0.55
MSF014-9	15	7	4	0	0	0	26	58	0.58
MSG227-2	18	3	6	1	0	0	28	64	0.64
MSB094-1	14	9	1	3	0	0	27	52	0.74
MSF313-3	18	5	5	0	2	0	30	60	0.77
P83-11-5	13	8	4	2	0	0	27	48	0.81
AF1475-20	10	13	2	1	1	0	27	37	0.89
MSG007-2	10	11	5	1	0	0	27	37	0.89
ERNTESTOLZ	10	7	6	1	0	0	24	42	0.92
MSE245-B	10	10	8	0	0	0	28	36	0.93
MSF020-23	10	13	5	1	2	0	31	32	1.10
P84-9-8	8	12	7	0	0	1	28	29	1.11
MSF059-1	13	7	3	0	2	2	27	48	1.15
ONAWAY	11	8	5	5	2	0	31	35	1.32
MSE011-14	9	8	6	5	1	0	29	31	1.34
MSE080-4	11	3	6	2	3	1	26	42	1.46
SNOWDEN	7	8	5	5	2	0	27	26	1.52
ATLANTIC	8	8	4	3	4	1	28	29	1.64
MSG104-6	9	3	5	5	3	2	27	33	1.85
MSF019-11	3	7	6	6	4	0	26	12	2.04
AF1753-16	4	4	5	4	4	2	23	17	2.26
MSF105-10	4	6	8	3	5	3	29	14	2.28
MSG274-3	2	4	7	9	4	1	27	7	2.44
SNACK FOOD ASSOCIATION (SFA) TRIAL									
ND2676-10	24	1	1	0	0	0	26	92	0.12
AF1433-4	18	6	1	0	0	0	25	72	0.32

							PERCENT (%)		
	NUMBER OF SPOT PER TUBER						TOTAL	BRUISE	AVERAGE
VARIETY	0	1	2	3	4	5+	TUBERS	FREE	SPOTS/TUBER
NY115	14	9	1	1	0	0	25	56	0.56
ATX85404-8	11	7	3	1	0	0	22	50	0.73
CHIPETA	12	8	3	0	1	1	25	48	0.92
MSNT-1	5	9	6	3	0	0	23	22	1.30
B0564-8	8	8	2	3	2	1	24	33	1.42
SNOWDEN	10	2	7	4	0	2	25	40	1.52
B0564-9	6	5	5	4	4	0	24	25	1.79
AF1668-60	6	7	2	8	3	2	28	21	2.04
MSE018-1	1	8	4	5	4	4	26	4	2.58
NY112	0	0	0	2	2	21	25	0	4.76

Table 8B **1998 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									
RUSSET BURBANK	27	1	0	0	0	0	28	96	0.04
RUSSET NORKOTAH	26	2	0	0	0	0	28	93	0.07
MSE192-8RUS	25	2	0	0	0	0	27	93	0.07
A8495-1	26	3	0	0	0	0	29	90	0.10
A7961-1	25	3	0	0	0	0	28	89	0.11
SHEPODY	22	3	0	0	0	0	25	88	0.12
MSB106-7	26	0	2	0	0	0	28	93	0.14
UMATILLA	25	2	1	0	0	0	28	89	0.14
INNOVATOR	23	5	0	0	0	0	28	82	0.18
MSG088-6RUS	20	6	0	0	0	0	26	77	0.23
DATE OF HARVEST: ROUND WHITES-LATE									
MSB073-2	28	0	0	0	0	0	28	100	0.00
MSB076-2	26	0	0	0	0	0	26	100	0.00
MSC103-2	25	0	0	0	0	0	25	100	0.00
MSE018-1	26	0	0	0	0	0	26	100	0.00
MSE149-5Y	28	0	0	0	0	0	28	100	0.00
MSE221-1	28	0	0	0	0	0	28	100	0.00
MSE228-11	28	0	0	0	0	0	28	100	0.00
MSE250-2	27	0	0	0	0	0	27	100	0.00
MSF015-1	29	0	0	0	0	0	29	100	0.00
MSF099-3	28	0	0	0	0	0	28	100	0.00
NY115	28	0	0	0	0	0	28	100	0.00
ONAWAY	28	0	0	0	0	0	28	100	0.00
SNOWDEN	28	0	0	0	0	0	28	100	0.00
ATLANTIC	27	1	0	0	0	0	28	96	0.04
MSE263-10	27	1	0	0	0	0	28	96	0.04
MSA091-1	25	1	0	0	0	0	26	96	0.04
MSE228-1	25	1	0	0	0	0	26	96	0.04
MSC148-A	26	2	0	0	0	0	28	93	0.07
MSE228-9	26	2	0	0	0	0	28	93	0.07
MSE230-6	26	2	0	0	0	0	28	93	0.07
MSE46-5	26	2	0	0	0	0	28	93	0.07
MSNT-1	26	2	0	0	0	0	28	93	0.07
MSB107-1	25	3	0	0	0	0	28	89	0.11
NY112	26	1	0	1	0	0	28	93	0.14
MSF373-8	24	3	1	0	0	0	28	86	0.18

** Tuber samples were collected at harvest, graded, and held until evaluation.
Samples were abrasive-peeled and scored on October 20, 1998.

VARIETY	0	NUMBER OF SPOT PER TUBER 1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
NORTH CENTRAL REGIONAL TRIAL									
FV8957-10	28	0	0	0	0	0	28	100	0.00
MSE192-8RUS	28	0	0	0	0	0	28	100	0.00
MSE230-6	27	0	0	0	0	0	27	100	0.00
ND4093-4RUS	28	0	0	0	0	0	28	100	0.00
NORLAND	28	0	0	0	0	0	28	100	0.00
W1348RUS	28	0	0	0	0	0	28	100	0.00
NORCHIP	35	1	0	0	0	0	36	97	0.03
MN17572	27	1	0	0	0	0	28	96	0.04
MSB073-2	27	1	0	0	0	0	28	96	0.04
ND2676-10	27	1	0	0	0	0	28	96	0.04
RUSSET BURBANK	27	1	0	0	0	0	28	96	0.04
RUSSET NORKOTAH	27	1	0	0	0	0	28	96	0.04
W1575-30	27	1	0	0	0	0	28	96	0.04
W1151RUS	24	1	0	0	0	0	25	96	0.04
ND2470-27	31	2	0	0	0	0	33	94	0.06
MN17922	27	2	0	0	0	0	29	93	0.07
ATLANTIC	26	2	0	0	0	0	28	93	0.07
MSA091-1	23	2	0	0	0	0	25	92	0.08
RED PONTIAC	25	3	0	0	0	0	28	89	0.11
W1313	23	5	0	0	0	0	28	82	0.18
W1355-1	24	3	1	0	0	0	28	86	0.18
MN16478	22	5	0	0	0	0	27	81	0.19
SNOWDEN	25	4	1	0	0	0	30	83	0.20
ND5084-3R	24	2	2	0	0	0	28	86	0.21
MN16966	21	4	1	0	0	0	26	81	0.23
YELLOW FLESH & EUROPEAN TRIAL									
DALI	27	0	0	0	0	0	27	100	0.00
LATONA	28	0	0	0	0	0	28	100	0.00
MS401-1	30	0	0	0	0	0	30	100	0.00
MSE226-4Y	28	0	0	0	0	0	28	100	0.00
TURBO	28	0	0	0	0	0	28	100	0.00
FAMBO	27	1	0	0	0	0	28	96	0.04
LILY	27	1	0	0	0	0	28	96	0.04
OBELIX	27	1	0	0	0	0	28	96	0.04
CAESAR	26	1	0	0	0	0	27	96	0.04
OBELIX	26	1	0	0	0	0	27	96	0.04
YUKON GOLD	26	1	0	0	0	0	27	96	0.04
MSE048-2Y	19	1	0	0	0	0	20	95	0.05
MSA097-1Y	27	2	0	0	0	0	29	93	0.07
MSF349-1YROSE	27	2	0	0	0	0	29	93	0.07
MSF165-6RY	26	2	0	0	0	0	28	93	0.07
MSC120-1Y	23	2	0	0	0	0	25	92	0.08
ACCENT	22	2	0	0	0	0	24	92	0.08

	NUMBER OF SPOT PER TUBER						PERCENT (%)	
VARIETY	0	1	2	3	4	5+	TOTAL TUBERS	BRUISE FREE	AVERAGE SPOTS/TUBER
SAGINAW GOLD	25	4	0	0	0	0	29	86	0.14
MATILDA	24	4	0	0	0	0	28	86	0.14
LADY ROSETTA	22	4	0	0	0	0	26	85	0.15
MIRAKEL	25	2	1	1	0	0	29	86	0.24
PICASSO	22	2	0	2	0	0	26	85	0.31
MSE222-5Y	4	4	6	9	3	2	28	14	2.32
MSU BREEDING LINES 2 X 23 TRIAL									
MSE026-A	20	0	0	0	0	0	20	100	0.00
MSE028-1	20	0	0	0	0	0	20	100	0.00
MSE040-6RY	20	0	0	0	0	0	20	100	0.00
MSE274-A	20	0	0	0	0	0	20	100	0.00
MSF001-2	20	0	0	0	0	0	20	100	0.00
MSF090-9	16	0	0	0	0	0	16	100	0.00
MSG004-3	20	0	0	0	0	0	20	100	0.00
MSG141-3	20	0	0	0	0	0	20	100	0.00
MSG145-1	20	0	0	0	0	0	20	100	0.00
MSG147-3P	20	0	0	0	0	0	20	100	0.00
MSG257-7	13	0	0	0	0	0	13	100	0.00
MSG301-9	20	0	0	0	0	0	20	100	0.00
MSH018-3	20	0	0	0	0	0	20	100	0.00
MSH031-5	20	0	0	0	0	0	20	100	0.00
MSH101-2Y	20	0	0	0	0	0	20	100	0.00
MSH130-2	20	0	0	0	0	0	20	100	0.00
MSH142-2	20	0	0	0	0	0	20	100	0.00
MSH308-2	20	0	0	0	0	0	20	100	0.00
MSH311-4	20	0	0	0	0	0	20	100	0.00
ONAWAY	20	0	0	0	0	0	20	100	0.00
MSG034-2	23	1	0	0	0	0	24	96	0.04
MSH369-2	22	1	0	0	0	0	23	96	0.04
MSH361-1	21	1	0	0	0	0	22	95	0.05
MSG130-1	20	1	0	0	0	0	21	95	0.05
MSH067-3	20	1	0	0	0	0	21	95	0.05
MSH120-1	20	1	0	0	0	0	21	95	0.05
AF1552-5	19	1	0	0	0	0	20	95	0.05
MSE084-5	19	1	0	0	0	0	20	95	0.05
MSG015-C	19	1	0	0	0	0	20	95	0.05
MSH136-2	19	1	0	0	0	0	20	95	0.05
MSH321-1	19	1	0	0	0	0	20	95	0.05
MSH392-1	19	1	0	0	0	0	20	95	0.05
SNOWDEN	19	1	0	0	0	0	20	95	0.05
MSF060-6	18	1	0	0	0	0	19	95	0.05
MSH086-3	18	1	0	0	0	0	19	95	0.05
AF1808-18	25	2	0	0	0	0	27	93	0.07
MSH098-2	20	2	0	0	0	0	22	91	0.09
ATLANTIC	19	0	1	0	0	0	20	95	0.10

VARIETY	NUMBER OF SPOT PER TUBER 0	1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
MSE074-1	19	0	1	0	0	0	20	95	0.10
MSG261-3	18	2	0	0	0	0	20	90	0.10
MSG279-4	18	2	0	0	0	0	20	90	0.10
MSH351-6	18	2	0	0	0	0	20	90	0.10
MSH419-1	20	3	0	0	0	0	23	87	0.13
MSH061-1	18	3	0	0	0	0	21	86	0.14
MSF420-1	19	0	0	1	0	0	20	95	0.15
MSG050-2	17	3	0	0	0	0	20	85	0.15
MSG139-1	17	3	0	0	0	0	20	85	0.15
MSH106-2	17	3	0	0	0	0	20	85	0.15
MSF369-1RY	16	0	0	1	0	0	17	94	0.18
MSG017-4	16	4	0	0	0	0	20	80	0.20
MSH095-4	15	5	0	0	0	0	20	75	0.25
ADAPTATION TRIAL									
AF1475-20	28	0	0	0	0	0	28	100	0.00
AF1763-2	28	0	0	0	0	0	28	100	0.00
MSB094-1	28	0	0	0	0	0	28	100	0.00
MSE030-4	28	0	0	0	0	0	28	100	0.00
MSE033-1RD	28	0	0	0	0	0	28	100	0.00
MSG007-2	28	0	0	0	0	0	28	100	0.00
MSG119-1RD	28	0	0	0	0	0	28	100	0.00
ONAWAY	28	0	0	0	0	0	28	100	0.00
SUPERIOR	28	0	0	0	0	0	28	100	0.00
MSF059-1	29	1	0	0	0	0	30	97	0.03
P83-11-5	28	1	0	0	0	0	29	97	0.03
ERNTESTOLZ	27	1	0	0	0	0	28	96	0.04
MSE080-4	27	1	0	0	0	0	28	96	0.04
MSF313-3	27	1	0	0	0	0	28	96	0.04
MSG104-6	27	1	0	0	0	0	28	96	0.04
NY119	26	1	0	0	0	0	27	96	0.04
MSB040-3	25	1	0	0	0	0	26	96	0.04
MSG227-2	25	1	0	0	0	0	26	96	0.04
NY121	25	1	0	0	0	0	26	96	0.04
MSG274-3	27	2	0	0	0	0	29	93	0.07
AF1753-16	26	2	0	0	0	0	28	93	0.07
MSE245-B	27	0	1	0	0	0	28	96	0.07
MSF014-9	26	2	0	0	0	0	28	93	0.07
MSF019-11	26	2	0	0	0	0	28	93	0.07
MSG049-4	25	2	0	0	0	0	27	93	0.07
SNOWDEN	25	3	0	0	0	0	28	89	0.11
MSE011-14	23	3	0	0	0	0	26	88	0.12
MSF105-10	23	3	1	0	0	0	27	85	0.19
ATLANTIC	24	1	1	1	0	0	27	89	0.22
P84-9-8	20	7	1	0	0	0	28	71	0.32

VARIETY	NUMBER OF SPOT PER TUBER 0	1	2	3	4	5+	TOTAL TUBERS	PERCENT (%) BRUISE FREE	AVERAGE SPOTS/TUBER
SNACK FOOD ASSOCIATION (SFA) TRIAL									
ND2676-10	23	0	0	0	0	0	23	100	0.00
NY115	24	1	0	0	0	0	25	96	0.04
SNOWDEN	23	2	0	0	0	0	25	92	0.08
CHIPETA	20	4	1	0	0	0	25	80	0.24
AF1668-60	20	4	1	1	0	0	26	77	0.35
MSNT-1	20	4	1	1	0	0	26	77	0.35
AF1433-4	16	8	1	0	0	0	25	64	0.40
B0564-9	18	3	2	0	1	0	24	75	0.46
ATX85404-8	16	8	2	0	0	0	26	62	0.46
B0564-8	16	5	3	1	0	0	25	64	0.56
MSE018-1	10	4	11	1	0	0	26	38	1.12
NY112	2	1	4	2	12	2	23	9	3.17
ROBINSON									
SAXON	28	0	0	0	0	0	28	100	0.00
YUKON GOLD	24	0	0	0	0	0	24	100	0.00
SUPERIOR	27	1	0	0	0	0	28	96	0.04
MARIS BARD	25	2	0	0	0	0	27	93	0.07
ROCKET	22	3	0	0	0	0	25	88	0.12
SNOWDEN	22	3	1	0	0	0	26	85	0.19
NAVAN	23	2	2	0	0	0	27	85	0.22
ATLANTIC	23	5	1	0	0	0	29	79	0.24

TABLE 9

LATE BLIGHT VARIETY TRIAL

INOCULATED JULY 22, 1998
Rating based upon 28-day evaluation

1998 Field RAUDPC[1] (Max = 100)

Line	RAUDPC	Line	RAUDPC
LBR8	0.6	PICASSO	25.6
LBR9	1.1	P88-5-12	25.8
G274-3[2]	3.8	LILY	26.1
B0692-4	4.9	F105-10	26.5
Q237-25[2]	5.1	A091-1	26.6
AWN86514-2	5.2	LBRY	27.0
B0718-3	8.2	**PIKE**	**27.1**
LBR0	8.4	B1004-8	27.2
BZURA	10.1	H120-1	27.2
ROBIJN	12.1	LBR3 TBR	27.3
B0288-17	14.1	H018-3	27.6
ZAREVO	16.2	G124-8P	27.7
ELBA	17.1	G050-2	28.0
STOBRAWA	17.4	TURBO	28.5
LBR5	18.2	MATILDA	28.7
ND02438-7R	19.1	G104-6	28.7
A084275-3	19.3	MIRAKEL	28.8
DORITA	19.4	C103-2	29.1
LBR1R2R3R4	19.9	W1355-1	29.9
ARS4219-1	20.3	ND5084-3R[3]	29.9
BERTITA	20.5	**R BURBANK**	**32.8**
GRETA	20.7	**ATLANTIC**	**34.6**
A080432-1	21.3	**SNOWDEN**	**35.0**
A84118-3	21.4	**YUKON GOLD**	**35.8**
LBR7	21.7	**ONAWAY**	**36.6**
B0811-13	22.2	**R NORKOTAH**	**38.4**
LBR2	24.3	**SUPERIOR**	**39.4**
A082611-7	24.4	**SHEPODY**	**39.5**
NORDONNA	25.1	**SAG GOLD**	**42.5**
B9922-11	25.4	E011-14	50.3

[1] Ratings indicate the RAUDPC (Relative Area Under the Disease Progress Curve) over the entire plot.

[2] G274-3 and Q237-25 displayed foliar infection atypical of late blight, so the actual percentage due specifically to late blight lesions is less than reported.

[3] All other susceptible clones not listed except check varieties and the clone with the highest rating.

Table 10

1998 FUSARIUM DRY ROT EVALUATION

LINE	Average Depth (mm)	LINE	Average Depth (mm)	LINE	Average Depth (mm)
SNOWDEN	**4.4**	P84-9-8	11.2	W1151RUS	16.0
P83-11-5	4.5	F060-6	11.2	W1S75-30	16.1
R. NORKOTAH (LONG)	**4.5**	E192-8RUS	11.3	C103-2	16.2
A091-1	4.8	H308-2	11.3	**ATLANTIC (DOHRW)**	**16.2**
GOLDRUSH	**5.1**	H031-5	11.4	NY115	16.3
NORLAND	**6.0**	**NORCHIP**	**11.6**	G145-1	16.5
INNOVATOR	6.2	**ONAWAY (DOHRW)**	**11.7**	F090-9	16.7
G034-2	6.3	H419-1	11.7	E246-5	16.7
G049-4	6.3	B094-1	11.8	G227-2	16.8
SAXON	6.7	F099-3	11.9	A097-1Y	17.0
E263-10	6.7	NT-1	12.0	AF1753-16	17.1
F165-6RY	6.7	NAVAN	12.0	E226-4Y	17.3
RED PONTIAC	**6.7**	**R. NORKOTAH (NC)**	**12.0**	E149-5Y	17.4
SNOWDEN (NC)	**6.9**	F019-11	12.2	FAMBO	17.4
E080-4	6.9	MARIS BARD	12.2	F015-1	17.5
SNOWDEN (2X23)	**7.3**	**RUSSET BURBANK (NC)**	**12.2**	E028-1	17.7
YUKON GOLD	**8.4**	MATILDA	12.3	H369-2	17.7
G088-6 RUS	8.4	**SNOWDEN (AD)**	**12.3**	F313-3	17.8
H067-3	8.5	MN17572	12.7	**ATLANTIC (ROBINSON)**	**18.0**
SNOWDEN (DOHRW)	**8.6**	F373-8	12.8	**SAGINAW GOLD**	**18.5**
E030-4	8.6	PICASSO	12.8	H142-2	18.5
SUPERIOR (ROBINSON)	**8.6**	E084-5	12.9	B107-1	18.8
F420-1	8.7	**ONAWAY (2X23)**	**13.2**	G007-2	18.8
E192-8RUS	8.8	H061-1	13.2	**ATLANTIC (2X23)**	**18.9**
ACCENT	8.8	H130-2	13.2	AF1808-18	19.0
SHEPODY	**8.9**	LATONA	13.3	E033-1RD	19.2
ND 2470-27	9.0	H361-1	13.5	H392-1	19.3
ONAWAY (AD)	**9.0**	ND2676-10	13.5	G147-3P	19.3
H136-2	9.1	AF1763-2	13.7	E228-1	19.3
MIRAKEL	9.1	NY119	13.7	G297-4	19.4
ROCKET	9.2	H106-2	13.8	H086-3	19.5
H311-4	9.2	B106-7	13.9	H120-1	19.6
F349-1Y ROSE	9.2	LADY ROSETTA	14.0	G261-3	19.7
B073-2	9.3	H101-2Y	14.0	ND5084-3R	19.8
G077-7Y	9.4	G104-6	14.6	G257-7	20.3
MN16966	9.6	F059-1	14.8	DALI	20.4
RUSSET BURBANK (LONG)	**9.7**	E074-1	14.8	F369-1RY	20.4
FV8957-10	9.7	UMATILLA R	14.8	G130-1	20.5
A091-1	9.7	LILY	14.8	E221-1	20.8
E222-5	9.9	E018-1	15.0	E228-9	21.1
G301-9	9.9	H098-2	15.0	ERNTESTOLZ	21.2
E274-4	10.1	A7961-1	15.0	E048-2Y	21.2
H351-6	10.2	C120-1Y	15.1	B040-3	21.9
F014-9	10.2	G139-1	15.3	E245-B	21.9
G050-2	10.3	H321-1	15.4	TURBO	22.1
F015-10	10.3	H095-4	15.6	**ATLANTIC (AD)**	**22.7**
F020-23	10.3	E230-6	15.6	CAESAR	23.4
A8495-1	10.4	ND4093-4RUS	15.7	E250-2	23.6
MS401-1	10.7	G015-C	15.8	G017-4	23.8
F001-2	10.7	AF1552-5	15.9	G119-1 RD	24.5
SUPERIOR (AD)	**10.7**	G274-3	15.9	B076-2	26.1
E040-6RY	10.9	MN17922	15.9	**ATLANTIC (NC)**	**26.8**
B073-2	10.9	G004-3	16.0	G141-3	29.0
NY121	11.0	C148-A	16.0	E011-14	29.6

$LSD_{0.05}$ 8.1

Funding: Federal Grant and SFA

1998 On-Farm Potato Variety Trials

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

Introduction

On-farm potato variety trials were conducted on thirteen farms in 1998; four evaluating fresh market entries, six evaluating processing entries, one in the Upper Peninsula, the SFA Chip Trial and one for yellow flesh entries. The fresh market trial cooperators were Terry Groulx (Bay), Horkey Bros. (Monroe), Tom Hansen (Montcalm) and Allen Erke (Presque Isle). The processing trial cooperators were Crooks Farms (St. Joseph), Fertile Valley Farms (Allegan), W.J. Lennard and Sons, Inc. (Monroe), Sandyland Farms (Montcalm) and L. Walther and Sons, Inc. (both Tuscola and St. Joseph). The U.P. variety plot was located at Lippens Potato Farm (Delta), 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 both the fresh market and processing trials and 17 of the total entries were from the MSU potato breeding program. For each trial, 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 and internal defects were determined at harvest and from collected samples, chip samples were processed in the MSU Processing Lab. Sugar samples were also prepared at MSU and readings were determined at Techmark, Inc. using a Dual Channel YS12700 select instrument.

Results

A. Freshpack Trial Results

The overall average of the four locations of the freshpack potato variety trials are shown in Table 1. Three of the locations were irrigated and had very good yields. The Presque Isle location was not irrigated and did suffer from the drought.

MSE228-1 (Russet Nugget x Spartan Pearl). Most of the seed planted was whole seed. Foliage is light green, average early growth, minimal internal defects, some scab-severe surface at Montcalm location, uniform sizing. Mid-season maturity.

NY101 (Steuben x Norwis). Mostly cut seed planted, average early growth, upright vines and big stalks, very good marketable yields, light yellow flesh similar to Norwis, some IBS noted in Bay County trial. Medium-late season maturity. Dr. Plaisted is considering naming and release. Consistently above average yields and good scab resistance.

MSB106-7 (LaBelle x Lemhi Russet). Some BC noted in tubers cut for seed. Above average early growth, tubers are generally oblong to long, good general appearance, growth crack and IBS noted. Mid-season maturity.

MSE221-1 (Superior x Spartan Pearl). Considerable HH noted in tubers cut for seed and some pointed tubers, average early growth, good yields with 24% over 3¼", internal defects low and tubers netted. Early maturity.

MSB107-1 (LaBelle x MS702-80). Tubers have good eye distribution, vigorous early vine growth, light tuber set, short stolons, high percent No. 1's, 20% over 3¼", some HH and IBS at Bay County location. Plants had severe wind damage in late May-early June at Bay County location. Late season maturity.

MSE228-11 (Russet Nugget x Spartan Pearl). Seed small, mostly whole seed well sprouted. Average early growth, small stems, tubers bright, minimal internal defects, some scab, uniform tuber sizing mostly 2"-3¼". Mid-season maturity.

Onaway. Check variety. Six entries produced similar or higher yields of U.S. No. 1 potatoes.

MSC103-2 (Eramosa x Nooksack). Both whole and cut seed were planted. Seed tubers had some feathering but interiors were clean. Early growth was average to uneven. Tubers generally large with 30% over 3¼". Some pitted scab noted at Monroe County trial. Late maturity.

MSE228-9 (Russet Nugget x Spartan Pearl). Seed tubers had clean interior and eyes mostly apical. Emergence and early growth were above average. Yields were below average, tubers are netted, some IBS and pitted scab noted. Early maturity.

P88-13-4 (Purdue seedling). Seed tubers were mostly B size, elongated and thin and planted whole. Emergence and early growth were uneven and below average. At harvest, yields were low with small tuber size. No internal defects and tubers have a uniform russeting. Appeared to have some drought tolerance in Presque Isle trial.

MSE192-8 Rus (A8163-8 x Russet Norkotah). A long russet with scab resistance and a very uniform russeting. Emergence and early growth were below average. Yields were lowest in this trial. Tuber size was small with no internal defects. Mid-season maturity.

B. Processing Trial Results

Table 2 contains the overall average from the Montcalm, St. Joseph, Allegan and Monroe County locations. Average yields among the four locations ranged from 213 to 431 cwt/A of U.S. No. 1's. Following are observations made during the season for each entry:

MSE149-5Y (ND860-2 x Saginaw Gold). Seed had good sprouting. Above average early growth vigor, small leaf type and early blossoming noted. High yields of U.S. No. 1's, low specific gravity and minimal pick outs and internal defects. Tubers well shaped and bright appearance.

MSE018-1 (Gemchip x W877). Eye distribution is sparse and some HH noted in planted seed. Emergence and early growth below average, however, large vigorous vines with upright growth. High yields of U.S. No. 1 potatoes with good size distribution and high specific gravity. Some HH and BC noted but mostly very good internals. Tubers smooth, very nice general appearance and round to oval with shallow eyes. Chip quality has been low due to off-color and defects.

MSE230-6Y (Superior x W870). Many seed tubers had to be desprouted and some tubers pointed ends. Emergence and early growth below average. Medium plants with lighter foliage color and early blossoming. Good yields, however, tuber size was small. Trace of BC but generally very good internally. Tubers have tendency for pointed end.

Atlantic. Check variety. Considerable HH and IBS noted. High percentage of potatoes over 3¼".

Snowden. Check variety. Yields and specific gravity somewhat lower than expected.

W1313 (W844 x S438). Some Fusarium dry rot noted in seed. Emergence was uneven and early growth was below average. Tuber size generally small and high specific gravity. Some pitted scab, IBS and hollow heart noted.

MSB076-2 (MS716-15 x Lemhi Russet). Mostly whole seed and several had to be desprouted. Emergence was uneven and early growth was average, however, later vine type is large, very upright and late maturity. Yields were slightly below average with good tuber type and specific gravity. Hollow heart was noted at four locations.

MSE250-2 (Andover x W877). Some of the seed was desprouted before cutting and planting. Emergence and early growth were average with light green foliage. Yields were slightly below average, good specific gravity and medium tuber size distribution. Some HH, BC and IBS were noted.

MSE263-10 (MS702-80 x W877). Seed nicely sprouted and a mix of whole and cut seed were planted. Emergence and early growth were average but above average at Monroe location. Yields were slightly below average with average of 1.070 specific gravity. Tuber size was large and maturity was medium. IBS and HH were noted.

W1355-1 (Snowden and S440). Seed was nicely sprouted and tubers had a heavy netting. Emergence and early growth were average but generally uneven. Foliage was dark green, medium size and very early blossom. Maturity was late, below average yields and small tuber size with high percentage of under 2 inches. No internal defects were noted, but scab was noted at St. Joseph and Monroe locations.

MSA091-1 (MS702-80 x Norchip). Seed was nicely sprouted. Emergence and early plant vigor were above average. Yields were below average when compared with previous trials. Minimal internal defects.

MSB073-2 (MS716-15 x Superior). Seed planted was a mix of whole and cut seed. Emergence and early plant growth were average. Foliage color is light green and medium vine growth. Maturity is medium-late. Tuber size was small with 15% under 2 inches. No internal defects were noted.

Seed of the entries at the L. Walther and Sons, Inc. Farm were divided and planted on one farm in Tuscola County and a second farm in St. Joseph County. At each location they were also planted at two spacings of 9 and 13 inches. The average data for the 9 inch spacing for the two locations are presented in Table 3. The average yields were exceptionally good as were the specific gravity values. There were six entries which produced average yields in excess of 500 cwt/A of No. 1's.

Table 4 summarizes the sucrose and glucose analysis and the chip quality data for all six locations. The chip quality data should be viewed as relative to the performance of Atlantic and Snowden. It should be mentioned that the chip quality data is scored on the basis of removing all defects from the acceptable chips. The 25 tubers used for chip processing are all cut from the apical end through the stem end which provides the greatest chance for defects to be visible, so defect scores are likely more severe than those received from processors. The incidence of stem end discoloration (SED), dark centers and vascular discoloration were more noticeable this year and may be related to the warmer and drier than normal season. MSE149-5Y, MSE018-1 and MSE230-6Y were greater than 20% undesirable color. External defects were greatest in Atlantic, MSE250-2 and MSA091-1 which was mainly SED. Internal defects of dark centers were greatest in MSB076-2, MSB073-2, Atlantic and MSE018-1.

C. Yellow Flesh Trial

Six MSU advanced seedlings, two New York seedlings (NY101 and NY103) and two European varieties (Sante and Penta) were compared with Yukon Gold in a trial at Tom Fedak Farm in Bay County. The cultivar characteristics are shown in Table 5 and the yield results in Table 6. In general, the marketable yields were lower than normally expected and may be due to a second year of being planted to potatoes. There were no entries which produced potatoes greater than 3¼ inches and MSE040-6RY and Penta had a high percentage of small potatoes. Internal defects were very minimal, however, IBS was noted in Penta, Sante and Yukon Gold. NY103 and MSE226-4Y had a trace of hollow heart.

D. SFA Chip Trial

Michigan is one of the seven regional locations of the SFA Potato Chip Variety Trial sponsored by the Snack Food Association. The trial was located at V&G Farms in Stanton. There were 10 advanced seedlings which were compared with Snowden and Chipeta. The 10 entries were provided by six potato breeders: MSE018-1 and MSNT-1 (MSU—Douches), ATX85404-8 (Texas A&M—Miller and Colorado—Holm), NY112 and NY115 (New York—Plaisted), AF1433-4 and AF1668-60 (Maine—Reeves), BO564-8 and BO564-9 (USDA Beltsville—Haynes) and ND2676-10 (N. Dakota—Novy). These were compared with Snowden and Chipeta.

Table 7 summarizes the yields, size distribution and internal quality. Yields were very good, however, specific gravity values for NY115, AF1433-4, BO564-8, BO564-9 and ND2676-10 were all below 1.070. When the seven U.S. regional trials are averaged, the specific gravity for these five advanced seedlings were 1.081, 1.074, 1.078, 1.079 and 1.075, respectively.

MSE018-1, ATX85404-8, NY112 and Chipeta all yielded higher than Snowden. NY112 had very good sizing and acceptable specific gravity but it had considerable hollow heart and the tubers from this trial were also very susceptible to blackspot bruise. MSE018-1 yields and specific gravity were excellent, however, chip quality and color have not been good.

Table 8 summarizes the chip quality data for samples collected at harvest and stored at MSU at 50F. Samples were fried and quality defects scored at Jays Foods on November 12, 1998.

E. U.P. Potato Variety Trial

The U.P. trial was conducted with Lippens Potato Farm in Delta County. The entries included NY101, Atlantic, MSB106-7, Pike, Russet Norkotah, A8495-1, A7961-1, Umatilla Russet, Snowden, Russet Burbank, MSE192-8Rus and ND4093-4Rus. The plots were planted on May 26 and harvested on October 2. Average yields were 172 cwt/A of U.S. No. 1's which was well below the potential yields. There was a severe drought resulting in suppressed yields and a very high percentage of tubers under 2 inches or 4 ounces in size. NY101 had the top yield of 303 cwt/A followed by Atlantic at 254 cwt/A and MSB106-7 and Pike at 200 cwt/A.

Table 1. 1998 Freshpack Potato Variety Trials

Overall Average — Four Locations
(Monroe, Bay, Montcalm, Presque Isle)

	Yield (cwt/A)		Percent Size Distribution					
Entry	No. 1	Total	No. 1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.
MSE228-1	455	523	87	11	78	9	2	1.071
NY101	451	500	89	11	74	15	0	1.071
MSB106-7	407	489	80	13	63	18	6	1.067
MSE221-1	399	439	90	8	66	24	2	1.068
MSB107-1	387	424	91	6	70	20	4	1.073
MSE228-11	379	490	71	28	70	1	1	1.080
Onaway	378	435	85	14	69	16	1	1.067
MSC103-2	343	377	87	11	57	30	2	1.069
MSE228-9	316	361	84	14	74	11	2	1.076
P88-13-4	242	401	61	32	59	2	7	1.086
MSE192-8 Rus	207	300	62	29	55	7	9	1.067

Table 2. 1998 MSU/MPIC Potato Processing Trial

Overall Average — Four Locations
(Montcalm, St. Joseph, Allegan, Monroe)

	Yield (cwt/A)		Percent Size Distribution					
Entry	No. 1	Total	No. 1	<2"	2-3¼"	>3¼"	Pick outs	S.G.
MSE149-5Y	486	516	93	6	76	17	1	1.066
MSE018-1	479	515	92	6	78	14	2	1.082
MSE230-6Y	380	490	77	18	76	1	4	1.083
Atlantic	370	419	88	6	68	20	6	1.079
Snowden	357	400	89	9	79	9	3	1.079
W1313	352	405	87	12	85	1	2	1.090
MSB076-2	331	364	89	8	81	8	3	1.080
MSE250-2	330	369	87	12	83	4	1	1.082
MSE263-10	329	361	90	8	80	10	0	1.070
W1355-1	312	406	75	25	73	2	0	1.078
MSA091-1	286	334	84	13	78	6	3	1.077
MSB073-2	268	314	84	15	83	1	1	1.082

Table 3. 1998 MSU/MPIC Potato Processing Trial

L. Walther and Sons, Inc. — Tuscola and St. Joseph Average
(13 inch spacing)

Entry	Yield (cwt/A) No. 1	Yield (cwt/A) Total	Percent Size Distribution No. 1	<1 5/8"	1 5/8-2 1/2"	2 1/2-3 3/4"	>3 3/4"	Pick outs	S.G.
MSE149-5Y	549	578	96	4	20	74	2	1	1.074
Atlantic	537	550	97	2	22	75	0	0	1.088
Snowden	503	522	96	4	24	70	2	0	1.089
MSE263-10	491	503	98	2	18	79	1	0	1.081
MSA091-1	470	500	94	4	25	67	2	2	1.088
MSE250-2	414	465	89	10	50	39	0	1	1.094
MSB076-2	414	451	92	4	26	66	0	4	1.087
MSE018-1	412	439	94	6	29	64	1	0	1.094
W1355-1	396	457	86	13	59	27	0	1	1.086
MSB073-2	392	433	91	10	48	43	0	0	1.088
W1313	365	409	89	9	33	56	0	2	1.096
MSE230-6Y	305	461	66	26	54	12	0	8	1.089

Table 4. 1998 MPIC/MSU Potato Processing Trial

Average Sugars and Chip Quality
(Six Locations)

Entry	Sugar Analysis[1/] Sucrose	Sugar Analysis[1/] Glucose	SFA[2/] Score	Percent Acc.	Percent Und. color	Percent Ext.	Percent Int.	Comments
MSE149-5Y	0.301	0.006	1.8	52	21	9	18	Dark centers, SED
MSE018-1	0.464	0.016	1.8	26	29	18	27	Vas. dis., SED
MSE230-6Y	0.417	0.004	2.3	48	26	11	14	SED, dark centers
Atlantic	0.335	0.005	2.2	25	8	40	27	SED, dark centers
Snowden	0.367	0.004	1.7	60	17	13	10	Dark centers, SED
W1313	0.376	0.005	2.0	57	15	17	11	SED, dark center
MSB076-2	0.334	0.007	1.7	34	19	15	32	Dark center, SED
MSE250-2	0.443	0.005	1.4	47	5	32	16	SED, vas. dis.
MSE263-10	0.493	0.004	1.8	40	14	25	21	SED, dark centers
W1355-1	0.215	0.004	1.5	68	14	6	12	Dark center, vas. dis.
MSA091-1	0.515	0.006	1.6	45	11	29	16	SED, vas. dis.
MSB073-2	0.610	0.009	2.0	33	13	21	32	Vas. dis., SED

[1/]Samples prepared at MSU, scored on YSI at Techmark.
[2/]SFA 1-5 score on acceptable chips only.

Table 5. 1998 Yellow Flesh Trial — Fedak Farms

Entry	Parents	Comments
MSA097-1Y	Superior and Norchip	Above average yield potential; excellent internals; good scab tolerance.
MSE048-2Y	Saginaw Gold x MS401-1	High yield potential; moderate tolerance to scab; some hollow heart in large tubers.
MSE222-5Y	Saginaw Gold x Lemhi Russet	High yield potential; excellent internals; intermediate scab tolerance.
MSE226-4Y	Saginaw Gold x MS702-80	High yield potential; excellent internals; good scab tolerance.
MSF165-5RY	Superior x Rose Gold	Red skin/yellow flesh; average yields; excellent internals; intermediate scab tolerance.
MSE040-6RY	Rose Gold x Fontenot	Red skin/yellow flesh; a new selection.
NY101	Steuben x Norwis	Late maturity; high yields; light yellow flesh; high scab resistance.
Yukon Gold	Check variety	
Sante	Holland	Tubers oval, light yellow flesh; intermediate scab PVY resistance; medium-early. 1994 Michigan yields 433/538 cwt/A, 1.081 specific gravity.
Penta	Holland	Medium-early; round-oval. Immune to PVX and PVS. 1994 Michigan yields 366/462 cwt/A, 1.075 specific gravity.
NY103	Steuben x (Neotbr x tbr.)	Medium-late maturity; excellent fresh pack type.

Table 6. 1998 Yellow Flesh Trial — Fedak Farms

	Yield (cwt/A)		Percent Size Distribution						
Entry	No. 1	Total	No. 1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.	Comments
NY103	350	396	89	10	89	0	2	1.067	1/10 HH.
MSE226-4Y	349	362	97	3	97	0	0	1.063	1/10 HH.
MSE048-2Y	307	350	88	12	88	0	0	1.075	1/10 BC.
MS401	260	307	85	14	85	0	1	1.077	0/10 clean scab.
Yukon Gold	254	266	95	3	95	0	2	1.081	1/10 IBS.
MSE222-5Y	229	281	82	18	82	0	0	1.077	0/10 clean.
MSA097-1Y	221	265	84	16	84	0	0	1.078	0/10 clean.
NY101	220	270	82	18	82	0	0	1.071	0/10 clean.
Penta	219	327	67	33	67	0	0	1.067	4/10 IBS, 3/10 BC.
Sante	189	243	78	22	78	0	0	1.066	2/10 IBS, 2/10 BC.
MSF165-5RY	172	210	82	18	82	0	0	1.076	0/10 clean.
MSE040-6RY	78	167	47	53	47	0	0	1.071	0/10 clean.
AVERAGE	237	287	81					1.072	

Planted: April 30, 1998.

Harvested: September 21, 1998 (144 days).

Average Spacing: 15.3 inches

Table 7. 1998 SFA Chip Trial — V&G Farms

	Yield (cwt/A)		Percent Size Distribution						Internal Quality				
Entry	US #1	Total	US #1	<2"	2-3¼"	>3¼"	Pick Outs	S.G.	HH	VD	IBS	BC	Total Cut
MSE018-1	501	529	95	5	79	15	0	1.090	3	2	0	0	30
ATX85404-8	421	496	85	15	83	2	0	1.076	3	0	0	0	30
NY112	397	413	96	3	85	11	1	1.080	10	1	0	0	30
Chipeta	381	420	91	9	78	13	0	1.081	6	1	0	0	30
Snowden	358	403	89	10	74	15	1	1.077	1	9	0	1	30
NY115	334	360	93	7	82	11	0	1.068	1	1	2	0	30
AF1433-4	304	344	88	10	74	14	2	1.065	0	4	0	0	30
B0564-9	292	326	90	10	84	6	0	1.066	9	0	0	0	30
B0564-8	286	349	82	18	81	1	0	1.067	0	2	0	0	30
AF1668-60	250	283	88	9	80	8	3	1.074	4	3	0	0	30
MSNT-1	211	321	66	34	66	0	0	1.079	1	3	0	0	30
ND2676-10	169	262	65	35	64	1	0	1.067	0	7	0	0	30
AVERAGE	325	376	86					1.074					

Planted: May 15, 1998. Harvested: October 5, 1998 (143 days).

Table 8. 1998 SFA Chip Quality* — V&G Farms

Entry	S.G.	Agtron color	Ext.	Int.	Total	Comments
Snowden	1.085	69.0	1.50	0	1.50	Sl. vas. and ext.
Chipeta	1.080	68.7	2.67	2.01	4.68	Good, some vas.
NY112	1.085	67.0	10.80	0	10.80	Some SED and vas.
NY115	1.060	66.9	2.42	0	2.42	Ex. color
AF1433-4	1.060	69.5	2.20	0	2.20	Ex. color
AF1668-60	1.070	68.0	0.50	0	0.50	Ex. color
B0564-8	1.060	66.0	1.60	0	1.60	V.G. color
B0564-9	1.070	67.1	7.10	0	7.10	Sev. vas. dis.
MSNT-1	1.080	68.0	0.80	0	0.80	V.G. color, sl. ext.
MSE018-1	1.085	58.7	33.40	8.30	41.70	Sev. ext.
ATX85404-8	1.075	65.1	3.30	2.00	5.30	SED, ext.
ND2676-10	1.070	67.8	2.36	0	2.36	

*Samples stored at MSU at 50F from harvest October 5 and chips processed and scored at Jays Foods, November 12, 1998.

Funding: Industry

Potato Seed Cutting and Seed Treatment Application: Agronomic Effect of Timing on Plant Emergence and Tuber Yield

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ABSTRACT
In the first year of a two-year study, seed potatoes (cv. Onaway) were cut at different times: 30, 10, 5, 2, 1 and 0 days before planting (DBP). A subset of these were treated with a fludioxinil-based seed treatment (Maxim) at the time of cutting, at the time of planting or left untreated. The tubers were planted under low and high late blight pressure conditions. The plants were assessed for emergence, canopy development and yield. Increased time between cutting and planting was proportional to increased earlier emergence, an increased rate of emergence, greater early biomass, and tended to result in greater tuber yield, irrespective of chemical treatment. The timing of application of chemical treatments did not result in significant differences in emergence, biomass or yield. High late blight pressure reduced overall yield, but did not otherwise change the pattern of development resulting from the varying timing of seed cutting.

Introduction
Potato production in North America commonly includes the use of certified seed. This seed is frequently cut before planting to increase the plants set from each pound of seed. This practice can lead to the development of pathogens such as Fusarium dry rot (*Fusarium sambucinum*) and soft rot (*Erwinia carotovora*) in cut seed pieces. In deciding how far in advance to cut seed, growers must balance the time required to allow full suberization of the cut surface of the tuber with the danger of creating and maintaining an environment that may encourage pathogen development. An additional consideration is the management effort of a cutting operation in the period preceding planting. The logistical challenges of moving seed from controlled storage to a cutting operation site, back to storage and then to planting equipment are compounded by the increased use of potato seed treatments applied pre-planting.

The most advantageous time to apply seed treatments, especially in relation to seed cutting, is not fully established. Seed treatments that suppress the development of seed-borne pathogens may counteract the negative consequences of a long delay between seed cutting and planting. The objectives of this experiment were to determine the effect on plant emergence, growth and tuber yield of a) varying delay between potato seed cutting and planting, b) varying timing of seed treatment application with respect to seed cutting, and c) varying late blight disease pressure (high and low).

Materials and Methods
Seed potatoes (cv. Onaway) were held in storage, 42°F, 95% rel. humidity. Seed potatoes were cut by hand at 30, 10, 5, 2, and 1 days before planting. On each cutting date, 100 cut pieces were immediately treated with a fludioxinil-based seed treatment (0.5 lb/cwt) (Maxim, a product of Novartis) and placed in storage, 42°F, 95% rel. humidity, until the day of planting. On each cutting date, a separate group of 100 cut pieces were held in storage until the day of planting, and treated just before planting. On each cutting date, a separate group of 100 cut pieces were held in storage until the day of planting, and were planted with no seed treatment. On the day of planting, seed

potatoes were cut, immediately treated and planted, while a separate group of seed potatoes were cut, planted, and the seed treatment applied in furrow over the cut pieces. Each treatment was hand planted with 25 seed pieces, and repeated 4 times. Treatments were examined for emergence beginning 21 days after planting (DAP), and for canopy development at 32 DAP. The relative area under the emergence curve (RAUEC) was calculated for each replicated treatment based on five (5) emergence assessments. Tuber yield and quality were taken.

Canopy volume was calculated by an ellipsoidal approximation. The volume of an ellipsoid is derived as: V=(4/3)(π)(ABC), where A, B an C are the semiaxes of the ellipsoid. In a potato plant, A=plant height (h) and B=C=radius of plant at ground level (r). The volume of the individual plant is therefore derived as: $V_{plant}=(4/3)(\pi)(hr^2)$. The average plant estimation is derived from and average of the two largest and the two smallest emerged plants. Total treatment canopy volume is the average single plant volume for each treatment multiplied by the number of emerged plants.

Treatments were replicated at the Montcalm Research Farm (MRF) under low late blight pressure and at the Muck Soils Research Station (MSRS) under high late blight pressure. Treatments were harvested after approximately 100 days. Tubers were sorted by size (B and A+oversize). Data were examined with one-way analysis of variance (ANOVA).

Results

There were significant difference between the different cutting dates. Earlier cutting promotes greater emergence early (Figure 1). Full emergence (95%) occurred in all treatments by 40 DAP. Earlier cutting promotes greater rate of emergence, a tendency to greater early plant biomass and greater total treatment biomass, irrespective of chemical treatment, while cutting closer to planting date tends to reduce early emergence and early biomass (Table 1). Although the pattern of plant development was similar under high and low disease pressure, treatments were not significantly different under high disease pressure (Table 3) Studies conducted under high late blight pressure tended to have reduced yield compared to studies conducted under low late blight pressure (Figure 2). The increased biomass in earlier cutting treatments tended to increase yields in these treatments under low disease pressure (Table 2). The lowest yields were seen in seed cut immediately before planting and those cut 10 days before planting. Under high disease pressure, yield difference were not significant among cutting timings (Table 3).

There is no significant difference between the chemical treatments with regard to early emergence (Figure 1). Tubers treated with Maxim at cutting, at planting or left untreated were equal with regard to rate of emergence, early plant biomass and total treatment biomass (Table 1). Chemical application treatments under low disease pressure (MRF) and under high disease pressure (MSRS) were not significantly different with regard to rate of emergence and yield (Tables 2 and 3).

Discussion

The primary effects observed in the study presented arose from the delay between potato seed cutting and planting. Increasing the amount of time between seed cutting and seed planting, up to the 30 days examined in this study, led to increased early emergence, an increased rate of emergence, tended to increase biomass and tended to increase yield. These results were obtained irrespective of seed chemical treatment application timing. The effects of the timing of seed treatment application were distinctly overwhelmed. The reduction of yield observed for seed cut 10 days in advance of planting may indicate a critical window in which the increased emergence and biomass is offset by incomplete suberization of the tuber. This effect is not completely understood, and will be a target of increased scrutiny in later studies.

Increased late blight pressure at the MSRS tended to reduce the overall yields obtained, when compared to the lower late blight pressure at the MRF. While the agronomic relationship between the length of delay between seed cutting and seed planting was generally consistent between the research sites, the maximal rate of emergence obtained at the MSRS was for seed cut 10 or 30 days before planting, rather than for seed cut solely 30 days before planting, as at the MRF.

The second year of this study will include longer-range seed cutting and treating, including seed cut up to 6 months before planting, and greater examination of seed cut 10 days in advance. It is expected that this data will be used in guiding management decisions related to the sequence of seed cutting and treating.

Acknowledgments
The authors would like to thank Rob Schafer and Katrina Mason for technical assistance. Mention of a product and/or brand name does not constitute an endorsement.

Table 1. Emergence and potato (cv. Onaway) plant vigor in response to varying seed cutting and Maxim seed treating times. Evaluations at 36 days after planting, Montcalm Research Farm.

cutting date (DBP)[a]	treating date (DBP)	Canopy volume (cc):[b] single plant average	Canopy volume (cc): total row average[c]	RAUEC[d]
30	-[e]	508.2 a[f]	11781.7 a	0.5420 a
10	-	222.6 a	3261.5 a	0.3113 cd
5	-	268.0 a	4738.5 a	0.2798 cd
2	-	290.2 a	4421.7 a	0.2866 cd
1	-	356.9 a	5407.9 a	0.2559 cd
0	-	196.7 a	3209.8 a	0.2836 cd
30	30	756.5 a	17943.5 a	0.5803 a
10	10	404.6 a	7204.2 a	0.3767 bc
5	5	306.0 a	6024.9 a	0.3536 cd
2	2	264.7 a	4750.3 a	0.2880 cd
1	1	326.5 a	5596.6 a	0.2973 cd
0	0	196.9 a	3168.7 a	0.2464 cd
30	0	496.0 a	11413.8 a	0.4967 ab
10	0	231.7 a	3072.4 a	0.2447 cd
5	0	275.7 a	4801.8 a	0.3131 cd
2	0	299.7 a	5885.2 a	0.3363 cd
1	0	195.3 a	3530.2 a	0.2955 cd
0	0[g]	230.4a	3021.0 a	0.2280 d

a - cutting and treating dates are given as DBP (days before planting)

b - canopy volume is calculated by ellipsoidal approximation. $V_{plant}=(4/3)(Pi)(hr^2)$, where h=plant height, r=radius of plant at ground level

c - row average canopy volume calculated as V_{row}=(single plant average)*(emerged plants)

d - RAUEC: relative area under the emergence curve

e - no chemical was applied in the control treatments

f - numbers in a given column with the same letter are not significantly (P<0.05) different.

g - Maxim was applied to the open row beneath the tubers as they were planted

Table 2. Potato (cv. Onaway) yield in response to varying seed cutting and Maxim seed treating times. Trials from the Montcalm Research Farm (low disease pressure).

cutting date (DBP)[a]	treating date (DBP)	Yield: B tubers (lb)[b]	Yield: A and oversize (lb)	Total yield (lb)
30	-[c]	2.3 a[d]	58.6 ab	60.9 ab
10	-	2.2 a	38.4 cd	40.6 cd
5	-	2.5 a	48.9 abcd	51.4 abcd
2	-	1.9 a	45.3 abcd	47.1 abcd
1	-	3.8 a	46.0 abcd	49.8 abcd
0	-	2.5 a	43.5 bcd	46.0 bcd
30	30	2.9 a	60.7 a	63.6 a
10	10	2.2 a	46.3 abcd	48.5 abcd
5	5	3.0 a	53.2 abc	56.2 abc
2	2	2.9 a	49.2 abcd	52.0 abcd
1	1	2.1 a	57.1 ab	59.3 ab
0	0	2.6 a	46.1 abcd	48.7 abcd
30	0	3.0 a	57.1 ab	60.1 ab
10	0	2.8 a	35.6 d	38.4 d
5	0	2.5 a	46.3 abcd	48.8 abcd
2	0	2.1 a	57.1 ab	59.2 ab
1	0	1.9 a	45.9 abcd	47.8 abcd
0	0[e]	1.6 a	43.2 bcd	44.8 bcd

a - cutting and treating dates are given as DBP (days before planting)
b - yields are in pounds per 25' test row, average of four (4) samples
c - no chemical was applied in the control treatments
d - numbers in a given column with the same letter are not significantly ($P<0.05$) different.
e - Maxim was applied to the open row beneath the tubers as they were planted

Table 3. Potato (cv. Onaway) yield in response to varying seed cutting and Maxim seed treating times. Trials from the Muck Soils Research Station (high disease pressure).

cutting date (DBP)[a]	treating date (DBP)	RAUEC[b]	Total yield (lb)[c]
30	-[d]	0.4009 a[e]	24.6 a
10	-	0.3262 a	26.0 a
5	-	0.2978 a	19.2 a
2	-	0.3676 a	21.8 a
1	-	0.3355 a	19.5 a
0	-	0.2943 a	20.6 a
30	30	0.3872 a	28.4 a
10	10	0.4736 a	24.3 a
5	5	0.3826 a	23.9 a
2	2	0.3490 a	23.4 a
1	1	0.2890 a	18.3 a
0	0	0.3431 a	20.5 a
30	0	0.3729 a	28.6 a
10	0	0.4157 a	24.7 a
5	0	0.3543 a	22.9 a
2	0	0.4134 a	20.7 a
1	0	0.2931 a	20.2 a
0	0[f]	0.3557 a	19.6 a

a - cutting and treating dates are given as DBP (days before planting)
d - RAUEC: relative area under the emergence curve
c - yields are in pounds per 25' test row, average of four (4) samples
d - no chemical was applied in the control treatments
e - numbers in a given column with the same letter are not significantly ($P<0.05$) different.
f - Maxim was applied to the open row beneath the tubers as they were planted

Figure 1. Emergence of potato plants (cv. Onaway) following cutting and Maxim treating at various times before planting. Trials conducted under low late blight pressure (Montcalm Research Farm). Bars equal standard error, n=4.

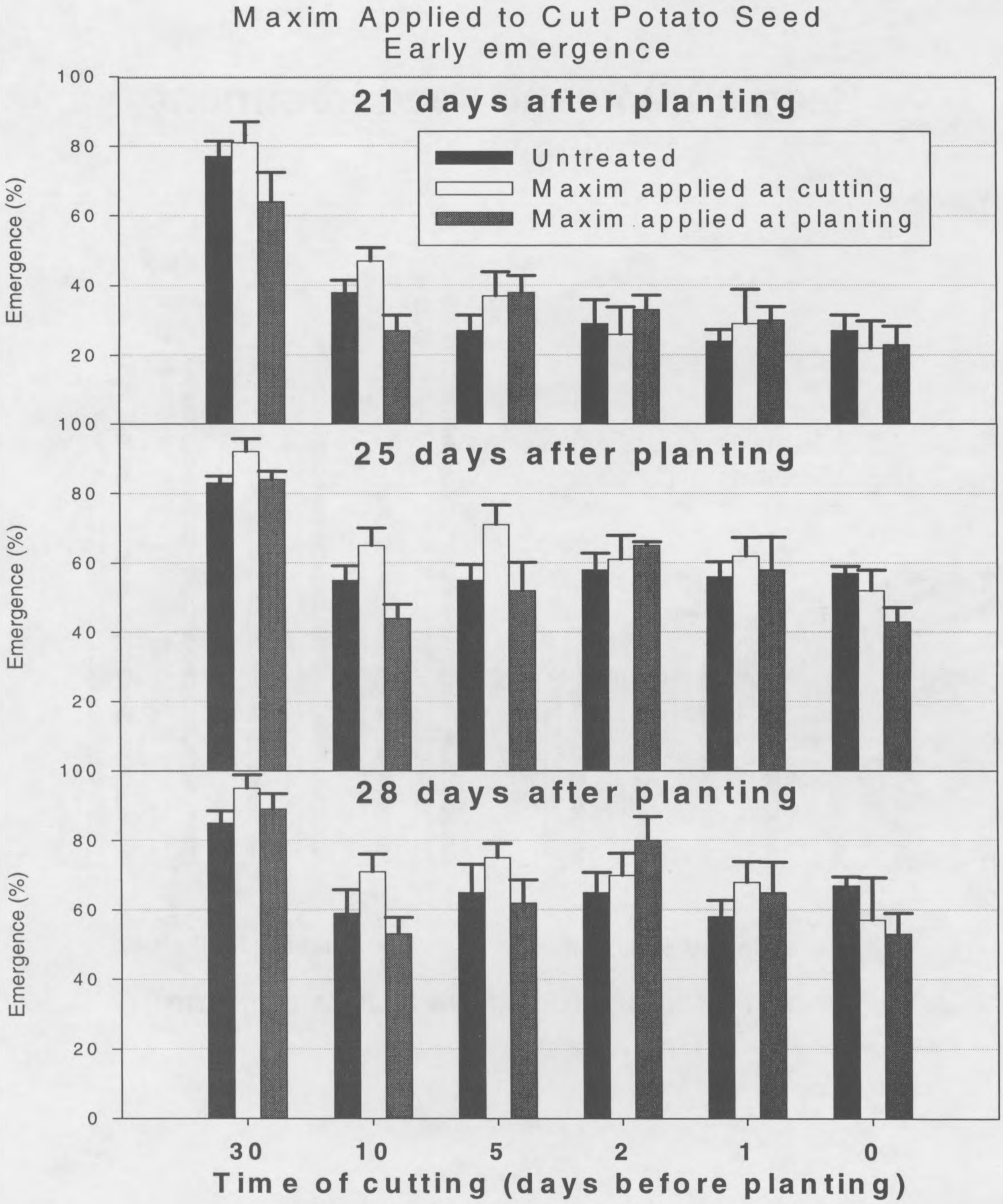
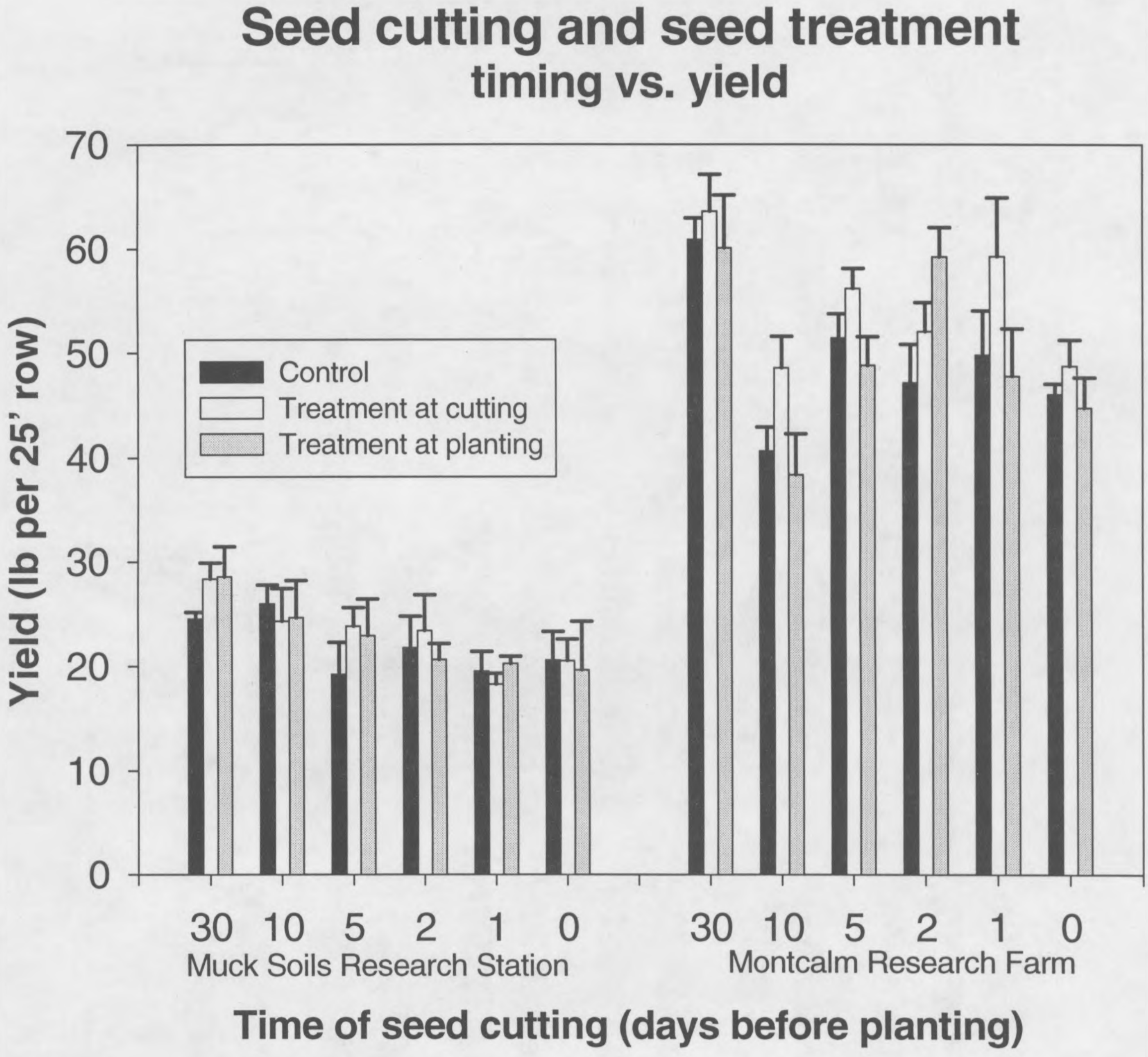


Figure 2. Yield of potato plants (cv. Onaway) following cutting and Maxim treating at various times before planting. Trials conducted under low late blight pressure (Montcalm Research Farm) and high late blight pressure (Muck Soils Research Station). Bars equal standard error, n=4.



Funding: Industry

Late Blight (*Phytophthora infestans* Mont. De Bary) Development from Infected Potato Seed Pieces Treated with Fungicides

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INTRODUCTION

Potato late blight (*Phytophthora infestans* Mont. De Bary) is the most important potato disease in North America. Control of late blight is traditionally achieved by cultural controls and crop protection strategies that rely on applications of foliar fungicides. Late blight is readily transmitted by seed-borne inoculum. Seed-borne pathogens of potatoes, such as *Fusarium* spp. and *Rhizoctonia solani* can be effectively controlled by application of fungicides to the seed piece. Prevention of establishment of late blight infection transmitted from infected to disease-free seed pieces by seed treatments has been demonstrated. Seed piece treatments may prevent early season establishment of late blight by persisting on the immature foliage after the plant has emerged and developed. Immature stems and leaves may be exposed to late blight from infected seed pieces or from foliar infection after emergence.

Trials in controlled environments and in the field were conducted to establish the efficacy of a variety of fungicides applied to the seed-piece in controlling tuber-borne and foliar phases of late blight. Three separate simulations of late blight establishment and potential prevention are described, infection carry-over within tubers stored for seed and infected during the seed cropping, transmission of late blight during seed cutting and foliar infection of the immature canopy.

METHODS

Potatoes with no visible symptoms of late blight or other diseases were selected for the trials. The field trials were located at the MSU Muck Soils Research Farm (organic muck), MI. A controlled environment study was initiated with the same treatments and simulations as in the field. Three different types of trial were done to simulate different phases of late blight infection. Seed pieces were either a) injected with a *P. infestans* sporangial suspension then treated with the seed piece fungicides 48 hours after inoculation to allow disease to develop and simulate potato seed infected at harvest b) cut and the cut face inoculated by dipping it into a mycelial homogenate of rye agar media and *P. infestans* to simulate infection spread during the cutting process and c) the potato plants were inoculated by a foliar spray of sporangial suspension of *P. infestans* to simulate a spore shower early in the development of the canopy.

The controlled environment experiments were carried out in temperature and humidity-controlled environment chambers. The chambers (120 ft^3) were situated within green houses and covered with 1mm transparent polyethylethene. Natural light was supplemented by high-pressure sodium lamps, 400w 14h-10h day-night. Relative humidity was maintained at greater than 90% by timer controlled humidifiers (Herrmidifier model 500). Temperature typically ranged between60 - 75°F. Ten replicate plants per treatment were used. Tubers (inoculated and non-inoculated) were planted into pots (5" diameter) in MSU potting compost. The pots were placed in trays and watered from beneath to prevent the compost from drying out.

The potatoes were hand-planted into closed beds in early June into two rows by 50 ft plots (34 in row spacing). Each treatment was replicated four times. Dust formulations were measured and added to tubers in a dry paper sack and shaken for two minutes to ensure even spread of the fungicide. The LS numbered treatments are combinations of thiophanate-methyl + mancozeb + cymoxanil for which Gustaffson have requested a Section 24c registration in Michigan, at present % composition is a trade secret. Seed treatments were applied when sprouts had broken dormancy. Sprouts averaged 15 leaf initials at the time of application (15.1 ± 0.45, $n = 20$), with about eight internodes between the base of the sprout and the first emerged leaf. The amount of fungicide required to treat the seed tubers was calculated from manufacturer recommended seed application rates. Untreated seed tubers and uninoculated, untreated seed tubers (tuber transmission) or untreated seed tuber and uninoculated potato vines (foliar infection) were included for comparison. Treatments were applied seven days prior to planting.

Inoculations were performed with a zoospore suspension of *P. infestans* US8 (insensitive to metalaxyl, A2 mating type) genotype (10^3 zoospores/ml) from cultures grown on rye agar plates of *P. infestans* propagated on rye agar for 14 days in the dark at 65°F. Sporangia were harvested from the petri dishes by rinsing the mycelium/sporangia mat in cold (40°F) sterile, distilled H_2O and scraping the agar surface with a rubber policeman. The mycelium/sporangia suspension was stirred with a magnetic stirrer for 1 hour. The suspension was strained through four layers of cheesecloth and sporangia concentration was adjusted to about 1×10^6 sporangia ml^{-1} and measured with a hemacytometer. Tubers were inoculated with about 0.1 ml of the zoospore suspension injected to a depth of 0.02 in below the periderm and 0.5 in from the main apical sprout. The wound was covered with a smear of petroleum jelly. After 24 hours, seed treatments were applied. The transmission of infection at seed cutting was simulated by cutting seed and immediately exposing the seed to late blight inoculum. The seed was cut into two pieces with a sterile knife. The exposed cut surface was placed face down on a 14 day old, homogenized mixture of mycelium and sporangia of *P. infestans* in rye agar for 30 sec, removed and seed treatments were immediately applied. The foliar infection 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. After the plants reached the rapid expansion phase, about 6 in tall with an average of 10 main leaves on each plant, the plants in the chambers were inoculated with 1000 ml of a 10^3 zoospore ml^{-1} suspension, delivered as an aerosol. In the field experiments all the rows were inoculated (100 ml/25 ft row) with the above described aerosol zoospore suspension on 23 July 1998.

Fertilizer was drilled into plots before planting, formulated according to results of soil tests. Additional nitrogen (final N 28 lb/A) was applied to the growing crop with irrigation 45 dap (days after planting). No fungicides were applied during the field experiment. A permanent irrigation system was established prior to the commencement of fungicide sprays and the fields were maintained at soil moisture capacity throughout the season by frequent (minimum 5 day) irrigations. Weeds were controlled by hilling and with metolachlor (Dual 8E) at 2 pt/A) 10 dap, bentazon salt (Basagran) at 2 pt/A on 20 and 40 dap, and sethoxydim (Poast) at 1.5 pt/A on 58 dap. Insects were controlled with imidacloprid (Admire 2F) at 1.25 pt/A at planting, carbaryl (Sevin 80S) at 1.25 lb/A on 31 and 55 dap, endosulfan (Thiodan 3 EC) at 2.33 pt/A on 65 and 87 dap and permethrin (Pounce 3.2EC) at 8 oz/A on 48 dap.

Plant emergence was rated in all experiments. The rate of emergence was calculated as the relative area under the plant emergence progress curve (RAUEPC). The AUEPC was calculated by adding the area under the linear progression of number of plants emerged between each successive estimation of emergence from planting to full emergence. The RAUEPC is calculated by dividing the measured AUEDPC by the maximum AUEPC (100 x duration of the emergence period, from planting to full or final plant number emerged).

Plots (field) and replicate plants (controlled environments) were rated visually for percent leaf area with symptoms of late blight. The average amount of disease that developed over the disease progress period was expressed as the relative area under the disease progress curve (RAUDPC). The AUDPC was calculated by adding the area under the linear progression of disease between each successive estimation of disease from inoculation to 100% plant death. The RAUDPC is calculated by dividing the measured AUDPC by the maximum AUDPC (100 x duration of the epidemic, from inoculation to 100% plant death). The disease progress was only followed in the group of plants that were foliar inoculated. Data were analyzed by two-way analysis of variance and means compared at $p = 0.05$ level of significance by a multiple range comparison of means (Tukey, SigmaStat).

Results

Controlled environment study (Table 1):

The rate of emergence (RAUEPC) and number of plants emerged after tubers were injected/inoculated and treated with any seed treatment was significantly lower than the untreated/uninoculated tubers but not significantly different from untreated/inoculated tubers. The rate of emergence (RAUEPC) and number of plants emerged after the cut surface of tubers were inoculated and treated with any seed treatment was not significantly different than the untreated/uninoculated tubers or untreated/inoculated tubers. Plants with lesions caused by *P. infestans* were observed after the cut face inoculation in some treatments but there were no significant differences between any treatments. Tubers that were not inoculated but were treated with a seed treatment, except LS209 DS, emerged at a rate (RAUEPC) not significantly different than the uninoculated/untreated check plants. The number of plants emerged was not significantly different between treatments. The rate of late blight after inoculation over a 21 day period was significantly higher in all treatments in comparison with the untreated/uninoculated check. The plants that developed form treated seed were infected with late blight at a rate that was not significantly different from plants that developed from untreated seed pieces.

Field study (Table 2 - 4): The rate of emergence (RAUEPC) and number of plants emerged after tubers were injected/inoculated and treated with any seed treatment was significantly lower than the untreated/uninoculated tubers but not significantly different from untreated/inoculated tubers. LS 208 DS and LS 209DS emerged significantly faster and had significantly more tubers than Alder bark and Myconate 1DS injected/inoculated treated seed (Table 2). The rate of emergence (RAUEPC) after the cut surface of tubers were inoculated and treated with Maxim + EBDC 1DS, LS130 DS, LS209 DS, LS208 DS and Tops MZ 8.5DS was not significantly different than that of the untreated/uninoculated tubers. The rate of emergence (RAUEPC) after the cut surface of tubers were inoculated and treated with GPXST-1, Maxim + EBDC 1DS, LS130 DS, LS209 DS, LS208 DS and Tops MZ 8.5DS was higher than that of untreated/inoculated tubers, Tops 5 2.5DS, Maxim 0.5D, Maxim + TBZ 1DS and Alder bark treated tubers. No plants with lesions caused by *P. infestans* were observed after the cut face inoculation. Maxim + EBDC 1DS, LS130 DS, LS209 DS, LS208 DS and Tops MZ 8.5DS and the untreated/uninoculated check had close to 100% plants emergence and had significantly more plants than that of the Maxim 0.5D and the untreated/inoculated plots. Untreated/uninoculated tubers produced a significantly higher number of plants than Tops 5 2.5DS, Maxim 0.5D, Maxim + TBZ, Myconate 1DS treated tubers and untreated/inoculated tubers. Plants developing from Tops 5 2.5DS, Maxim 0.5D, and Maxim + TBZ 1D were significantly more elongated than the untreated/uninoculated check. The rate of emergence (RAUEPC) and number of plants emerged after tubers were treated with any seed treatment but not inoculated was not significantly different from the untreated/uninoculated tubers or the untreated/inoculated tubers. No abnormal intenode elongation was observed in plants developing from treated tubers. The rate of late blight development after inoculation over a 21 day period was significantly higher in all treatments in comparison with the untreated/uninoculated check which was infected by secondary inoculation. The plants that developed form treated seed were infected with late blight at a rate that was not significantly different from plants that developed from untreated seed pieces.

Conclusions

The simulation of seed treatments applied to seed infected at harvest indicated that internal infections are difficult to control with the seed treatments tested. The low number of emerged plants and decreased raudpc indicated that sprouts were becoming infected and killed prior to emerging from the soil. The simulation of cut surface spread of late blight form tuber to tuber indicated that cut surfaces are readily infected by late blight.

Seed treatments that contained cymoxanil and/or mancozeb e.g. Maxim + EBDC 1DS, LS130 DS, LS209 DS, LS208 DS and Tops MZ 8.5DS had higher plant numbers and rates of emergence than seed treatments where they were absent e.g. Tops 5 2.5DS, Maxim 0.5D, Maxim + TBZ, Myconate 1DS treated tubers and untreated/inoculated tubers. Also, phytotoxicity (abnormal intenode elongation) was more evident in the cut surface simulation. The cut surface is readily infected by late blight but is also accessible to the active ingredients contained in the seed treatments. It is likely that the infection was partially inhibited by the mancozeb component of the seed treatments. Mancozeb is not thought to move far from the site of application i.e. the cut surface of the tuber but may move sufficiently far inside the cut tuber to prevent the establishment of late blight and prevent the infection of sprouts. The cymoxanil component of e.g. LS130 DS, which is systemic in plant tissue, may be important in prevention of late blight in cut seed where the application of the seed treatment is delayed. Enhanced intenode elongation also indicated that accelerated movement of the active ingredient across the cut surface of the seed tuber may result in phytotoxic effects. The phytotoxicity was less evident in plants developing from tubers treated with seed treatments containing mancozeb. This simulation, in the controlled environment experiment, produced plants that were infected with late blight lesions. No treatments gave significant control of this infection which indicates that the fungicides are not fully effective against late blight.

Plants developing from tubers uninfected with late blight but treated with any of the seed treatments were not less susceptible to late blight than plants developing from untreated tubers uninfected with late blight.

Table 1. Potato late blight seed piece treatment experiment - controlled environment study : emergence rate (RAUEPC) and final plant number of potato plants emerging from seed pieces that were either a) injected with a *P. infestans* sporangial suspension then treated with the seed piece fungicides 48 hours after inoculation to allow disease to develop and simulate potato seed infected at harvest b) cut and the cut face inoculated by dipping it into a mycelial homogenate of rye agar media and *P. infestans* or c) the potato plants were inoculated by a foliar spray of sporangial suspension of *P. infestans*. Plants with lesions caused by *P. infestans* were only observed after the cut face inoculation. The disease progress was only followed in the group of plants that were foliar inoculated.

Treatment and rate of application (lbs/cwt)	inoculation type							
	injection		cut face and dip			foliar		
	RAUEPC[1] max = 100 calculated over 8 day period	final number of plants emerged (%)	RAUEPC max = 100 calculated over 8 day period	final number of plants emerged (%)	% plants with lesions caused by *P. infestans*	RAUEPC max = 100 calculated over 8 day period	final number of plants emerged (%)	RAUDPC[2] max = 100 calculated from 0 - 21 dai[3]
Tops 5 2.5DS 1.0 lb..........	0 b[4]	0 b	22.5 a	40 a	20 a	45.0 ab	80 a	39.1 b
Tops MZ 8.5DS 0.5 lb.....	0 b	0 b	56.3 a	100 a	0 a	46.3 ab	100 a	35.8 b
LS208[5] DS0.5lb................	1.3 b	20 b	35.0 a	80 a	0 a	13.8 ab	60 a	37.9 b
LS209[5] DS0.5 lb..............	11.3 b	20 b	45.0 a	80 a	0 a	6.3 b	100 a	33.1 b
LS130[5] DS0.5 lb..............	0 b	0 b	35.0 a	80 a	20 a	35.0 ab	80 a	38.7 b
Maxim 0.5DS 0.5 lb.........	1.3 b	20 b	33.8 a	60 a	20 a	46.3 ab	100 a	35.6 b
Maxim/TBZ 1DS0.5 lb....	0 b	0 b	12.5 a	40 a	20 a	46.3 ab	100 a	33.3 b
Maxim/EBDC 1DS 0.5 lb.	12.5 b	40 b	33.8 a	60 a	0 a	25.0 ab	80 a	39.9 b
Myconate 1DS 0.5 lb........	0 b	0 b	35.0 a	80 a	0 a	12.5 ab	40 a	38.5 b
Alder bark 0DS 0.5 lb.......	0 b	0 b	45.0 a	80 a	0 a	15.0 ab	80 a	33.7 b
Untreated..........................	0 b	0 b	22.5 a	40 a	20 a	45.0 ab	80 a	37.4 b
Untreated/uninoculated.....	56.3 a	100 a	56.3 a	100 a	0 a	56.3 a	100 a	0 a
sem p=0.05	4.72	12.0	11.8	20.1	10.3	9.92	16.4	2.31

[1]Relative area under the emergence curve estimates the rate of emergence. Higher numbers equate to a greater rate of emergence. Calculated from day of planting to 8 days after planting.

[2] RAUEPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight.

3 days after inoculation.

[4] values followed by the same letter, or followed by no letters, are not significantly different at p = 0.05 (Tukey Multiple Comparison).

[5] Numbered formulations of thiophanate-methyl + mancozeb + cymoxanil (composition is a trade secret).

Table 2. Potato late blight seed piece treatment experiment - emergence rate (RAUEPC), final plant number and phytotoxicity symptoms on potato plants emerging from seed pieces that were injected with a *P. infestans* sporangial suspension then treated with the seed piece fungicides 48 hours after inoculation to allow disease to develop and simulate potato seed infected at harvest.

Treatment and rate of application (lbs/cwt)	emergence			
	RAUEPC[1] max = 100 calculated from 0 - 21 dap[2]		final number of plants emerged (%)	
Tops 5 2.5DS 1.0 lb	16.6	bc[3]	35.0	bcd
Tops MZ 8.5DS 0.5 lb	12.2	bc	25.0	bcd
LS208[4] DS0.5lb	22.8	b	48.3	b
LS209[4] DS0.5 lb	22.8	b	46.7	b
LS130[4] DS0.5 lb	14.0	bc	35.0	bcd
Maxim 0.5DS 0.5 lb	12.4	bc	25.0	bcd
Maxim/TBZ 1DS0.5 lb	14.4	bc	31.7	bcd
Maxim/EBDC 1DS 0.5 lb	11.0	bc	26.7	bcd
Myconate 1DS 0.5 lb	6.4	c	11.7	d
Alder bark 0DS 0.5 lb	5.8	c	16.7	cd
Untreated	14.2	bc	35.0	bcd
Untreated/uninoculated	58.0	a	100	a

[1] Relative area under the emergence estimates the rate of emergence. Higher numbers equate to a greater rate of emergence. Calculated from day of planting to 21 days after planting.

[2] Days after planting.

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

[4] Numbered formulations of thiophanate-methyl + mancozeb + cymoxanil (composition is a trade secret).

Table 3. Potato late blight seed piece treatment experiment - emergence rate (RAUEPC), final plant number and phytotoxicity symptoms on potato plants emerging from seed pieces that were cut and the cut face inoculated by dipping it into a mycelial homogenate of rye agar media and *P. infestans*

Treatment and rate of application (lbs/cwt)	emergence				Phytotoxicity[1]			
	RAUEPC[2] max = 100 calculated over 21 day period		final number of plants emerged (%)		20 dap[3]		29 dap	
Tops 5 2.5DS 1.0 lb	31.4	c[4]	61.7	bc	11.6	ab	36.7	bc
Tops MZ 8.5DS 0.5 lb	57.8	a	98.3	a	0	a	11.7	ab
LS208[5] DS0.5lb	55.8	ab	95.0	ab	0	a	8.3	ab
LS209[5] DS0.5 lb	57.8	a	98.3	a	1.7	a	3.3	a
LS130[5] DS0.5 lb	54.8	ab	93.3	ab	3.3	a	3.3	a
Maxim 0.5DS 0.5 lb	28.0	c	58.3	c	13.3	ab	30.0	bcd
Maxim/TBZ 1DS0.5 lb	32.4	c	68.3	bc	11.7	ab	40.0	d
Maxim/EBDC 1DS 0.5 lb	57.0	a	98.3	a	1.6	a	3.3	a
Myconate 1DS 0.5 lb	38.6	bc	68.3	bc	15.0	ab	12.0	abc
Alder bark 0DS 0.5 lb	36.6	c	70.0	abc	15.0	ab	26.7	abcd
Untreated	32.2	c	60.0	c	15.0	ab	20.0	abcd
Untreated/uninoculated	57.2	a	100	a	0	a	0	a

[1] The symptom of phytotoxicity was elongation of the internodes.

[2] Relative area under the emergence estimates the rate of emergence. Higher numbers equate to a greater rate of emergence. Calculated from day of planting to 21 days after planting.

[3] Days after planting..

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

[5] Numbered formulations of thiophanate-methyl + mancozeb + cymoxanil (composition is a trade secret).

Table 4. Potato late blight seed piece treatment experiment - emergence rate (RAUEPC), final plant number and phytotoxicity symptoms on potato plants emerging from seed pieces that were cut, treated and planted. The potato plants were inoculated by a foliar spray of sporangial suspension of *P. infestans*.

Treatment and rate of application (lbs/cwt)	emergence RAUEPC[2] max = 100 calculated over 21 day period		emergence final number of plants emerged (%)		Phytotoxicity[1] 20 dap[3]		Foliar disease RAUDPC[4] max = 100 calculated over 21 day period	
Tops 5 2.5DS 1.0 lb	55.0	a[5]	95.0	a	0	a	22.4	b
Tops MZ 8.5DS 0.5 lb	57.2	a	100	a	3.3	a	22.8	b
LS208[6] DS0.5lb	57.2	a	100	a	1.7	a	22.4	b
LS209[6] DS0.5 lb	57.2	a	100	a	0	a	23.2	b
LS130[6] DS0.5 lb	57.2	a	100	a	6.7	a	23.2	b
Maxim 0.5DS 0.5 lb	56.4	a	100	a	11.7	a	22.8	b
Maxim/TBZ 1DS0.5 lb	56.4	a	100	a	5.0	a	23.0	b
Maxim/EBDC 1DS 0.5 lb	51.8	a	93.3	a	0	a	22.6	b
Myconate 1DS 0.5 lb	55.8	a	100	a	0	a	25.0	b
Alder bark 0DS 0.5 lb	57.2	a	100	a	0	a	22.4	b
Untreated	58.0	a	100	a	0	a	22.8	b
Untreated/uninoculated	58.0	a	100	a	0	a	11.6	a

[1] The symptom of phytotoxicity was elongation of the internodes.

[2].Relative area under the emergence estimates the rate of emergence. Higher numbers equate to a greater rate of emergence. Calculated from day of planting to 21 days after planting.

[3] Days after planting.

[4] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight.

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

[6] Numbered formulations of thiophanate-methyl + mancozeb + cymoxanil (composition is a trade secret).

Funding: MDA

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

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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. The primary objective of the project was to establish N stewardship plots on potato farms to evaluate petiole nitrate testing and leaf chlorophyll content as a tool for reducing N fertilizer use and for adjusting mid-season N fertilization.

ESTABLISHMENT OF N STEWARDSHIP PLOTS

In 1998, N stewardship plots were established in 20 different fields to serve as a reference point for determining the N status of the entire field. At 15 of the sites, the stewardship plots consisted of long 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, ranging from 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. At five sites, we established small plots, usually four rows 50 feet long, comparing two or three different N rates.

PETIOLE NITRATE TESTING AND LEAF CHLOROPHYLL READINGS

Weekly potato petiole nitrate testing started the first week of June and ended the second week of August. Whenever we observed a significant chlorophyll difference between the two strips, as measured by the Minolta SPAD meter, three to four composite samples of petioles were taken from the two areas. Whenever possible, the test results were faxed to the County Extension agents and to the growers on the same day of the analysis. The results were used to assess the N status of the potato crop and adjust mid-season N fertilizer applications. This year we used the services of Techmark, Inc. for dry petiole analysis.

Leaf chlorophyll readings were made each time petiole samples were collected. Approximately 120 readings were made in each strip with a hand held Minolta SPAD 502 chlorophyll meter. The SPAD readings were normalized using the highest chlorophyll reading in each replication as 100 percent.

SOIL 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 residual soil nitrate levels in each field. All samples were analyzed for nitrate N using a nitrate auto-analyzer.

POTATO HARVEST

In 1998, 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. U.S. #1 grade included all tubers greater than 1 7/8 inches in diameter. Tubers smaller than 1 7/8 inches were graded as B's. Tubers greater than 3 1/4 inches were classified as premium oversize.

POTATO GROWERS SURVEY

A limited survey was conducted of potato growers who participated in the 1995-98 nitrogen stewardship program. A copy of the survey can be found in the Appendix. The survey was conducted during August and September 1998.

RESULTS AND DISCUSSION

Rates and times of N fertilizer application for 1998 are presented in Table 1. Nitrogen rates varied from a low of 73 to a high of 280 lb/acre. The number of N applications at each location varied from one to eight times. The varieties grown were Snowden, Pikes, Onaway, and Russet Norkotah.

POTATO YIELD

Potato yield data from 13 of the 20 N stewardship plots are presented in Table 2. Sites 10, 11,12, 17, 18, 19 and 20 were not harvested. We are unable to calculate statistical differences for each site because these trials included only one strip across the field which was not replicated. However, we did perform a statistical analysis for high and low N rates over all sites. At most sites, we harvested one to two truck loads from each strip. Harvest strips varied from 4 to 12 rows wide and 800 to 2000 feet long. Truck loads varied from 7 to 14 tons of fresh weight tubers. Sites 13-16 were hand-harvested from small plots; 3 to 4 rows and 10 to 20 feet long.

Eight sites (1, 4, 5, 6, 7, 8, 9 and 15) showed a slight increase in U.S. #1 and total yields due to the extra N while five sites (2, 3, 13, 14 and 16) yielded slightly less with more N. The overall statistical analysis shown at the bottom of Table 2 indicates that the high N rate did not significantly out-yielded the low N rate for U.S. #'s 1 or total yields ($p \leq 0.05$). Sites 13-16 are seed potato fields located in Northern Michigan and showed a great deal of yield variation..

Specific gravity of tubers increased or decreased with N rates but the analysis over all sites showed no significant difference. Gross margins, calculated as the gross price times yield minus the fertilizer N costs, favored the higher N rates by $83/acre. Differences between high and low N rates varied from a loss of $238 per acre for Site 13 to a gain of $732 per acre for Site 6. A price of $6.00/cwt for potatoes and $0.22/lb of N fertilizer was used in the analysis.

Table 3 shows a combined analysis for the last four years. The table includes only data where there was a complete set of information for all measurements. A statistical analysis of the data shows that there were differences between years but not between the two N rates. There is a tendency, however, for slightly higher yields with higher N rates. For the 33 locations, there was an 7 cwt/acre yield advantage in U.S. #1 yields (352-345) for a gross margin advantage of $27/acre in favor of higher N rates.

This year's data continues to support the N stewardship practice of reducing N fertilizer use on potatoes but not as strongly as it did in other years. When the data were statistically analyzed over four years (1995-1998), the extra 70 lb of N/acre (256-186) did not significantly increase yields. The use of farm equipment for harvesting 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.

PETIOLE NITRATE TESTING AND LEAF CHLOROPHYLL READINGS

Weekly petiole nitrate test data from the stewardship plots are shown in Tables 4, 5 and 6. Petiole nitrate levels declined during the growing season which is normally expected but values at most sites were above the critical levels throughout the season. Only Sites 1, 2, 9 and 14 exhibited deficient petiole nitrate concentration with reduced N fertilizer. At Site 2, both the high and low N areas exhibited deficient nitrate levels.

Leaf chlorophyll readings were made each week when petioles were sampled for nitrate N. Previous research has shown that leaf chlorophyll is closely correlated with N content of the leaf. The data presented here were normalized as a percent of the high N treatment. Chlorophyll SPAD readings for 1998 ranged from 39-45. Relative chlorophyll readings (percentage based on the highest SPAD reading in each replication) ranged from 81 to 100 percent. Research at the Montcalm Research Farm and MSU Agronomy Farm in 1997 indicated that any value above 96 percent was adequate for maximum production.

From these data, we continue to support the use of the chlorophyll meter for evaluating the N status of the potato crop. The tool is quick, nondestructive and reliable and has great potential for evaluating the N status of the potato crop in the field.

PREPLANT AND POST-HARVEST RESIDUAL SOIL NITRATE

Soil nitrate data for the nitrogen stewardship plots are shown in Tables 7, 8 and 9. The data for initial soil samples taken prior to establishing the 1998 studies is reported in Table 7. Seven sites showed only small amounts of nitrate N in the 3-foot profile (less than 14 lb per acre 3-feet). One site in Central Michigan (5) and five sites in Northern Michigan (13-17) had more than 30 lb of nitrate N in the 3-foot profile.

The post-harvest data are shown in Table 8. Not all sites sampled prior to planting were sampled at harvest. Residual soil N was found to be significantly different between sites but the difference between low and high N rates was not significant. When the analysis was combined over all sites, there was a significant difference between low and high N plots. The average for eight of the sites was 71.5 lb/acre-3 feet for the low N plots compared to 97.4 lb/acre-3 feet in the high N plots.

Table 9 shows the data summarized for 24 sites over four years. In 1997 and 1998, 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. When the data were analyzed over all sites and years, the high N profiles averaged 23 (75-52) lb N per acre more than the low N profiles.

From these data we conclude that potato growers are leaving approximately 50-75 lb of nitrate N in their soil profile at potato harvest time. In dry years like 1998, the amount will be greater than in wet years because smaller amounts of water and nitrates will be leached through the profile before harvest. The amount of N remaining in sandy soils after harvest is difficult to recover because very few crops have the ability to grow rapidly late in the season. By spring, this residual N is usually leached out of the profile. 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. Most of the water supplied to the 1998 crop was by irrigation. Total rainfall for the season ranged from 3 to 5 inches while irrigation ranged from 10 to 17 inches. Excess rainfall was very low (0-1.5 inches). Excess irrigation water ranged from 0-5 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 and after 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 through the soil profile.

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 33 locations from 1995 to 1998. The percent N recovery from the low N plots was 61 percent of that applied. The amount recovered in the high N plots was 45 percent,.while 61 percent of the N in these plots was unaccounted for by crop removal. **These data emphasize the importance of managing N fertilizer properly. The reduced N plots lowered yields by only 2 percent (7 cwt/acre) but improved N recovery by 16 percent.**

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 chlorophyll testing, 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 greater 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 made extensive use of this tool in the field to quickly determine the N status of the crop.

Potato growers are leaving approximately 50-75 lb of nitrate in the soil profile at harvest time. In dry years, the amount is 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 before frost. 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 lb per acre. These findings emphasize the importance of managing N fertilizer properly. The four-year average showed that the reduced N plots lowered yields by only 2 percent (7 cwt per acre) but improved N recovery by 16 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 causes a great deal of variability in the amount of nitrate N measured. This variability makes 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 - 1998.

Site No	Treatment	lb N per Acre								
1	**Date applied**	**Preplant**	**4/16**	**5/4**	**5/27**					**Total**
Onaway	Low N	--	28	123	0[1]					**151**
	High N	--	28	123	92					**243**
2	**Date applied**	**Preplant**	**5/9**	**5/15**	**6/18**					**Total**
Snowden	Low N	--	57	76	21					**154**
	High N	--	57	76	76					**209**
3	**Date applied**	**Preplant**	**5/12**	**5/22**	**6/17**	**7/20**	**7/25**			**Total**
Snowden	Low N	--	30	60	60	45	15			**210**
	High N	--	30	60	90	45	15			**240**
4	**Date applied**	**Preplant**	**5/19**	**5/30**	**6/29**					**Total**
Snowden	Low N	--	78	55	50					**183**
	High N	--	78	55	150					**283**
5	**Date applied**	**Preplant**	**5/15**	**6/15**	**6/22**					**Total**
Snowden	Low N	--	50	60	66					**176**
	High N	--	50	90	96					**236**
6	**Date applied**	**Preplant**	**4/29**	**6/7**	**6/13**	**Foliar**	**7/10**	**7/24**	**Foliar**	**Total**
Pikes	Low N	21	48	64	39	2	32	21	3	**230**
	High N	21	48	94	39	2	32	21	3	**260**
7	**Date applied**	**Preplant**	**5/12**	**5/26**	**6/19**	**6/30**	**7/18**			**Total**
Snowden	Low N	--	43	35	70	69	15			**232**
	High N	--	43	35	70	117	15			**280**
8	**Date applied**	**Preplant**	**5/21**	**6/18**	**6/22**	**7/1**	**7/9**			**Total**
Snowden	Low N	--	57	105	45	23	20			**230**
	High N	--	57	105	90	23	20			**275**
9	**Date applied**	**Preplant**	**5/18**	**6/2**	**6/26**					**Total**
Snowden	Low N	--	50	60	0					**110**
	High N	--	50	60	120					**230**

[1] Shaded values denote where different amounts of N were applied during the growing season.

Table 1. Continued

Site No	Treatment	---------------------------------- lb N per Acre ----------------------------------					
10	**Date applied**	**Preplant**	**5/22**	**6/16**	**6/22**	**7/30**	**Total**
Snowden	Low N	--	50	0[1]	90	20	**160**
	High N	--	50	50	90	20	**210**
11	**Date applied**	**Preplant**	**5/22**	**6/26**	**7/2**		**Total**
Snowden	Low N	--	25	90	80		**195**
	High N	--	25	90	105		**220**
12	**Date applied**	**Preplant**	**5/21**	**6/24**	**6/30**		**Total**
Snowden	Low N	--	25	90	80		**195**
	High N	--	25	90	105		**220**
13	**Date applied**	**Preplant**	**5/18**	**6/2**	**6/20**		**Total**
Onaway	Low N	--	44	50	55		**149**
	High N	--	44	50	83		**177**
14	**Date applied**	**Preplant**	**5/19**	**6/15**			**Total**
Russet Norkotah	Low N	--	44	107			**151**
	High N	--	44	137			**181**
15	**Date applied**	**Preplant**		**6/18**			**Total**
Russet Norkotah	Low N	--	44	80			**124**
	High N	--	44	138			**182**
16	**Date applied**	**Preplant**	**5/12**	**6/8**	**6/23**		**Total**
Snowden	Low	30	43	0	0		**73**
	Medium	30	43	27	23		**123**
	High	30	43	54	46		**173**
17	**Date applied**	**Preplant**	**5/12**	**6/8**	**6/23**		**Total**
Snowden	Low	40	43	0	23		**106**
	Medium	40	43	27	23		**133**
	High	40	43	54	46		**183**

[1] Shaded values denote where different amounts of N were applied during the growing season.

Table 2. Tuber yield, size distribution, specific gravity and economic returns for the nitrogen stewardship plots - 1998.

Site No.	Variety	N Rate	U.S. #1	Total	Percent of the Total[1] U.S. #1	B's	A's	OV	UC	Sp Gr	Gross Margin ($)[2]
1	Onaway	151	229	314	73	23	64	9	4	nd	$1,341
		243	275	352	78	17	63	15	5	nd	$1,597
2	Snowden	154	397	418	95	5	94	1	nd[3]	1.085	$2,348
		209	373	401	93	7	88	5	nd	1.086	$2,192
3	Snowden	210	406	414	98	2	72	25	nd	1.078	$2,390
		240	402	414	97	3	79	18	nd	1.079	$2,359
4	Snowden	183	428	437	98	2	72	26	nd	1.084	$2,528
		283	466	475	98	2	70	28	nd	1.081	$2,734
5	Snowden	176	335	340	99	1	85	14	nd	1.079	$1,971
		236	358	365	98	2	85	13	nd	1.080	$2,096
6	Pikes	230	305	323	94	6	87	6	nd	1.085	$1,779
		260	353	376	94	6	87	7	nd	1.086	$2,061
7	Snowden	232	288	310	93	5	88	7	nd	1.080	$1,677
		280	321	338	95	6	89	5	nd	1.078	$1,864
8	Snowden	230	372	384	89	8	89	3	nd	1.084	$2,181
		275	400	408	91	8	89	2	nd	1.084	$2,340
9	Snowden	110	389[3]	409	95	nd	nd	nd	nd	nd	$2,310
		230	465	489	95	nd	nd	nd	nd	nd	$2,739

[1] Tuber sizes, U.S. #1 >1 7/8", B's < 1 7/8", A's = 1 7/8" - 3 1/4", OV = > 3 1/4", UC = Unclassified, nd = Not determined

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

[3] Shaded values are estimates rather than actual measured values because actual data were not collected.

Table 2. Continued.

Site No.	Variety	N Rate	U.S. #1	Total	Percent of the Total [1] U.S. #1	B's	A's	OV	UC	Sp Gr	Gross Margin ($)[2]
13	Onaway	149	256	299	86	14	82	4	0	1.074	$1,503
		177	219	270	80	19	77	3	1	1.078	$1,275
14	Russet Norkotah	151	101	170	59	40	59	0	1	1.079	$573
		181	93	180	52	48	52	0	0	1.083	$518
15	Russet Norkotah	124	74	119	62	37	62	0	1	1.074	$417
		182	76	178	76	22	76	0	2	1.075	$416
16	Pikes	73	411 [3]	433	95	nd	nd	nd	nd	nd	$2,450
		123	371	391	95	nd	nd	nd	nd	nd	$2,199
		173	404	425	95	nd	nd	nd	nd	nd	$2,386
Mean Values	Low N	166	307	336	87	13	77	9	1	1.080	$1,805
	High N	228	323	359	88	13	78	9	1	1.081	$1,888

[1] Tuber sizes, U.S. #1 >1 7/8", B's < 1 7/8", A's = 1 7/8" - 3 1/4", OV = > 3 1/4", UC = Unclassified, nd = Not determined

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

[3] Shaded values are estimates rather than actual measured values because actual data were not collected.

Table 3. Tuber yield, size distribution, specific gravity and economic returns for the nitrogen stewardship plots - Summary 1995-98 for 33 locations.

Year	Average N rate (lb/acre)	U.S. #1	Total	Percent of the Total: U.S. #1	B's	A's	OV	Sp Gr	Gross Margin ($)[1]
		Overall means[2]							
1995 (6)	238	321c	371b	87c	12a	77b	10	1.074c	$1,874c
1996 (7)	236	402a	428a	93b	5b	83a	11	1.083a	$2,360a
1997 (7)	215	355b	382b	93b	11a	76b	17	1.079b	$2,047b
1998 (13)	197	315c	348c	88b	13a	78b	9	1.081ab	$1,847c
N Rate		Overall means							
Low N	186	345	378	90	9	79	11	1.079	$2.029
High N	256	352	387	90	11	78	12	1.079	$2,056

[1] 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).

[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 nitrogen fertilizer rate and sampling date on petiole nitrate and leaf chlorophyll content for Sites 1-6 - 1998.

DATE	1-L*	1-H	2-L	2-H	3-L	3-H	4-L	4-H	5-L	5-H	6-L	6-H
	Petiole Nitrate - ppm											
June 1-5	15,893	15,535										
June 8-12	—	—										
June 15-19	33,975	42,664										
June 22-26	*****12,630***	33,193	34,720	36,808	—	33,138	—	46,501	41,722	50,401	—	34,143
June 29-July 3	***6,831***	43,300	27,947	41,415	46,860	45,490	45,865	42,236	41,969	49,929	36,288	31,221
July 6-10	—	—	***5,972***	14,948	18,056	18,365	57,207	49,010	42,836	59,912	18,308	16,885
July 13-17	***2,672***	20,775	***2,951***	***8,756***	13,966	12,023	29,947	33,399	25,247	28,805	16,039	15,576
July 20-24			***1,897***	***7,990***	22,993	26,314	25,382	26,617	26,898	26,480	17,019	18,691
July 27-31			***1,012***	***3,566***	15,535	17,501	16,496	23,696	16,201	21,008	8,005	8,042
Aug 3-7					12,963	16,801	17,618	21,228	13,729	14,882	7,045	8,638
Aug 10-14					10,999	13,385	18,562	20,587	15,663	15,392	2,557	3,450
	Relative Leaf Chlorophyll Content											
June 1-5	96%	100%										
June 8-12	—	—										
June 15-19	***93%***	100%			100%	97%			100%	99%	100%	100%
June 22-26	***91%***	100%	100%	100%	97%	100%	97%	100%	99%	100%	100%	99%
June 29-July 3	***90%***	100%	***95%***	100%	100%	100%	97%	100%	100%	100%	100%	100%
July 6-10	—	—	***94%***	100%	97%	100%	96%	100%	98%	100%	100%	99%
July 13-17	***81%***	100%	***92%***	100%	100%	99%	100%	99%	98%	100%	100%	98%
July 20-24			***92%***	100%	100%	99%	***95%***	100%	97%	100%	100%	97%
July 27-31			***92%***	100%	98%	100%	98%	100%	98%	100%	98%	100%
Aug 3-7					100%	100%	96%	100%	100%	99%	100%	97%
Aug 10-14					100%	100%	100%	99%	100%	100%	100%	97%

* Site Number - area (L = low nitorgen, H = high nitrogen).

** Values in bold and italics are deficient on based the guidlines for interpreting potato petiole nitrate and leaf chlorophyll content.

Table 5. Effect of nitrogen fertilizer rate and sampling date on petiole nitrate and leaf chlorophyll content for Sites 7-12 - 1998.

DATE	Site Number											
	7-L*	7-H	8-L	8-H	9-L	9-H	10-L	10-H	11-L	11-H	12-L	12-H
	Petiole Nitrate - ppm											
June 1-5												
June 8-12												
June 15-19												
June 22-26	—	23,634	—	30,621		38,817			42,555	—	36,546	—
June 29-July 3	24,636	24,900	44,766	50,715	46,156	47,616	—	48,562	—	—	—	—
July 6-10	32,402	30,209	50,214	51,096	17,078	24,376	18,164	22,409	25,107	23,320	19,554	20,346
July 13-17	19,324	18,361	23,709	26,615	12,720	25,022	14,976	21,219	28,329	30,219	28,906	24,902
July 20-24	22,302	21,405	31,573	—	6,560	18,742	8,740	15,079	18,778	17,386	20,047	26,612
July 27-31	12,616	12,067	15,622	20,979	7,943	19,065	7,088	13,482	21,132	15,880	25,484	21,814
Aug 3-7	9,453	11,381	15,977	20,796	*****4,263***	18,162	6,575	24,120	13,034	9,675	11,174	18,322
Aug 10-14	8,638	10,953	16,264	16,543	—	13,845	—	—	17,526	11,527	10,933	18,788
	Relative Leaf Chlorophyll Content											
June 1-5												
June 8-12												
June 15-19			100%	100%								
June 22-26	100%	99%	98%	100%	100%	98%						
June 29-July 3	100%	100%	100%	100%	100%	97%	100%	98%				
July 6-10	100%	99%	99%	100%	—	—	99%	100%				
July 13-17	100%	99%	99%	100%	100%	***91%***	100%	***95%***	99%	100%	98%	100%
July 20-24	100%	96%	98%	100%	***91%***	100%	100%	100%	100%	98%	99%	100%
July 27-31	98%	100%	97%	100%	***88%***	100%	98%	100%	100%	97%	98%	100%
Aug 3-7	100%	98%	99%	100%	97%	100%	99%	100%	100%	100%	97%	100%
Aug 10-14	100%	98%	100%	99%	98%	100%			100%	100%	99%	100%

* Site Number - area (L = low nitorgen, H = high nitrogen).

** Values in bold and italics are deficient based on the guidlines for interpreting potato petiole nitrate and leaf chlorophyll content.

Table 6. Effect of nitrogen fertilizer rate and sampling date on petiole nitrate and leaf chlorophyll content for Sites 13-17 - 1998.

	Site Number											
DATE	13-L*	13-H	14-L	14-H	15-L	15-H	16-L	16-M	16-H	17-L	17-M	17-H
	Petiole Nitrate - ppm											
June 1-5												
June 8-12												
June 15-19												
June 22-26												
June 29-July 3	35,475	44,179	56,308	50,388			47,193	54,017	60,324	61,497	61,146	68,513
July 6-10	21,999	32,015	33,082	37,021			32,291	32,779	34,975	31,614	37,547	37,835
July 13-17	17,506	31,777	29,734	36,113	50,151	42,366	—	—	—	—	—	—
July 20-24	4,026	16,647	19,143	18,256	40,341	36,335	14,330	8,415	12,703	11,389	5,697	14,339
July 27-31	4,992	14,704	21,551	23,551	32,765	32,961	13,439	15,583	19,894	8,937	8,798	14,913
Aug 3-7	**1,005	18,064			31,490	34,910	9,682	15,910	19,940			
Aug 10-14												
	Relative Leaf Chlorophyll Content											
June 1-5												
June 8-12												
June 15-19												
June 22-26												
June 29-July 3	97%	100%	96%	100%			99%	100%	100%	99%	100%	99%
July 6-10	***93%***	100%	98%	100%			96%	100%	100%	100%	98%	99%
July 13-17	***94%***	100%	99%	100%	100%	97%	—	—	—	—	—	—
July 20-24	97%	100%	98%	100%	100%	96%	99%	99%	100%	97%	99%	100%
July 27-31	***85%***	100%	***94%***	100%	98%	100%	98%	100%	99%	96%	100%	100%
Aug 3-7	***81%***	100%			96%	100%	95%	100%	97%			
Aug 10-14												

* Site Number - area (L = low nitrogen, M = medium nitrogen, H = high nitrogen).

** Values in bold and italics are deficient on based the guidlines for interpreting potato petiole nitrate and leaf chlorophyll content.

Table 7. Preplant soil nitrate-nitrogen levels for thirteen nitrogen stewardship plots - 1998.

Site Number	---- Sample Depth (inches) ----			Total
	0 - 12"	12 - 24"	24 - 36"	
	----- lb of Nitrate-Nitrogen per Acre -----			
1	2.8	2.6	1.7	**7.1 c[1]**
2	2.6	0.2	0.4	**3.2 c**
3	4.1	1.8	1.1	**7.0 c**
4	1.2	0.3	0.1	**1.6 c**
5	18.4	4.5	7.6	**30.5 b**
6	7.7	1.9	2.4	**12.0 c**
7	1.9	1.4	4.7	**8.0 c**
8	5.9	2.4	5.5	**13.9 c**
13	33.6	16.8	10.8	**60.9 a**
14	32.4	18.7	14.7	**65.8 a**
15	33.6	16.8	10.8	**61.2 a**
16	43.2	9.46	5.8	**58.5 a**
17	42.3	14.8	10.7	**67.7 a**
Mean	17.7 a	7.0 b	5.9 b	**30.6**

[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 8. Post-harvest soil nitrate-nitrogen levels as affected by nitrogen fertilizer rate and profile depth for eight nitrogen stewardship plots - 1998.

Site Number	N Rate -lb/A-	---- Sample Depth (inches) ---- 0 - 12"	12 - 24"	24 - 36"	Total
		----- lb of Nitrate-Nitrogen per Acre -------			
2	154	17.8	7.9	7.1	**32.8 f**
	209	19.5	7.2	5.5	**32.3 f**
3	210	18.4	14.5	8.8	**41.8 ef**
	240	26.4	26.9	19.9	**73.1 cdef**
4	183	15.0	21.1	6.0	**42.1 ef**
	283	54.0	22.1	6.5	**82.6 cdef**
5	176	56.8	47.3	18.8	**122.8 abc**
	236	97.1	54.4	13.2	**164.6 a**
6	230	42.6	28.9	19.3	**90.8 cdef**
	260	53.2	21.2	9.9	**84.2 cdef**
7	232	53.9	33.6	11.4	**98.9 bcde**
	280	86.4	32.8	11.2	**130.4 abc**
8	230	17.5	47.6	48.0	**113.1 abcd**
	275	21.5	40.4	93.2	**155.1 ab**
9	110	20.1	5.3	4.9	**30.2 f**
	230	26.5	21.3	9.2	**56.9 def**
Low N	**191**	**30.2**	**25.8**	**15.5**	**71.5 b**
High N	**252**	**48.1**	**28.3**	**21.1**	**97.4 a**

[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 1995-98 for 24 sites.

Site Years ( ) No. Sites[1]	Average N Rate -lb/A-	---- Sample Depth (inches) ---- 0 - 12"	12 - 24"	24 - 36"	Total
		----- lb of Nitrate Nitrogen per Acre[2] -------			
1995 (3)	264	17.4 bc	10.4 bc	8.9 c	**36.9 b**
1996 (7)	239	12.1 bc	10.8 bc	13.2 bc	**36.1 b**
1997 (6)	224	40.1 a	26.5 ab	14.4 bc	**81.0 a**
1998 (8)	221	39.2	27.0	18.3	**84.5 a**
Treatment		------------ **Overall means** --------------			
Low N	201	23.5 ab	16.9 b	11.8 b	**52.2 b**
High N	264	34.0 a	23.3 ab	17.5 b	**74.9 a**

[1] The only sites included were those with a complete set of data.
[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 10. Seasonal rainfall and irrigation amounts with calculated excess based on a water balance from an irrigation scheduling program for the six 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-------		
3	4.10	13.40	17.50	1.03	5.36	6.39	25	40	37
4	5.36	10.40	15.76	1.18	2.84	4.02	22	27	26
5	2.95	11.80	14.75	1.56	2.11	2.60	52	17	18
6	3.85	10.50	14.35	0.23	2.66	2.89	6	25	20
7	3.40	7.00	10.40	0.00	0.10	0.10	0	1	1
8	3.15	10.30	13.45	1.14	2.47	3.61	36	24	27
Average	3.88	11.28	15.16	1.03	3.09	3.90	28	27	26

[1] June 9 through September 15, 1998.

Table 11. Estimated recovery of applied N by potatoes as affected by two nitrogen fertilizer rates - Summary 1995-98 for 26 locations.

N Treatment	N Rate (lb N/A)	U.S. #1 Yield (cwt/A)	N Recovered [1] (lb N/A)	N Unrecovered (lb N/A)	Recovery [2] (%)
Low N	186	345	114	72	61
High N	256	352	116	140	45

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

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

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Effects of Nitrogen Fertilizer Management on Nitrate Leaching

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This study represents the continuation of research initiated in 1988 at the MSU Potato Research Farm to evaluate the impact of contrasting nitrogen (N) management strategies on potato yields and nitrate leaching.

Two permanently-installed drainage lysimeters have been used to monitor the soil water drainage and nitrate leaching at this site. Each year, a treatment consisting of a High Nitrogen Management (HNM) and Reduced Nitrogen Management (RNM) was applied on each of the lysimeters. The HNM represents a conventional nitrogen management while the RNM represents a conservation/research nitrogen management. The nitrogen application difference between the two treatments has been 100 lbs/ac.

This study provided direct evidence of the impact of fertilizer management of potential groundwater contamination and the results of long term management decisions.

METHODOLOGY

The lysimeters used in this study are steel, box shape containers that are 48" wide, 68" long and 72" deep. These boxes have open tops and are installed so that there 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 plots were planted with potatoes on May 14, 1998, following as part of the rotation with corn. The potato variety used in this study was Snowden. Row spacing was 34 inches and seed spacing was 9 inches.

The HNM treatment received a total of 220 lbs N/ac while the RNM received 120 lbs N/ac split in two applications. Both plots had the same amount of starter fertilizer (60 lbs N/ac) at time of planting.

Yields were measured on carefully controlled area directly over the top of each lysimeter and from two randomly chosen areas outside the direct area but near the lysimeters. The potatoes were separated according to size and condition, and subsamples were taken from each harvest sample for specific gravity measurements.

Irrigation was supplied with the schedule used by the Montcalm Farm and using the regular sprinkler system.

RESULTS

The results for this study will be split into two sections: first, the 1998 results will be reviewed and then the cumulative results for the past ten years (1988-1998) will be discussed.

Results: 1998

Total tuber yield averaged 244.1 cwt/ac for the RNM treatment compared to 187.7 cwt/ac for the HNM. As Table 1 shows, the RNM treatment also produced the most favorable tuber size distribution.

Table 1. Yield and Size Distribution, 1998.

Treatments	Total Yield (cwt/ac)	Yield U.S. No. 1 (cwt/ac)	Tuber class "B" (cwt/ac)
HNM	187.7	170.5	17.2
RNM	244.1	234.9	9.2

Figures 1 to 4 illustrate data collected from the lysimeters during 1998. Figure 1 shows the cumulative drainage that occurred during the year. Throughout most of the year the two lysimeters drainage was approximately the same.

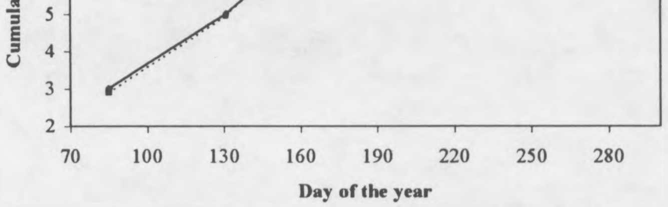

Figure 1. Cumulative Drainage, 1998.

The nitrate leaching data are shown in Figures 2 and 3. Figure 2 shows the nitrate-N concentration for the drainage water for the lysimeters. The HNM lysimeter had a higher nitrate concentration. Nitrate-N concentration dropped in both lysimeters as the season began. At the end of the season the HNM showed higher concentration again due to higher nitrogen fertilizer application.

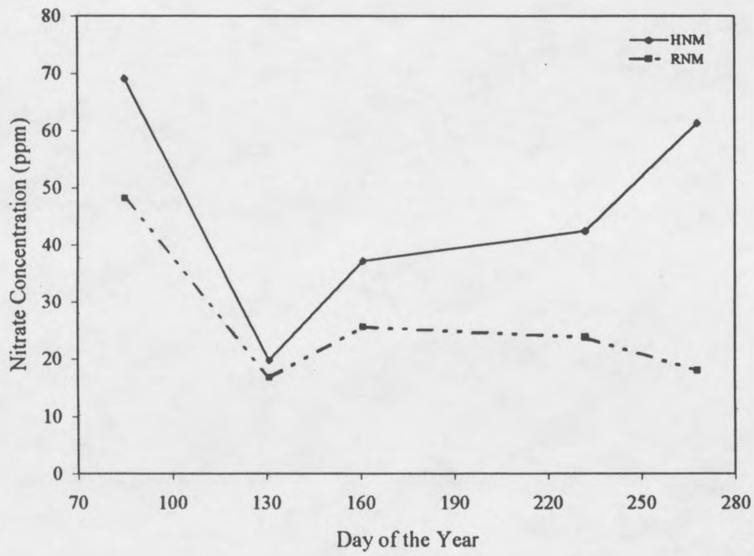

Figure 2. Nitrate-N concentration of the drainage water, 1998.

The nitrate leaching as depicted in Figure 3, was considerably higher for the HNM. Figure 4 shows the nitrate leaching versus the cumulative drainage measured for the two treatments. The lysimeters lost nitrate-N at about the same rate for the first 3 inches of drainage, after that point the RNM began to lose nitrate-N at a slower rate. This is indicated by the lower slope of the curve.

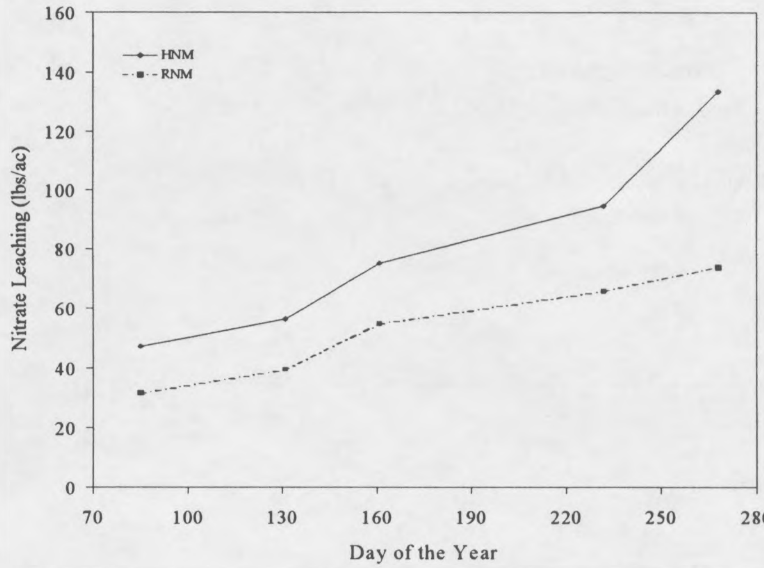

Figure 3. Cumulative Nitrate-N leached, 1998.

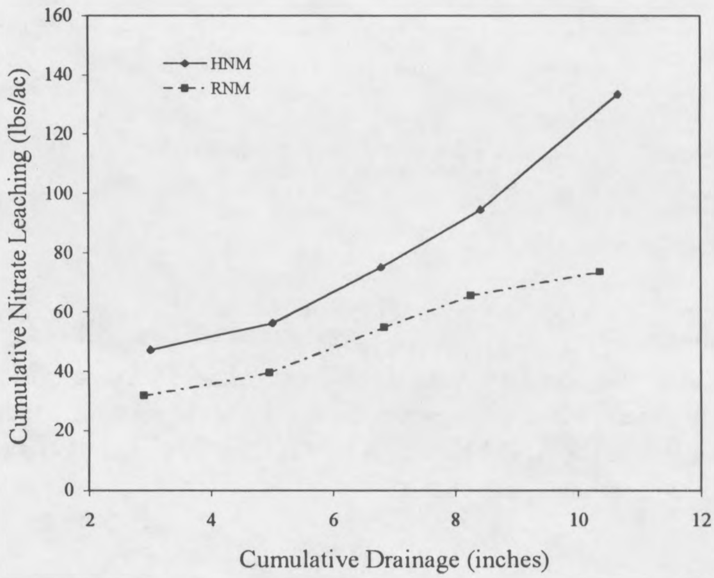

Figure 4. Cumulative Drainage versus Cumulative Nitrate Leaching, 1998.

Results: 1988-1998

The data obtained over the 11-year period gives a better perspective on long term trends and/or impact. Tables 2 and 3 illustrate a summary of yields and nitrogen balance for the two treatments in comparison for 1988-1998.

Table 2. Summary Yield for the High Nitrogen Management and Reduced Nitrogen Management for 1988-1998.

YEAR	CROP TYPE	YIELD Cwt/ac-potato Bu/ac-corn	
		HNM	RNM
1988	Potato	233	219
1989	Corn	154	158
1990	Potato	198	277
1991	Potato	148	214
1992	Corn	143	119
1993	Potato	134	184
1994	Potato	323	359
1995	Corn	155	149
1996	Potato	441	345
1997	Corn	152	156
1998	Potato	244	188

Table 3. Summary Table for Annual N Balance for 1988-1998.

YEAR	CROP TYPE	FERTLIZER APPLIED (lbs/acre)		N UPTAKE BY THE CROP (lbs/acre)		NO_3^--N LEACHED (lbs/acre)		N APPL. - N UPTAKE (lbs/acre)	
		RNM	HNM	RNM	HNM	RNM	HNM	RNM	HNM
1988	Potato	110	200	80	81	58	73	30	119
1989	Corn	130	200	100	106	200	215	30	94
1990	Potato	110	193	68	102	110	160	42	91
1991	Potato	125	200	51	79	74	84	74	121
1992	Corn	90	230	93	80	56	117	-3	150
1993	Potato	158	196	46	68	23	40	112	128
1994	Potato	107	196	111	133	52	57	-4	63
1995	Corn	148	260	101	100	75	97	47	160
1996	Potato	160	260	152	128	73	102	-8	132
1997	Corn	120	220	183	204	77	124	-63	16
1998	Potato	140	240	81	62	73	133	59	178
AVERAGE		**127**	**235**	**97**	**104**	**79**	**109**	**29**	**114**

Corn yields have been consistently good but potato yields have ranged from 134 cwt/ac to 441 cwt/ac. This variability in yield is mostly due to pest or weather problem. During the low yield years, leaching increased because of the lack of N uptake.

The average annual fertilizer input for the 11-year period was 108 lbs N/ac more for the HNM; while the N removed by the crop averaged only 7 lbs N/ac per year more for the HNM. The leaching averaged 30 lbs N/ac per year more for the HNM, a difference that has been identical for the last few years. The difference between the nitrogen fertilizer applied and the N removed by the crop is the amount available for leaching or changes in concentration on N within the soil. This difference after the 11-year period averaged 85 lbs N/ac more for the HNM. A net of 126 lbs N/ac were added to the soil for the HNM, while a net of 48 lbs N/ac were added to the soil for RNM for the 11 year period.

The long term drainage and leaching data are shown in Figures 5-7. Figure 5 shows the cumulative drainage for the 11 years. The water drained from the two lysimeters was about the same.

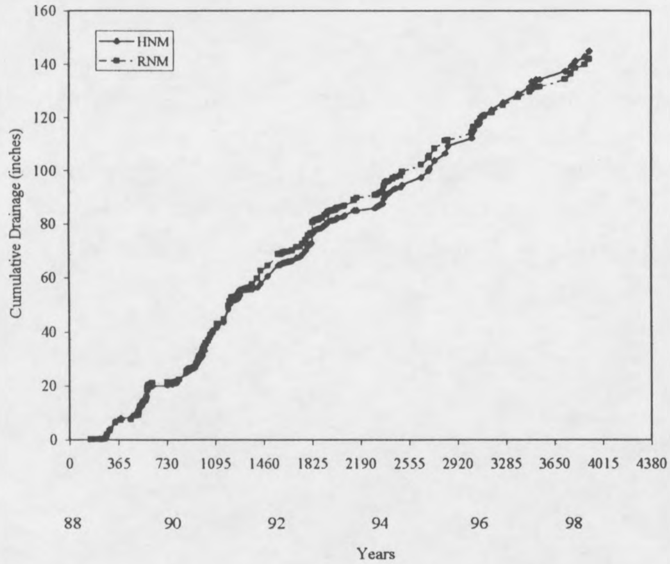

Figure 5. Cumulative Drainage, 1988-1998.

The nitrate-N leached during the 11-year period is depicted in Figure 6. About the same amount of nitrogen was leached from the two lysimeters during the first two years and then the RNM treatment began to leach less. By the end of 1998 the RNM leached 924 lbs N/ac while the HNM leached 1250 lbs N/ac.

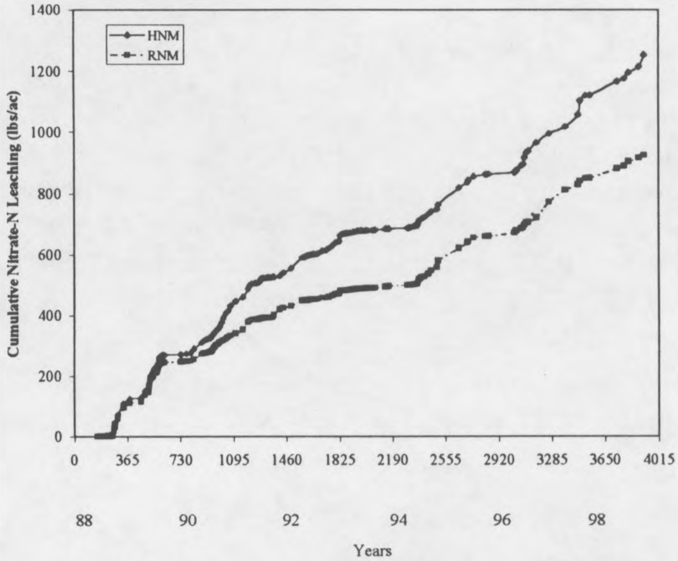

Figure 6. Cumulative Nitrate Leaching, 1988-1998.

By plotting cumulative Nitrate-N leached versus cumulative drainage (Figure 6), the nitrate leaching trends can be seen. The lysimeters lost nitrate-N at about the same rate for the first 10 inches of drainage, after that point the RNM began to lose nitrate-N at a slower rate. During the other years the rate of nitrate-N loss has continued to go down in the RNM while the HNM lysimeter's rate increased.

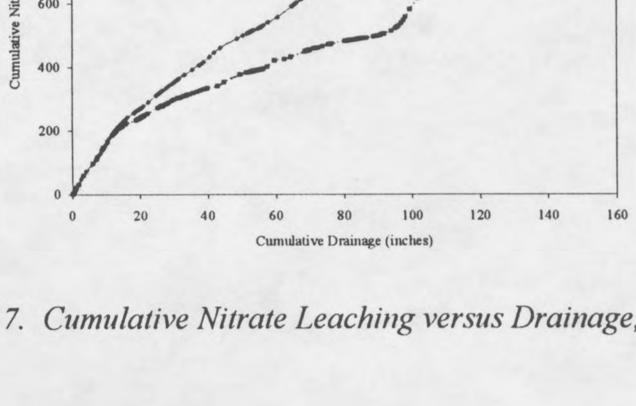

Figure 7. Cumulative Nitrate Leaching versus Drainage, 1988-1998.

CONCLUSION

The data obtained during this long term study give useful insights on how nitrogen management fertilization has impacted the leaching of nitrates and yield of irrigated potatoes rotated with corn crops on a sandy soil.

The results indicate that most of the fertilizer N added that is not removed by the harvested crop is lost by leaching.

This long term study also indicate that there is no absolutely best N management practices that will maximize yield with minimum leaching because of the uncertainty of the N removed by the crop, due to weather and pests.

The corn yields were above average indicating that it is possible to obtain high efficiency, conservative, and management practices without sacrificing profitability.

ACKNOWLEDGEMENT

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Insect Management in Potatoes
1998 Research Report

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Summary:
During 1998, we conducted research that included: 1) investigating the inheritance of Admire resistance in the Colorado potato beetle and determining the effects of synergists for testing possible mechanisms of resistance. 2) monitoring Colorado potato beetle field populations for resistance to Admire®, 3) examining the interaction between Admire poisoning in Colorado potato beetles and predation by ground beetles, 4) investigating if and how low levels of resistance in Colorado potato beetles reduce length of control with Admire, and, 5) determining efficacy of registered and new insecticides for control of Colorado potato beetle and potato leafhopper.

Colorado potato beetle numbers were low to moderate during most of the potato growing season. The previous winter's mild temperature resulted in a greater number of volunteer potatoes in fields rotated out of potatoes. These volunteers served as a food source for Colorado potato beetles emerging from overwintering and, in some cases, persisted through the growing season. In some situations, large numbers of Colorado potato beetles, presumably maintained on volunteer potatoes, migrated into potato fields late in the season.

Inheritance of Admire resistance in the Colorado potato beetle and the effect of synergists.
Two laboratory strains of Colorado potato beetle were used in this study. The resistant strain (LI) was originally collected from a potato field on Long Island, NY in 1997. The susceptible strain (UP) was originally collected from an organic potato farm in the upper peninsula of Michigan in 1996. Both strains were reared without exposure to insecticides at 25±1°C and L:D 16:8 on potato leaves grown in the greenhouse.

Topical application was used for all bioassays. For adults, a 1 μl droplet of imidacloprid solution in acetone was applied to the underside of the abdomen of each beetle. Doses were chosen based on preliminary tests to give a range of 0 to 100% mortality. For each test, five or six doses plus a control were replicated at least three times with 10 beetles per replicate. All treated beetles were placed in petri dishes with fresh potato foliage and kept at 25±1°C and L:D 16:8. Intoxication was evaluated 1, 3, and 7 days after treatment. Beetles were recorded as alive, affected, or dead. Affected beetles were unable to walk forward one body length, or unable to grasp the tip of a pencil with all 6 legs and walk up the pencil. Dead beetles did not move even if their legs were pinched and had shrunken abdomens and dark elytra. For larvae, 4-day-old second instars weighing 5.5 ± 0.3 mg per larva were used. Droplets (0.22 μl) of acetone solutions of imidacloprid were applied to the top of the abdomen of each larva. Mortality was assessed 3 days after treatment. Data were analyzed by probit analysis (Finney 1971). No overlap between the 95% fiducial limits (FL) of LD_{50} (dose lethal to 50% of the test population) was used as the criterion for a significant difference ($P<0.05$).

To investigate the inheritance of imidacloprid resistance, the LI and UP strains were reciprocally crossed in pair-by-pair matings to produce the F_1 offspring. Newly emerged virgin females and males of each strain were kept individually until use. One male and one female were paired in plastic cups and fed with potato leaves. There were 20 pairs for each of the reciprocal crosses. Progeny (F_1) from each cross (LI female x UP male and UP female x LI male) were tested. Ten pairs of back crosses between F_1 males and UP females were done to determine whether resistance was inherited as a monogenic or polygenic trait.

In synergism tests, PBO or DEF was applied by topical application 1 hour prior to imidacloprid bioassay. Based on preliminary tests, the doses of PBO and DEF were 1 μg of either per adult, and 5 ng or 20 ng per larva, respectively. Other methods were the same as above.

The resistance ratio (LD_{50} for LI strain to imidacloprid compared with the LD_{50} for UP strain) of adult LI potato beetles was 100.8, 7 days after treatment (Table 1). For larvae, the resistance ratio of the LI strain (LD_{50} for the LI strain larvae compared with the LD_{50} for the UP strain) was 13.2, 3 days after treatment.

Table 1. Toxicity of imidacloprid to susceptible (UP) and resistant (LI) Colorado potato beetle adults and larvae

Adults	**(LD_{50}; μg per beetle)**	**Resistance Ratio[a]**
UP	0.024 (0.018-0.031)	-------
LI	2.422 (1.581-3.710)	100.8
Larvae	**(LD_{50}; ng per larva)**	**Resistance Ratio[a]**
UP	0.60 (0.40-0.92)	-------
LI	7.91 (5.23-12.00)	13.2
F1 offspring	**(LD_{50}; μg per beetle)**	**Resistance Ratio[a]**
LI x UP	0.184 (0.118-0.285)	7.5
UP x LI	0.191 (0.127-0.288)	7.9

[a] Resistance ratio (LD_{50} of R strain/ LD_{50} of S strain)

In all of the bioassays on adults in this study, some recovery from initial intoxication (1 day after treatment) occurred in the UP, LI and F_1 strains by 3 and

7 days after treatment. However, the number of beetles recovering from intoxication depended on the strain, dose of imidacloprid, pretreatment with synergist, and days after treatment. Bioassays with small larvae do not show this recovery, likely because second instars cannot survive 3 days or more without feeding.

No significant differences in LD_{50} values were observed between the progeny of the two reciprocal crosses (Table 1). Analysis of probit lines from F_1 reciprocal crosses indicated that resistance to imidacloprid was inherited autosomaly in an incompletely recessive manner. The X^2 analysis of response ratio statistics from F_1 x S back crosses 7 days after treatment compared to a monogenic model showed significant deviation between observed and expected responses . This indicates that more than one locus may be responsible for resistance to imidacloprid in Colorado potato beetle.

PBO and DEF did not significantly synergize imidacloprid activity in the UP strain; 95% FL of LD_{50} values overlapped for beetles with and without synergist (Table 2). In the LI strain, pretreatment with synergist decreased the resistance ratios from 110.8 to 20.0 with PBO and from 110.8 to 40.7 with DEF, 3 days after treatment. The synergistic ratios (ratio of LD_{50} values with and without the synergist) were 6.0 with PBO and 2.6 with DEF. However, 7 days after treatment there was no significant synergism with PBO or DEF (95% FL for LD_{50} values with and without synergist overlapped); this is because some beetles treated with the synergists recovered from intoxication between 3 and 7 days after treatment. There may be other resistance factors involved or the amount of synergist used may have been too low to fully block detoxification. The apparent delayed detoxification activity would be expected if mixed-function oxidase activity had been reduced but not eliminated by synergists.

In the F_1 strain, pretreatment of resistant beetles with PBO showed significant synergistic effects both 3 and 7 days after treatment (Table 2). Synergism ratios were 6.5, 3 days after treatment, and 7.6, 7 days after treatment. For the F_1 strain, no significant synergism was observed with DEF.

Table 2. Toxicity of imidacloprid to adults of UP, LI and F_1 (UP x LI) strains of the Colorado potato beetle with and without synergists

Strain	Synergist	LD_{50} (95%FL) (μg/beetle)	Resistance ratio [a]	Synergism ratio [b]
7 days after treatment				
UP	--	0.024 (0.018-0.031)	--	--
	PBO	0.019 (0.011-0.033)	--	1.3
	DEF	0.025 (0.016-0.038)	--	0.9
LI	--	2.422 (1.581-3.710)	100.8	--
	PBO	1.059 (0.309-3.627)	62.9	1.6
	DEF	1.507 (1.010-2.249)	62.9	1.6
UP x LI	--	0.191 (0.127-0.288)	7.9	--
UP x LI	PBO	0.025 (0.014-0.045)	1.0	7.6 [d]
LI x UP	--	0.184 (0.118-0.285)	7.5	--
LI x UP	DEF	0.139 (0.073-0.263)	6.7	1.2

[a] LD50 of LI strain/ LD50 of S strain

[b] LD50 without synergist / LD50 with synergist

[c] $p > 0.10$ for all _[2] values (data do not differ significantly from log probit line)

[d] LD50 significant lower than without synergism

For larvae, PBO significantly synergized activity of imidacloprid in the R strain with a ratio of 2.3 (Table 3). DEF had no significant synergistic activity for larvae of S or R strains.

Table 3. Toxicity of imidacloprid to larvae of susceptible (UP) and resistant (LI) strains of the Colorado potato beetle with and without synergists

Strain	Synergist	LD_{50} (95%FL) (ng/larva)	Resistance ratio [a]	Synergism ratio [b]
UP	None	0.60 (0.40-0.92)	--	--
	PBO	0.47 (0.35-0.63)	--	1.3
	DEF	0.58 (0.41-0.83)	--	1.0
LI	None	7.91 (5.23-12.0)	13.2	--
	PBO	3.41 (2.28-5.10) [d]	7.3	2.3
	DEF	7.42 (4.85-11.4)	12.8	1.1

Our results suggest that elevated mixed-function oxidase mediated detoxification is involved in resistance to imidacloprid in Colorado potato beetle adults, and probably is the most important factor. Esterase-based detoxification appears to be an additional factor in this resistance. Mixed-function oxidase mediated detoxification is probably the primary resistance mechanism in the larvae. Since the synergists used did not completely eliminate the resistance, there may also be other mechanisms responsible.

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

Admire® and Provado® (imidacloprid) were used extensively for Colorado potato beetle control throughout Michigan and the northeastern and north central U.S. again in 1998. Overall, it continued to provide excellent control. However, because of intensive use over the past four years, concerns about resistance developing in Colorado potato beetle are increased.

During 1998, 14 populations of Colorado potato beetle (3 laboratory populations, 6 Michigan populations, and 5 populations from other states) were assayed for resistance to Admire.

Adult Colorado potato beetles were obtained from laboratory populations, or were collected in the field. Potato beetles were either stored at room temperature (25° C) and were fed potato foliage daily, or, for longer term storage, were kept in a controlled environment chamber (11 °C) and were fed weekly. Prior to each bioassay, beetles to be tested were combined in one container, and then were randomly assigned to treatments.

Colorado potato beetle adults were treated with 1 μl of acetone/ insecticide solution of known concentration. Solutions were applied to the first abdominal sternite. Potato beetles were then placed in petri dishes lined with filter paper and were fed fresh potato foliage. Foliage and filter paper was checked daily and changed as needed. Petri dishes were kept at 25 °C (± 1).

Each population was first screened to determine relative susceptibility to Admire by testing 10 beetles each with three concentrations of solution (plus an acetone control). Based on results of this screen, a range of five concentrations, plus an acetone control, was selected for each population for bioassays. Each bioassay was replicated three times, using three different serial dilutions, each made at a different time. Within each replication, from 12-18 beetles were treated with each concentration (4-6 beetles per petri dish/3 petri dishes per concentration).

The effect of treatment was assessed 7 and 10 days after treatment. A potato beetle was classified as "dead" if its abdomen was sunken, it did not move when it's legs were pinched and its elytra was dark. Dead beetles were removed from the petri dish. A potato beetle was classified as "walking" (i.e., unaffected) if it was able to walk forward normally and its antennae were visible when walking. A potato beetle was classified as "poisoned" if it was unable to walk forward normally 1 body length, its antennae were not visible and its legs were extended.

All data were analyzed by probit analysis (Finney 1971), using Polo PC.

LD_{50}'s at 7 and 10 days after treatment are shown in Table 4. Bioassays of one population (Wisconsin) resulted in a very large Chi-square value ($P<0.05$), indicating a poor fit of the probit line. Control mortality in the Oregon (OR) population exceeded 20%, 10 days after treatment so probit analysis was not done. LD_{50}'s of field-collected Colorado potato beetles 7 days after treatment ranged from 0.028 μg per beetle (MN-2) to 0.134 μg per beetle (MI-6).

Table 4. LD_{50} values (μg/ beetle)and 95% confidence limits of Colorado potato beetle populations in response to imidacloprid

	7 days after treatment		10 days after treatment	
	LD_{50} (μg/beetle)	(95% Confidence Limits)	LD_{50} (μg/beetle)	(95% Confidence Limits)
Michigan Field		**Strains**		
MI-1	0.083	(0.053-- 0.151)	0.101	(0.056-- 0.276)
MI-2	0.034	(0.021-- 0.050)	0.046	(0.036-- 0.061)
MI-3	0.083	(0.061-- 0.109)	0.083	(0.061-- 0.109)
MI-4	0.068	(0.056-- 0.080)	0.065	(0.053-- 0.078)
MI-5	0.035	(0.019-- 0.049)	0.040	(0.023-- 0.057)
MI-6	0.134		0.144	(0.086-- 0.205)
Laboratory Strains				
LI	1.952	(1.060-- 2.814)	2.820	(1.230-- 5.163)
MIR	0.132	(0.082-- 0.354)	0.132	(0.100-- 0.195)
UP	0.071	(0.045-- 0.222)*	0.083	(0.052-- 0.278)*
Out of State Field		**Strains**		
NY	0.124	(0.082-- 0.197)	0.135	(0.106-- 0.175)
OR	0.040	(0.024-- 0.050)*	not analyzed***	
MN-1	0.045	(0.019-- 0.077)	0.062	(0.041-- 0.081)
MN-2	0.028	(0.017-- 0.036)	0.025	(0.009-- 0.035)
WI	0.087**		0.106	(0.061-- 0.326)

*90% Confidence Limits are given
** Chi-Square value P<0.05
*** Control mortality > 20%

Although the LD_{50}'s of most field-collected populations did not differ significantly (overlapping 95% confidence limits), the LD_{50}'s of some populations did. For example, The LD_{50}'s of MN-2, MI-2 and MI-5, 7 days after treatment were significantly lower than LD_{50}'s of NY, MI-1, MI-3, and MI-4. LD_{50}'s of the laboratory strains were higher. As expected, the LD_{50} of the LI (resistant) laboratory strain was 1.952 μg per beetle, 7 days after treatment, nearly 16 times the LD_{50} of the least susceptible field-collected NY and 70 times the LD_{50} of the most susceptible field-collected strain MN-2. The LD_{50} of the Michigan resistant laboratory strain (MIR) was 0.132 μg per beetle 7 days after treatment. This is similar to previous LD_{50} values obtained for this population. The LD_{50} for the susceptible UP strain was 0.071 μg per beetle. This was different from previous values for this strain, perhaps indicating some "contamination" with resistant beetles during the rearing process.

In 1997, 3 out of 10 Colorado potato beetle populations collected from Michigan potato fields were found to have a low level of resistance to Admire, as defined by less than 70% of the beetles being affected by a dose of 0.1 μg per beetle. In 1998, three out of six Michigan populations (MI-1, MI-3, and MI-6) were also found to have a low level of resistance to Admire, using this same criteria (Figure 1) . This was also found in the population from NY and the population from Wisconsin.

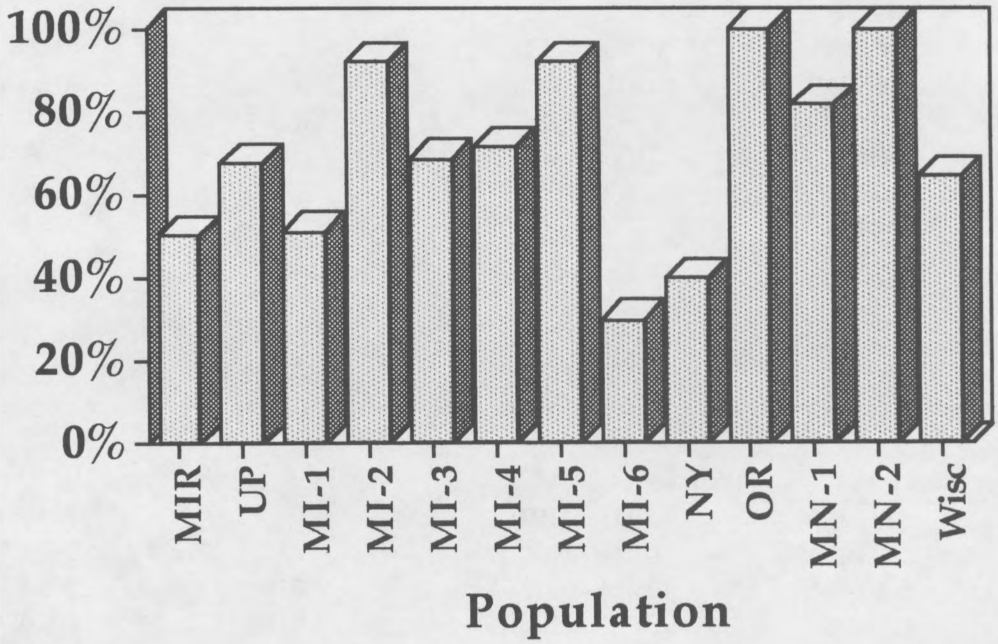

Figure 1. Percent of Colorado potato beetles poisoned or killed by being treated with 0.1 μg Admire. 1998.

We also performed bioassays on all of the Colorado potato beetle populations to determine the LD_{50}'s for CGA 293343, an experimental insecticide from Novartis. Admire LD_{50}'s were higher than LD_{50}'s for CGA 293343 in most populations. The range of values was greater for Admire than for CGA 293343. Colorado potato beetle populations with the highest LD_{50} for Admire also tended to have higher LD_{50}'s for CGA 293343, while populations with the lowest LD_{50}'s for Admire tended to have lower LD_{50} values for CGA 293343.

Admire poisoning in Colorado potato beetle and predation by ground beetles. Colorado potato beetles with low-levels of resistance to Admire often succumb to initial exposure and are knocked off the plant and show signs of poisoning for several days, before recovering. We tested whether these poisoned beetles would be vulnerable to predation in the field, and, if so, would consumption of poisoned potato beetles affect predators.

Colorado potato beetles from a laboratory strain showing low levels of resistance to Admire (MIR, LD_{50} = was 0.132 μg) were treated in the laboratory with 0.2 μg of imidacloprid applied to the first abdominal sternite. After 2 h, potato beetles showing symptoms of poisoning were placed in the bottom of a 100 x 15 mm plastic petri dish lined with filter paper (5 beetles per dish). Half of the dishes were left uncovered, and the other half were placed inside a nylon "knee-high" stocking, which was stretched over the petri dish and tied with a knot.

One pair of petri dishes (covered and uncovered) was placed in each of 10 different locations in a potato field at the MSU Montcalm Potato Research Farm and the MSU Muck Research Farm. Dishes were left overnight and were collected the next day. Dishes were brought back to the lab and the beetles left in each dish were counted and classified as "walking", "poisoned" or "dead" (see section above for classification criteria). Petri dishes containing poisoned potato beetles were set out at the both locations on 23, 28 and 30 July, and were collected the following day.

To collect potential predators of Colorado potato beetles, 10 pitfall traps were placed in 10 different locations at the Montcalm Potato Research Farm and MSU Muck Research Farm on 23 July. Traps were checked regularly from 24 July to 11 August. Ground beetles captured in pitfall traps were placed individually in petri dishes and were provided with either a Colorado potato beetle that had been poisoned by treating it with 0.2 μg of Admire, or an untreated potato beetle. Ground beetles were grouped by general appearance, and about half of each type were provided with poisoned potato beetles, the other half were provided with untreated beetles. Petri dishes were checked periodically, any mortality of either the Colorado potato beetle or ground beetle and any evidence of predation was recorded.

All of the Colorado potato beetles placed in the covered petri dishes were still found in the dish the day after being set out (Table 5). Of these, only a small percentage had recovered from poisoning (3, or 6% at Montcalm, 2.3, or 4.6% at the Muck Farm). The remainder were either still showing symptoms of poisoning, or were dead. Assuming the same percentage of potato beetles in the uncovered petri dish had recovered and had climbed out of the dish and walked away, between 46 to 50 of the beetles should still remaining in the uncovered dish. Instead, we found many fewer potato beetles remaining in the uncovered dish (31.7, or 63.3% at Montcalm, 64.7, or 32.3% at the Muck Farm). These results suggest that up to 30% of poisoned potato beetles were consumed by predators at each site in one night.

Table 5. Number of Colorado potato beetles remaining in petri dishes (open and covered with nylon stocking).

Date	Montcalm			Muck Farm		
	Not Covered	Covered		Not Covered	Covered	
		Walking	Poisoned & Dead		Walking	Poisoned & Dead
July 23	33 66%	3 6%	47 94%	27 54%	3 6%	47 94%
July 28	31 62%	3 6%	47 94%	41 82%	0 0%	50 100%
July 30	31 62%	3 6%	47 94%	29 58%	4 8%	46 92%
Mean	31.7 63.3%	3 6%	47 94%	32.3 64.7%	2.3 4.6%	47.7 95.4%

If predators consume a number of poisoned beetles, is there any impact of the poisoning on these predators. We collected a number of different ground beetles in pitfall traps. Some of these ground beetles consumed the Colorado potato beetles we provided, both poisoned and untreated. A small number of ground beetles that consumed poisoned beetles showed some symptoms of Admire poisoning. These studies are continuing.

The implications of these findings are considerable. If Colorado potato beetles with low levels of resistance to Admire are consumed by predators before they are able to recover and resume feeding and reproducing, then the development of resistance may be slowed. On the other hand, if consumption of poisoned potato beetles affects ground beetles, then the predator population may be reduced.

Resistance to Admire in Colorado potato beetles and length of control.
Low levels of resistance to Admire were present in our laboratory strains of Colorado potato beetle and in field populations. Such low levels would not result in potato beetles surviving on Admire-treated plants early in the season, when the level of Admire in the plant was high. However, as the potato plant grows and the level of Admire in it declines, Colorado potato beetles with low levels of resistance would be able to survive 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.

We tested this idea by feeding Admire-treated potato foliage to laboratory strains of Colorado potato beetle (differing in resistance level), at two-week intervals after planting. We did three separate tests, one using potatoes planted at the MSU Montcalm Research Farm, one using potatoes planted at the MSU Muck Research Farm, and the final test using potted potatoes planted in the greenhouse.

Three different laboratory strains of Colorado potato beetles were used for testing, LI (LD_{50} 1.952), MIR (LD_{50} 0.132 and UP (LD_{50} 0.071). Potato leaves were snipped from plants (Admire-treated or untreated) and the petiole was placed in a water pick, which was then placed in a hole made in the bottom of a 12 oz wax drinking cup so that the potato foliage extended into the cup and the vial hung outside of the cup. Cups were placed in a PVC frame. Untreated foliage was added to half of the cups first, using gloves, the gloves were changed, then Admire-treated foliage was added to the remainder of the cups. Five Colorado potato beetles of either the LI, MIR or UP strains were added to each cup. There were 8 cups, 40 potato beetles total, for each strain and foliage type.

Defoliation was assessed and all foliage was replaced, on days 3, 7, and 10 of the experiment (see below). Newly-collected foliage was used to replace existing foliage. Colorado potato beetle poisoning was assessed on day 7 and day 14 by removing them from the wax cups, and placing them in petri dishes for 30 minutes, after which time they were classified as walking, poisoned, or dead (see previous section for classification criteria). On day 7, dead beetles were removed, and the rest were placed back in the cups with fresh foliage.

Field Testing

Potatoes ('Snowden') were planted at the MSU Montcalm Potato Research Farm on 15 May and at the MSU Muck Research Farm on 21 May. Some of them were treated with Admire (0.9 fl oz/1000 ft) at planting and some were left untreated.

Foliage was collected from a number of different locations in Admire-treated plots and a number of different locations in untreated plots. Care was taken to pick leaves from different positions on the potato plant. Gloves were used to collect the foliage, and the gloves were changed between collecting from Admire-treated plants and untreated plants. Foliage was transported back to the lab in an ice-filled cooler.

Foliage was collected from the Montcalm Potato Research Farm on June 16 and the experiment was set up the same day (33 days after planting). Foliage was collected on 29 Jun and the experiment was set up the following day (30 Jun, 47 days after planting). Foliage was collected from the Muck Farm on 22 Jun and the experiment was set up the following day (33 days after planting). Foliage was again collected on 7 Jul (47 days after planting) and the experiment was set up the same day.

Greenhouse Potted Potato Plants:
Potato seed was cut on 12 Oct. Seed pieces were then placed into 6 in. pots on 14 Oct. Half were treated with the field rate (0.9 fl oz/1,000 ft, 30 gpa) of Admire (4.9 ml of Admire/water solution was applied to each seed piece using a pipette). The other seed pieces were left untreated as a check. The first experiment was started on 16 Nov (33 days after planting). The experiment was repeated on 1 Dec (47 days after planting), and at on 15 Dec (61 days after planting). Foliage was collected from plants ca 1 h before each experiment was set up.

In general, more UP Colorado potato beetles were affected by feeding on Admire-treated foliage than were LI or MIR beetles fed the same foliage. However, a large proportion of potato beetles fed untreated foliage died, and this complicates interpretation of results. We are continuing to perfect the methodology in order to reduce control mortality. Experiments will be repeated once this is achieved.

Efficacy of registered and new insecticides for control of Colorado potato beetle and potato leafhopper.
Colorado potato beetle control.
Fourteen insecticides were tested at the MSU Montcalm Research Farm, Entrican, MI, for control of Colorado potato beetle. 'Snowden' potatoes were planted 12 in apart with a 34 in row spacing on 15 May. Treatments were replicated four times in a randomized complete block design (except for Admire and check, which were only replicated three times). Plots were 50 feet long and were three rows wide. Adjacent plots were separated by 68 in of bare ground. Eight treatments were applied at planting: Admire, CGA 293343 (low rate), and CGA 293343 (high rate) were all sprayed to seed pieces in furrow using a single nozzle hand held boom (at 30 gpa, 35psi); Gaucho 1.54, Gaucho 2.0, Maxim, Maxim plus Adage were all pre-mixed dust applications applied to seed pieces (in a plastic tub) before they were planted in furrow. The eighth treatment applied at planting was Maxim (dust applied to seed pieces as described above) followed by CGA 293343 as an in furrow spray. Foliar sprays included: Agrimek and Agenda, applied on 16 Jun and 1 Jul, and Capsyn, CGA 293343, and both rates of Alert applied on 16 and 23 Jun and 1 Jul. Maintenance sprays of Agrimek were applied to all treatments to control second generation Colorado potato beetle. On 27 Aug the middle row of each plot was harvested. The tubers were separated by size and weighed. Data were analyzed using a two-way ANOVA and significance was found at the 0.05 level with Fisher's Protected LSD.

Colorado potato beetle numbers were moderate. Most treatments resulted in significant control of Colorado potato beetle, as compared with untreated plots (Table 6). All treatments except Capsyn and the fungicide Maxim resulted in significantly lower numbers of large Colorado potato beetle larvae than the check on 25 Jun and 2 Jul. Likewise, yields in all treatments but Capsyn and Maxim were higher than in untreated plots (Table 7).

Table 6. Mean number of Colorado potato beetle larvae per plant on three different sampling dates.

Treatment	Rate	Mean Number of Colorado potato beetle larvae per plant (± S.E.) June 18	June 25	July 2
Admire[ac]	0.9 fl oz/1000ft	0.0±0.0	0.0±0.0a	0.0±0.0a
Agenda	0.05 lb AI/acre	0.0±0.0	0.3±0.2a	0.1±0.1a
Agrimek	8 fl oz form/acre	0.0±0.0	0.6±0.4a	0.6±0.4a
Alert High	0.2 lb AI/acre	0.0±0.0	0.0±0.0a	0.1±0.1a
Alert Low	0.1 lb AI/acre	0.0±0.0	0.3±0.2a	0.2±0.2a
Capsyn + M-Pede	1.1 +2.2 liter per acre	0.0±0.0	16.9±5.3c	3.7±1.0b
CGA 293343 2SC high[a]	1.0 g AI/100m	0.0±0.0	0.0±0.0a	0.0±0.0a
CGA 293343 2SC low[a]	0.5 g AI/100m	0.0±0.0	0.0±0.0a	0.0±0.0a
CGA 293343 foliar	8.7 oz form/acre	0.0±0.0	0.0±0.0a	0.0±0.0a
Gaucho 1.54 DS[b]	8.0 oz /cwt	0.0±0.0	0.0±0.0a	0.1±0.1a
Gaucho 2.0 DS[b]	8.0 oz /cwt	0.0±0.0	0.0±0.0a	0.3±0.3a
Maxim[b]	8.0 oz /cwt	0.0±0.0	12.9±4.4c	10.2±2.1c
Maxim[b] + Adage[b]	8.0 oz /cwt	0.0±0.0	0.0±0.0a	0.0±0.0a
Maxim[b] + CGA 293343[a]	8.0 oz /cwt	0.0±0.0	0.0±0.0a	0.0±0.0a
Untreated[c]		0.0±0.0	6.3±2.7b	5.9±3.1b

[a] Treatments applied in furrow at planting.
[b] Treatments applied as a dust at planting.
[c] Treatments were only replicated three times.
Means followed by different letter are significantly different at the 0.05 level (Fisher's Protected LSD).

Table 7. Mean weight of potatoes (size A and total) harvested from plots.

Treatment	Rate	Yield of A's (mean lb/plot)	Total Yield (mean lb/plot)
Admire[ac]	0.9 fl oz/1000ft	68.6ab	73.5abc
Agenda	0.05 lb AI/acre	80.6b	87.5c
Agrimek	8 fl oz form/acre	82.1b	86.7c
Alert High	0.2 lb AI/acre	77.1b	83.8c
Alert Low	0.1 lb AI/acre	93.3bc	98.2cd
Capsyn + M-Pede	1.1 liter per acre	58.05a	63.1ab
CGA 293343 2SC high[a]	1.0 g AI/100m	96.4bc	100.3cd
CGA 293343 2SC low[a]	0.5 g AI/100m	80.0ab	88.75c
CGA 293343 foliar	8.7 oz form/acre	99.35bc	105.0cd
Gaucho 1.54 DS[b]	8..0 oz /cwt	80.3b	84.65c
Gaucho 2.0 DS[b]	8.0 oz /cwt	124.4c	129.9d
Maxim[b]	8.0 oz /cwt	75.8b	80.3abc
Maxim[b] + Adage[b]	8.0 oz /cwt	76.9ab	81.7bc
Maxim[b] + CGA 293343[a]	8.0 oz /cwt	79.45b	84.15c
Untreated[c]		56.5a	61.5a

[a] Treatments were applied in furrow at planting.
[b] Treatments were applied as a dust at planting.
[c] Treatments were only replicated three times.
Means followed by different letters are significantly different at the 0.05 level (Fisher's Protected LSD).

Potato leafhopper Control.

Insecticide trials were conducted at the MSU Montcalm Potato Research Station, Entrican, Michigan to test for control of potato leafhopper. 'Russet Burbank' Bt by Newleaf seed potatoes were planted on 27 May 1998, 8 in. within the row and 34 in. between rows. Plots were a 25 ft single row arranged in a randomized complete block design with, four replications per treatment. Adjacent plots were separated by a single row of untreated potatoes. Dust formulations (Maxim, Maxim + Adage, Gaucho 1.54 DS, and Gaucho 2.0 DS) were applied to seed pieces prior to planting in the field. Other treatments (Admire, CGA 293343 (two rates), and Temik) were applied in furrow at planting. Temik was applied by sprinkling the granular material in the furrow over the seed piece. Admire and the low and high rates of CGA 293343 were applied using a handheld single boom sprayer (35 psi, 30 gpa) applying the spray in furrow over the seed piece. Foliar treatments were applied using the same handheld single boom sprayer (35 psi, 30 gpa). Foliar applications were made on 23 and 29 Jul and 12 Aug. Insecticide effectiveness was determined by counting the total number of insects on four randomly selected plants in each replication on 24 Jul, 31 Jul, and 13 Aug. On 16 Sep the rows were harvested from each plot. Tubers were separated by size and weighed. Data were analyzed using a two- way ANOVA and significance was determined at the 0.05 level with Fisher's Protected LSD.

Leafhopper numbers were low throughout most of the season, only gradually increasing late in the season (Table 8). Except for Capsyn and the fungicide, Maxim, treatments controlled potato leafhoppers, resulting in significantly lower leafhoppers numbers per plant, as compared with the check on most sampling dates. Total yield (lb tubers per plot) was significantly higher than in check plots for all treatments except for Capsyn, Maxim, and the low and high rates of CGA 293343 applied at planting (Table 9).

Table 8. Mean number of potato leafhopper nymphs per plant on three different sampling dates.

		Mean number of potato leafhopper nymphs per plant (± standard error)		
Treatment	**Rate**	**7/24**	**7/31**	**8/13**
Admire[a]	0.9 fl oz/1000ft	0.3±0.2abc	0.0±0.0a	0.3±0.2a
CGA 293343 foliar low	25.0 g AI/ha	0.0±0.0a	0.0±0.0a	0.0±0.0a
CGA 293343 foliar high	50.0 g AI/ha	0.1±0.1ab	0.0±0.0a	0.1±0.1a
CGA 293343 low[a]	0.5 g AI/100m	0.1±0.1ab	0.0±0.0a	0.1±0.1a
CGA 293343 high[a]	1.0 g AI/100m	0.1±0.1ab	0.1±0.1ab	0.0±0.0a
Gaucho 1.54 DS[b]	8 oz prod./cwt	0.1±0.1ab	0.1±0.1ab	0.1±0.1a
Gaucho 2.0 DS[b]	8 oz prod./cwt	0.2±0.1ab	0.4±0.1 cd	3.4±1.2b
Maxim + Adage[b]	2.5 g AI/100kg 60 g AI/100kg	0.0±0.0a	0.0±0.0a	0.0±0.0a
Maxim[b] + CGA 293343[a]	2.5 g AI/100kg 0.5 g AI/100m	0.1±0.1ab	0.0±0.0a	0.6±0.1a
Maxim[b]	2.5 g AI/100kg	0.8±0.3 d	0.8±0.3 d	1.6±0.5b
Capsyn + M-Pede	2.2 liter per acre 2.2 liter per acre	0.3±0.1 bcd	0.6±0.2 cd	2.5±0.9b
Temik[a]	3 lb AI/acre	0.0±0.0a	0.1±0.1ab	0.1±0.1a
Untreated		0.6±0.2 cd	0.4±0.3 bc	2.9±0.9b

[a] Treatments were applied in furrow at planting
[b] Treatments were applied to seed as dust formulation at planting
Means followed by different letters are significantly different at the 0.05 level (Fisher's Protected LSD)

Table 9. Mean weight of potatoes (size A and total) harvested from plots.

Treatment	Rate	Yield of A's (mean lbs./plot)	Total Yield (mean lbs./plot)
Admire[a]	0.9 fl oz/1000ft	42.6±2.8 de	53.3±4.2 cd
CGA 293343 foliar low	25.0 g ai/ha	39.3±4.4abcd	52.1±3.5 bcd
CGA 293343 foliar high	50.0 g ai/ha	48.2±1.7 e	60.2±1.8 e
CGA 293343 low[a]	0.5 g ai/100m	38.5±2.2abcd	48.2±2.5abc
CGA 293343 high[a]	1.0 g ai/100m	37.5±0.0abcd	48.5±0.0abcd
Gaucho 1.54 DS[b]	8 oz prod../cwt	42.7±0.4 de	52.8±0.5 cd
Gaucho 2.0 DS[b]	8 oz prod. ./cwt	39.9±1.8 bcd	51.0±2.0 bcd
Maxim + Adage[b]	2.5 g ai/100kg 60 g ai/100kg	41.9±1.6 cd	52.3±1.4 cd
Maxim[b] + CGA 293343[a]	2.5 gai/100kg 0.5 g ai/100m	45.5±2.6 de	56.8±1.7 de
Maxim[b]	2.5 g ai/100kg	36.8±2.9abc	47.9±2.9abc
Capsyn + M-Pede	2.2 liter/ acre 2.2 liter/ acre	35.6±3.6ab	45.9±3.5ab
Temik[a]	3 lb ai/acre	45.4±2.6 de	56.5±2.6 de
Check		33.7±2.2a	44.5±1.6a

[a] treatments were applied in furrow at planting
[b] treatments were applied to seed pieces as dust before planting
Means followed by different letter are significantly different at the 0.05 level (Fisher's Protected LSD)

Funding: MPIC

RESISTANCE AND CROSS-RESISTANCE OF COLORADO POTATO BEETLE TO IMIDACLOPRID AND CLOSELY RELATED INSECTICIDES

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Justification:

In 1997, the Colorado potato beetle (CPB), *Leptinotarsa decemlineata* (Say) and green peach aphid (GPA), *Myzus persicae*, were effectively controlled by Michigan potato growers with application in furrow at planting or as foliar spray. Prior to release of this insecticides, losses attributed to CPB in Michigan were estimated at 14% gross crop value or $13 million (Grafius 1996). we estimated that over 90% of Michigan growers have used imidacloprid to control CPB in 1996, and the parent company estimated that 100% of the potato acreage in the Midwest used imidacloprid in 1997. Most of Michigan potato growers have become dependent on imidacloprid to control CPB.

Imidacloprid is a new class of insecticide, the chloronicotinyls that target the nicotinic acetylcholine receptors of insect nervous systems. Imidacloprid's mode of action is not new. Nicotine, currently a greenhouse insecticide but historically used in the fieldto control CPB, also target this receptor site (Leicht 1996). Other nicotine analogue insecticides, nereistoxins, in use for insect control include nitenpyram, acetamiprid and bensultap. In addition, DowElanco is introducing a new line of chemicals that are closely related to imidacloprid and have the same nicotine target site. Their first product, Tracer®, was introduced into cotton production in the southern US in 1977 with outstanding success. DowElanco (under a new company name in 1998) will be introducing additional products into fruit and vegetables production. This new chemistry like imidacloprid is highly effective on Colorado potato beetle and aphids. There is considerable speculation on whether these two insecticides will have cross-resistance in beetles and aphids especially since CPB has developed resistance to nereistoxins in Poland (bensultap) and is developing resistance to imidacloprid in Michigan and Long Island, NY.

We have already documented higher levels of imidacloprid resistance in field strains of CPB. Laboratory strains of CPB selected for resistance to imidacloprid are being maintained here at MSU. We have established six separate laboratory colonies of CPB collected from potato fields in Michigan, Long Island and Minnesota. The response to imidacloprid for each colony was determined with a leaf-dip bioassay and compared to the response of a susceptible laboratory colony. The LC_{50} for adults from susceptible laboratory strain was 10.5 mg IA imidacloprid/liter. The responses of all other colonies were significantly different, based on non-overlap of confidence intervals about the LC_{50} and resistance ratios ranged from 3.2 to the high of 16.0 fold in a population collected from Michigan. Imidacloprid resistance is developing in field populations of CPB in Michigan.

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 CPB with resistance to bensultap. However, the DowElanco products are much more likely to be introduced into Michigan potato production before the nereistoxins. Therefore we need to evaluate these new potential compounds for cross resistance to imidacloprid CPB strains from Michibgan potato fields. This information will give us insight on whether or not these new compounds will be the 'resistance stoppers' for imidacloprid resistant CPB.

The objectives of this study were to evaluate the levels of resistance to imidacloprid in field populations of Colorado Potato Beetle from Long Island and use the resistant populations to determine the pattern of cross resistance in imidacloprid resistant CPB populations to compounds that act at the insect nicotine acetylcholine receptor.

Progress Report:

CPB adults were collected from 6 locations (near Riverhead (LIGR) collected in 1997, and Riverhead (Rh), Jamesport (Jp), Calverton (Cv), Mattituck (Mt) and Cutchogue (Ct) collected in 1998) on Long Island, NY to determine the levels of resistance to imidacloprid and cross-resistance to compounds that act at the insect nicotine acetylcholine receptors. The approximate distance between the potato fields were 4 to 10 miles. Imidacloprid has been used to control CPB since 1995. The application of imidacloprid ranged from 1 to 4 times per season (total 6 to 10 times in 4 seasons). Long Island CPB populations and an insecticide susceptible CPB strain (S64) were maintained in isolation from each other. Technical grade insecticides (imidacloprid (Admire®), thiometoxan (Platinum®) and bensultap(Bancol®)) were diluted with acetone. Topical bioassays were performed on the adult stage. Eight to ten beetles were treated with one µl of the insecticide. Five to seven doses were used per bioassay and two to three replications were made per insecticide. Treated beetles were transferred to Petri dishes and were fed with potato leaves. Beetles that were dead or knocked down ten days after the treatment were counted as dead. The results were analyzed by probit analysis. The levels of resistance to imidacloprid in the Long Island CPB field populations range from 8 to 155 fold of the susceptible population. The LD_{50} value from the susceptible colony (S64) was 0.076 µg/beetle. The LD_{50} value of the Long Island populations were: 0.620(Rh), 2.1(Jp), 2.15(LI GR), 5.71(Cv), 10.4(Mt), and 11.81(Cg) µg/beetle. The LIGR population was maintained in our laboratory since 1997 without any exposure to imidacloprid. After raising for few geneartions free from imidacloprid, the resistance level of the LIGR did not decrease substantially. This indicates that the imidacloprid resistance is stabel.

The imidacloprid resistant CPB populations from Long Island were used to evaluate cross-resistance between imidacloprid and thiamethoxam and bensultap. The LD_{50}s in thiometoxan were 0.159 (S64), 0.228 (Rh), 0.256 (Cg), 0.270 (Jp), 0.373 (Mt), and 0.497 (LIGR) µg/beetle. The ratio of resistance were S64 1, Rh 1.4, Cg 1.6, Jp 1.7, Mt 2.3, and LIGR 3.1 fold. The LD_{50}s to bensultap were 7.1 and 11.1 µg/beetle for the susceptible (S64) and resistant LIGR populations, respectively. The LIGR population showed a very low level cross resistance between imidacloprid and thiamethoxam and no cross resistance between imidacloprid and bensultap in adult CPBs.

The results show that the continuos and intense use of imidacloprid and lack of pesticide resistant management's strategies in Long Island, NY have resulted in high levels of resistance to imidacloprid in the CPB populations. The LIGR population expresses low levels of cross-resistance between imidacloprid and thiametoxan. The results of this study alarms us to implement strategies to preserve the effectiveness of this valuable resources. Future studies are needed to evaluate cross-resistance between imidacloprid and other new compunds (such as spinosad), metabolism of imidacloprid in resistant CPB, neurophisiology of resistance to imidacloprid in CPB and the genetics inheritance of imidacloprid resistance. This information will provide methods to monitor and potentially slow down CPB resistance development to imidacloprid in Michigan.

Funding: MPIC

1998 POTATO NEMATODE RESEARCH REPORT
GEORGE W. BIRD, PROFESSOR, MICHIGAN STATE UNIVERSITY

The 1998 Potato Nematode Research Report consists of the following six projects: 1) Nematicide Trials, 2) Long-Term Potato-Early Die Management Trial, 3) Date-of-Planting Trial, 4) Potato Nematode Resistance Literature Website, 5) Potato Line Evaluation, and 6) Glucose-oxidase Transgenic Line Evaluation. The work was jointly supported by the Michigan Potato Industry Commission, United States Department of Agriculture and Michigan State University.

1998 Nematicide Trials.- Two nematicide trials were conducted at the Montcalm Potato Research Farm. The first trial was designed to evaluate eight treatments. Vapam applied two weeks before planting resulted in a tuber yield increase of 153 cwt per acre compared to the non-treated control (Table 1). The second highest yield response was associated with a new formulation, Telone C-35. Telone II applied on a broadcast basis and Temik 15G also resulted in significant (P=0.05) increases in tuber yields. Telone II (applied in-row), Mocap and Vydate did not result in statistically significant increases in tuber yeilds. Vapam applied at-planting at 1.0 gal/acre was phytotoxic, resulting in a stand reduction of about 40%. Treatment yields ranged from 190 to 370 cwt per acre. The second nematicide trial evaluated the response of three potato cultivars (Chieftain, Shepody and Russett Burbank) to Vapam applied two weeks before planting in a high risk early-die site (Table 2). Chieftain had both the highest yield in the non-fumigated site (259.8 cwt per acre), and the greatest response among the three cultivars to soil fumigation (109.2 cwt/acre).

Long-Term Potato Early-Die Management Trial.- The Long-Term Potato Early Management Trial was initiated in 1991 and is scheduled to be completed in 2000. The trial was modified significantly in 1998 to include both corn and wheat rotations in the final three years of the research project. The highest yield was produced following two years of alfalfa and the lowest yield was associated with the second year of continuous potatoes Table 3). The second highest yield was with the crop following composted buckwheat. In July, the greatest level of soil nitrate followed two years of alfalfa, and the conventional soil fertility program was generally higher than that associated with the alternative system (Table 4). This was also reflected in petiole nitrogen in both July and August. The August soil nitrate levels may be a reflection of the ability of the plant to acquire this ion. Soil pH was significantly higher in the alternative management system, and this had an impact on the detectable cation exchange capacity. Calcium appeared to be impacted by both alfalfa and the type of soil nutrient management system. The highest levels of both potassium and phosphorus were associated with the potato crop following two-years of alfalfa. The level of manganese associated with the composted buckwheat may have been greater than that associated with the other systems.

The nematode population dynamics at this site has changed significantly since the beginning of the experiment. The dominant plant-parasitic nematode is shifting from the root-lesion to the northern root-knot nematode. This may be a key observation in relation to the future of the Michigan potato industry on sandy loam soils. The 1998 information related to corn and wheat is also highly signficant. Nitrogen management under the alternative system appears to be more difficult than originally thought based on the results of the 1995-96 composted buckwheat system.

Population densities of the root-lesion nematode associated with the composted buckwheat crop and corn were significantly lower than those associated with first-year alfalfa, wheat or potato following two years of alfalfa. Population densities of the northern root-knot nematode were highest on potato and first year alfalfa. Those associated with both composted buckwheat and corn were very low.A sequence of potato early-die management plots based on what has been learned in this study will be initiated in 1999 for use as demonstration sites in 2000 and 2001.

Influence of Date-of-Planting on Potato Early-Die.- In 1997, it was observed at the Montcalm Potato Research Farm that some of the latest planted potatoes were impacted less by potato early-die than many of the earlier planting. An experiment was conducted in 1988 to evaluate the impact of date-of-planting on the incidence of potato-early-die. The trial consisted of the first and the last 1998 plantings of potato at the Montcalm Potato Research Farm, and an intermediate planting. There were no significant differences in potato tuber yields among the three planting dates at this high potato early-die risk site.

Potato Nematode Resistance Literature Website.- An interactive literature database of potato germplasm with known resistance , tolerance and susceptibility to *Pratylenchus* spp., *Meloidogyne* spp., *Verticillium* spp., *Ditylenchus destructur*, *Globodera rostochiensis* and *G. pallida* was completed in 1998. It can be accessed at

Http://nematode.ent.msu.edu/nematology.

Potato Line Evaluation for Tolerance to Potato Early-Die.- 1998 was the second year of the potato early-die component of the Federal Project. During the past year, twenty-two lines or potato varities were field evaluated in relation to their susceptibility, tolerance or resistance to potato early-die. These entries were based on symptoms of potato early-die observed at the Montcalm Potato Research Farm in 1997. One line, F349-1RY was identified as having possible resistance to potato early-die. Eight of the lines plus Chieftian exhibited possible tolerance to the disease complex. Three lines and four varieties were susceptible, and the data were inconclusive for the remaining five lines (Table 5). The results significantly expanded the initial observations made in 1997. It will, however, be necessary to repeat these results in 1999; and possibly also in 2000 for lines before a final conclusion can be made on the potential resistance, tolerance and susceptibility to potato early-die associated with this germplasm.

Glucose-oxidase Transgenic Line Evaluation.- The plantlet inoculations with *P. penetrans*, *Verticillium dahliae* and a combination of these two organisms were inconclusive on all three lines. Shading from companion potato plants in the field was also a problem. Both Spunta and the A line responded to soil fumigation in relation to plant weight, number of tubers, tuber weight and nematode population reduction. Tuber weight increase was greater for the A line than for Spunta. The B line grew very poorly under field conditions, and did not respond to soil fumigation, with the exception of root-lesion nematode population density reduction. The work will be continued in 1999 using a different potato variety and experimental protocol.

Table 1. 1998 Potato Nematicide Trial Results, Montcalm Potato Research Farm.

Nematicide (treatment)	Tuber Yield (cwt/acre)	Nematodes per 100 cm3 root tissue	
		Root-lesion	Root-knot
Nontreated Control	217.4 ab	92.4 c	0.00
Mocap	239.5 bc	14.6 ab	0.00
Vydate	260.5 bc	49.6 abc	0.00
Temik 15G (3.0 lb ai/a)	266.6 cd	1.0 a	0.00
Telone II (4 gal/a in-row)	245.6 bc	70.6 bc	0.00
Telone II (12 gal/a broadcast)	305.6 de	68.6 bc	0.00
Telone C-35 (10 gpa broadcast)	320.2 e	32.0 abc	0.00
Vapam (1.0 gal/a in-row at-plant)	190.3 a	40.0 abc	0.00
Vapam (37.5 gal/a broadcast)	370.4 f	0.4 a	0.09

Table 2. 1998 Potato Variety Fumigation Trial Results, Montcalm Potato Research Farm.

Variety (treatment)		Tuber Yield (cwt/a)
Russett Burbank		
	Vapam at 37.5 gal/a	299.9
	Non-treated Control	236.7
Shepody		
	Vapam at 37.5 gal/a	246.9
	Non-treated Control	198.4
Chieftain		
	Vapam at 37.5 gal/a	369.0
	Non-treated Control	259.8

Table 3. **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.**

Farm system	Crop								Relative Yield, U.S. No. 1 Potato Tubers[1]							
	1991	1992	1993	1994	1995	1996	1997	1998	1991	1992	1993	1994	1995	1996	1997	1998
1	Potato[2]	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	0.61
2	Alfalfa[2]	Potato[2]	Potato[2]	Potato[2]	Hairy vetch[2]	Potato[2]	Buck-wheat[2]	Potato[2]	---	**1.00**	0.54	0.34	---	0.95	---	0.77
3	Alfalfa[2]	Alfalfa[2]	Potato[2]	Potato[2]	Nematode tri-mix[2]	Oats[2]	Potato[4]	Potato[4]	---	---	**1.00**	0.57	---	---	**1.05**	0.33
4	Oats[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	Alfalfa[2]	---	---	---	**1.00**	---	---	**1.00**	---
5	Oats[2]	Potato[2]	Potato[2]	Potato[2]	Annual rye grass[2]	Oats/Red clover[2]	Potato[2]	Wheat[2]	---	0.97	0.53	0.32	---	---	0.88	---
6	Oats[2]	Soybean[2]	Alfalfa[2]	Alfalfa[2]	Potato[3]	Alfalfa[3]	Alfalfa[4]	Potato[2]	---	---	---	---	**1.00**	---	---	**1.00**
7	Oats[2]	Soybean[2]	Light red kidney beans[2]	Alfalfa[2]	Alfalfa[2]	Potato[2]	Alfalfa[4]	Alfalfa[2]	---	---	---	---	---	**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]	Corn[2]	---	---	---	---	---	**1.14**	---	---
9	Oats[2]	Soybean[2]	Light red kidney beans[2]	Green peas[2]	Potato[3]	Oil seed radish[2]	Potato[2]	Buck-wheat[4]	---	---	---	---	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]	Potato[4]	---	---	---	---	---	**1.35**	---	0.86

[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, and in 1996 and 1997 when situations of over-yielding existed.

[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 4. 1998 Long-Term Potato Early-Die Management Trial Results.

No.	Farming system	7/24/98		Yield (cwt/A)	Soil N (ppm)		Petiole N (ppm)		pH	CEC	Nutrients (ppm)							
		Pp	Mh		7/14	8/5	7/14	8/5			Ca	K	P	Mg	Mn	Fe	Zn	Ca
CONVENTIONAL:																		
1.	P,P,P	52	739	84	12.7	17.2	1500	1684	5.7 a	2.6 a	285	79	205	35	10	38	1.0	1.0
2.	P,B,P	85	840	105	14.0	12.8	1475	1674	6.1 a	2.8 a	285	73	180	49	10	35	1.0	1.0
6.	A,A,P	132	184	137	14.2	13.8	1700	2133	7.0 b	4.6 bc	571	100	235	35	11	34	2.0	1.0
4.	A,P,A	129	1103	—	—	—	—	—	5.9 a	2.9 ab	—	—	—	—	—	—	—	—
7.	P,A,A	47	666	—	—	—	—	—	7.1 b	4.8 c	—	—	—	—	—	—	—	—
5.	O,P,W	176	203	—	—	—	—	—	5.9 a	2.8 a	—	—	—	—	—	—	—	—
8.	P,OSR,C	28	5	—	—	—	—	—	7.1 b	4.0 abc	—	—	—	—	—	—	—	—
ALTERNATIVE																		
3.	O,P,P	59	805	43	11.5	17.4	1625	1565	6.8 b	3.6 abc	524	68	165	25	11	32	2.0	1.0
9.	OSR,P,B	6	0.6	—	—	—	—	—	6.1 a	3.2 abc	—	—	—	—	—	—	—	—
10.	P,B,P	81	1026	120	9.8	13.2	1290	1411	7.2 b	4.2 abc	720	79	184	30	14	36	2.0	1.0

Table 5. Results of the 1997 and 1998 Potato Early-Die Tolerance Research.[1]

1997.

Possible Tolerance	Susceptible
Chieftian	Atlantic
	Onaway
	Russett Burbank
	Russet Norkotah
	Shepody
	Snowden

1998

Possible Resistance	Possible Tolerance	Susceptible	Inconclusive
F349-1RY	E226-4Y	E018-1	B107-1
	E228-1	F-313-3	C103-2
	E-228-11	E149-5Y	E026-B
	F373-8	Russett Burbank	E030-4
	G104-6	Reddale	E033-1RD
	G119-1R	Shepody	
	MSB107-1[1]	Superior	
	E048-2Y[1]		
	Chieftian		

[1] Results based on tuber yield and nemtode reproduction in both fumigated and non-fumigated field sites.

Funding: Industry

Chemical Control of Potato Late Blight 1998

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INTRODUCTION

Potato late blight (*Phytophthora infestans*) is the most important potato pathogen in Michigan. For four years in succession, successful epidemics have been established at the Michigan State University Experimental Research Farm, Bath, MI. In 1998, several foliar fungicide effieacy 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) were planted at the Michigan State University Muck Soils Experimental Station, Bath, MI on 26 May 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 unplanted row. Plots were irrigated as needed with sprinklers and were hilled immediately before sprays began. All plots, unless otherwise stated, were inoculated (100 ml/25-foot row) with a zoospore suspension of *Phytophthora infestans* US8 biotype (insensitive to metalaxyl, A2 mating type) at 10^3 spores/ml on 23 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 5 Jun), two applications of Basagran (2 pt/A on 15 Jun and 5 Jul) and one application of Poast (1.5 pt/A on 23 Jul). Insects were controlled with applications of Admire 2F (20 fl oz/A at planting on 26 June), Sevin 80S (1.25 lb on 1 and 23 Jul), Thiodan 3EC (2.33 pt/A on 1 and 21 Aug) and Pounce 3.2EC (8 oz/A on 23 Jul). Plots were rated visually for percentage foliar area affected by late blight on 23, 31 Jul, 7, 14 and 23 Aug and for percentage green leaf area on 2 Sep. The relative area under the disease progress curve was calculated for each treatment. Vines were killed with Diquat 2EC (1 pt/A on 10 Sep). Plots were harvested between 5 and 10 Oct. and individual treatments were weighed and graded.

Results (general)

Late blight developed rapidly during August and untreated controls reached 85 - 95% foliar infection by 14 Aug. *Botrytis cinerea* and *Alternaria solani* developed during the last week of August, and potato plants in some treatments were severely infected. 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 were low in 1998 due to high temperatures that were responsible for a second period of tuber initiation. No significant tuber rot was detected 90 days after storage in any treatment.

General Conclusion

Under the conditions experienced at the research farm in 1998, 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 Quadris 80WDG ± Bond, Bravo WS 6SC and Terranil WS 6SC applied as a protectant strategy.

Introduction

Quadris 80WDG contains azoxystrobin and is due to be registered for use as a late blight and early blight fungicide in 1999. This trial compared different dose rates of Quadris 80WDG ± Bond in alternation with Bravo WS 6SC for the first six applications then the season was completed with Bravo WS 6SC. Two formulations of chlorothalonil (Bravo WS 6SC and Terranil WS 6SC) were compared and a program where Terranil WS 6SC was alternated season long with Manzate 75DF.

Foliar disease (Table 1)

All fungicide programs with seven-day application intervals reduced the level of late blight foliar infection significantly compared to the untreated control. The programs with the least amount of late blight (percentage final foliar disease and RAUDPC) and most green leaf area at the end of the season were Quadris 80WDG with and without Bond alternated with Bravo WS 6SC, Bravo WS 6SC and Terranil WS 6SC. No dose response was observed in the Quadris 80WDG alternated with Bravo WS 6SC programs and the addition of Bond to Quadris 80WDG did not affect disease control. The program alternating Terranil WS 6SC with Manzate75DF had three times as much foliar late blight than the Bravo WS 6SC standard. Phytotoxicity was not noted in any of the treatments

Yield and Tuber disease

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

Conclusions and Recommendations

Quadris 80WDG applied at 0.31 lb/acre should be recommended as an effective fungicide applied early within protectant protection programs in alternation with an appropriate residual fungicide for the control of foliar late blight.

The addition of Bond to Quadris 80WDG applied at 0.31 lb/acre is unnecessary for effective control of foliar late blight.

Terranil WS 6SC and Bravo WS 6SC should continue to be recommended for effective control of foliar late blight.

The alternating program of Manzate 75DF and Terranil 75DF should be recommended for late blight control under conditions considered less conducive for 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 1.

Treatment and rate/acre	final foliar disease (%) 32 dai [1]	green leaf area (%) 42 dai [2]	RAUDPC max = 100 0 - 32 dai[3]	Yield (cwt/acre)		% rotted tubers 90 das[4]
				US1	Total	
Quadris 80WDG 0.31lb + Bond 0.13 pt (A,C,E)[5].... Bravo WS 6SC 1.5 pt (B,D,F,G,H,I)	8.5 a[6]	60.0 a	2.0 a	100 a	223 a	0 a
Quadris 80WDG 0.46 lb + Bond 0.13 pt (A,C,E).... Bravo WS 6SC 1.5 pt (B,D,F,G,H,I)	14.3 a	56.3 a	3.5 a	110 a	248 a	0 a
Quadris 80WDG 0.31lb (A,C,E)............................ Bravo WS 6SC 1.5 pt (B,D,F,G,H,I)	6.5 a	73.8 a	1.5 a	121 a	264 a	0 a
Quadris 80WDG 0.46 lb (A,C,E)............................ Bravo WS 6SC 1.5 pt (B,D,F,G,H,I)	10.0 a	73.8 a	2.2 a	149 a	305 a	2.5 a
Bravo WS 6SC 1.5 pt (A,C,E,G,H,I)........................ Quadris 80 WDG 0.31 lb (B,D,F)	8.3 a	68.8 a	2.0 a	148 a	286 a	0 a
Bravo WS 6SC 1.5 pt (A,C,E,G,H,I)........................ Quadris 80 WDG 0.46 lb (B,D,F)	6.0 a	76.3 a	2.0 a	109 a	248 a	0 a
Bravo WS 6SC 1.5 pt (A,B,C,D,E,F,G,H,I)............	7.5 a	73.8 a	2.0 a	124 a	297 a	0 a
Terranil WS 6SC 1.5 pt (A,B,C,D,E,F,G,H,I)..........	11.3 a	61.3 a	3.0 a	142 a	267 a	0 a
Terranil WS 6SC 1.5 pt (A,C,E,G,I)...................... Manzate 75DF 2.0 lb (B,D,F,H)	22.0 a	56.3 a	4.0 a	110 a	243 a	0 a
Untreated..	98.8 b	1.3 b	25.2 b	98 a	270 a	1 a

[1] Days after inoculation with *Phytophthora infestans*, US8, A2

[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.

[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight

[4] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development

[5] Application dates: A= 23 Jun; B= 1 Jul; C= 8 Jul; D= 15 Jul; E= 22 Jul; F= 30 Jul; G= 7 Aug; H= 14 Aug; I= 21 Aug.

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

Trial 2. Comparison of control of potato late blight (*Phytophthora infestans*) attained with Bravo ZN + Champ formulations, Ridomil Gold and reduced application rate Tattoo C programs applied as a protectant strategies and Ridomil Gold and Tattoo C applied to the soil.

Introduction

Agtrol are introducing a new formulation (DF) of Champ and in this trial tested an inreased dose rate in combination with Bravo ZN. Ridomil Gold is recommended in Michigan for the control of tuber pathogens such as pink rot and Pythium leak. Soil applications of Ridomil Gold and Tattoo C were tested in this trial along with the more traditional application recommendations for both products. In addition, a comparison of Tattoo C, applied at full and half the recommended rate was tested.

Additional Methods

Ridomil 2EC was applied to the soil and incorporated at planting in that treatment only. Tattoo C 6.35SC was applied to the soil at hilling on 5 Jun in that treatment only.

Foliar disease (Table 2)

All fungicide programs with seven-day application intervals reduced the level of late blight foliar infection significantly compared to the untreated. All programs had a low amount of late blight (percentage final foliar disease and RAUDPC) and retained a high amount of green leaf area at the end of the season.. Phytotoxicity was not noted in any of the treatments.

Yield and Tuber disease

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

Conclusions and Recommendations

The increasing rate program of Bravo ZN + Champ FL or DF should be recommended as an effective fungicide combination for the control of foliar late blight.

The inclusion of Ridomil Gold EC + Bravo WS 6SC in preventative strategies should continue to be recommended for effective control of foliar late blight.

The application of either Tattoo C or Ridomil Gold to the soil neither improved nor detracted from late blight control however the effect of these soil applications on tuber disease could not be assessed due to low levels of tuber infection in stored tubers.

Tattoo C applied at half rate gave similar control to the full rate application when applied twice a) immediately prior to canopy closure and b) 14 days later and a half rate of Tattoo C could therefore be recommended as an effective fungicide for the control of foliar 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 2.

Treatment and rate/acre	% final foliar disease 32 dai[1]	% green leaf area [2] 42 dai	RAUDPC max = 100 0 - 32 dai[3]	Yield (cwt/acre)		% rotted tubers 90 das[4]
				US1	Total	
Bravo ZN 6SC1.8 pt +Champ FL 2.0 pt (C,D)[5] .... Bravo ZN 6SC2.0 pt + Champ FL 2.67 pt (E,F,G,H,I,J,K)	7.3 a[6]	70.0 a	2.5 a	149 a	279 a	0 a
Bravo ZN 6SC1.8 pt +Champ DF 2.0 lb (C,D).................... Bravo ZN 6SC2.0 pt + Champ DF 2.67 lb (E,F,G,H,I,J,K)	6.5 a	73.8 a	2.3 a	139 a	285 a	0 a
Bravo WS 6SC1.5 pt (C,E,G,H,I,J,K).................................. Ridomil Gold EC 0.2 pt + Bravo WS 6SC1.5 pt (D,F)	6.5 a	58.8 a	2.3 a	101 a	219 a	1 a
Bravo WS 6SC1.5 pt (C,D,F,G,H,I,J,K)............................... Ridomil Gold EC 0.2 pt + Bravo WS 6SC1.5 pt (E,F)	7.8 a	66.3 a	2.0 a	115 a	256 a	0 a
Ridomil Gold EC 0.2 pt (A).. Bravo WS 6SC 1.5 pt (C,D,E,F,G,H,I,J,K)	8.3 a	70.0 a	2.0 a	108 a	279 a	25 a
Bravo WS 6SC1.5 pt (C,E,G,H,I,J,K)................................. Tattoo C 6.25SC 2.3 pt (D,F)	9.0 a	61.3 a	3.0 a	67 a	203 a	0 a
Bravo WS 6SC 1.5 pt (C,E,G,H,I,J,K)................................ Ridomil Gold MZ68WP 2.64 lb (D,F)	5.8 a	73.8 a	1.8 a	123 a	291 a	0 a
Bravo WS 6SC1.5 pt (C,D,E,F,G,H)................................... Tattoo C 6.25SC 2.30 pt (I,J,K)	7.8 a	55.0 a	3.0 a	116 a	291 a	0 a
Tattoo C 6.25SC 2.3 pt (B).. Bravo WS 6SC 1.5 pt (C,D,E,F,G,H,I,J,K)	5.8 a	68.8 a	1.8 a	139 a	283 a	1 a
Tattoo C 6.25 SC 1.15 pt (C,D).. Bravo WS6SC1.5 pt (E,F,G,H,I,J,K)	8.3 a	62.5 a	2.0 a	128 a	272 a	0 a
Tattoo C 6.25 SC 2.3 pt (C,D).. Bravo WS6SC1.5 pt (E,F,G,H,I,J,K)	7.0 a	65.0 a	2.3 a	86 a	262 a	0 a
Untreated..	100 b	0 b	26.8 b	78 a	205 a	1 a

[1] Days after inoculation with *Phytophthora infestans*, US8, A2

[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.

[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight

[4] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development

[5] Application dates: A= 23 Jun; B= 1 Jul; C= 8 Jul; D= 15 Jul; E= 22 Jul; F= 30 Jul; G= 7 Aug; H= 14 Aug; I= 21 Aug.

[6] 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 Manzate 75DF, Manex, Supertin and Kocide varying rate programs applied as protectant strategies.

Introduction
Combinations of Manzate 75DF, Supertin 80WP and Kocide 4.5FL at different rates and timings within protectant strategy programs were evaluated for the control of foliar and tuber blight. In addition a rescue treatment that consisted of two applications of Supertin + Manex with Supertin applied at double the recommended field rate when late blight had developed to a level of about 5% foliar infection was evaluated.

Additional method
Supertin was added to Diquat in some treatments at desiccation. The time to desiccate to 100% vine death was evaluated.

Foliar disease (Table 3)
All fungicide programs with seven-day application intervals, except the increasing rate of Manzate 75DF program and the decreasing rate of Manzate 75DF program, reduced the level of late blight foliar infection significantly compared to the untreated control. All fungicide programs with seven-day application intervals, except the increasing rate of Manzate 75DF program and the decreasing rate of Manzate 75DF program had reduced amounts of green leaf area at the end of the growing season significantly compared to the untreated control. The programs with the least amount of late blight (percentage final foliar disease and RAUDPC) and most green leaf area at the end of the season was the full rate Manzate 75DF + Supertin 80WP. The application of two doses 5 days apart of Supertin 80WP (0.47 lb) + Manex 4FL prevented further significant blight development on the foliage after disease had become established. The 0.47 lb application rate of Supertin 80WP is not a registered use rate. Phytotoxicity was not noted in any of the treatments.

Desiccation, Yield and Tuber disease
There was no difference between any treatments in the time taken to desiccate. Total yields were very low in this block. The yields did not correlate well with observed 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.

Conclusions and Recommendations
Manzate + Supertin should be recommended as an effective fungicide combination for the control of foliar late blight.

The effect of the combining Supertin with Diquat at desiccation could not be assessed due low levels of tuber infection in stored tubers, however, the rate of desiccation was not altered by the addition of Supertin to Diquat.

The effect of the inclusion of Kocide at the end of the season (after desiccation) could not be assessed due low levels of tuber infection in stored tubers.

Increasing and decreasing rate programs of Manzate cannot be recommended to give adequate disease control under conditions highly conducive to late blight.

The addition of Supertin to Manzate early in the management program is recommended for late blight control under conditions highly conductive to late blight.

The addition of Kocide to Bravo early and late in the management program is recommended for late blight control under conditions highly conducive to late blight.

Established late blight infection in cv. Snowden (up to 5% foliar infection) was controlled by the application of two double rate applications of Supertin, and should be considered for emergency situations to prevent epidemic 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 3.

Treatment and rate/acre	final foliar disease (%) 32 dai [1]	green leaf area (%) 42 dai [2]	RAUDPC max = 100 0 - 32 dai[3]	Yield (cwt/acre) US1	Yield (cwt/acre) Total	% rotted tubers 90 das[4]	days to desiccate 100%
Manzate75WP 2.0 lb (A,B,C,D,E,F,H,I,J)[5] + Supertin 80WP 0.13 lb Supertin 80 WP 0.23 lb + Diquat 36.4 EC 1.0 pt (K) Kocide 4.5FL 2.67 pt (L)	11.3 a[6]	63.8 a	2.5 a	106 a	262 a	0 a	13 a
Manzate 75WP 2.0 lb (A,B,C,D) Manzate75WP 2.0 lb + Supertin 80WP 0.13 lb (E,F,H,I) Manzate75WP 2.0 lb + Supertin 80WP 0.23 lb (J) Supertin 80 WP 0.23 lb + Diquat 36.4 EC 1.0 pt (K) Kocide 4.5FL 2.67 pt (L)	10.8 a	53.8 ab	2.8 a	85 a	242 a	1 a	12 a
Manzate 75WP 2.0 lb (A,B,C) Manzate 75WP 1.33 lb (D,E,F,H,I) Manzate75WP 1.0 lb + Supertin 80WP 0.23 lb (J) Supertin 80 WP 0.23 lb + Diquat 36.4 EC 1.0 pt (K) Kocide 4.5FL 2.67 pt (L)	53.8 a	13.8 cd	9.8 a	78 a	267 a	0 a	13 a
Manzate 75WP 1.0 lb (A,B,C) Manzate 75WP 1.33 lb (D,E,F,H,I) Manzate75WP 1.0 lb + Supertin 80WP 0.23 lb (J) Supertin 80 WP 0.23 lb + Diquat 36.4 EC 1.0 pt (K) Kocide 4.5FL 2.67 pt (L)	61.3 ab	7.5 cd	12.5 a	67 a	214 a	0 a	13 a
Manzate 75WP 1.0 lb (A,B,C) Manzate75WP 1.0 lb (D,E,F,H,I) + Supertin 80WP 0.23 lb Supertin 80 WP 0.23 lb + Diquat 36.4 EC 1.0 pt (J)	15.0 a	41.3 abc	4.5 a	113 a	237 a	0 a	13 a
Supertin 80WP 0.47 lb + Manex 4FL 3.2 pt (G,H) Manex 4FL 3.2 pt (I,J,K,L)	12.0 a	60.0 a	3.8 a	79 a	260 a	0 a	13 a
Bravo WS 6SC 1.0 pt + Kocide 4.5FL 2.0 pt (A,B,C) Manzate 75WP 2.0 lb (D,F,I) Bravo WS 6SC 1.5 pt (E,H) Bravo WS 6SC 1.0 pt + Kocide 4.5FL 2.67 pt (J,K,L)	25.0 a	40.0 ab	5.3 a	106 a	252 a	0 a	13 a
Untreated	100 b	0 d	29.2 b	70 a	252 a	0 a	

[1]Days after inoculation with *Phytophthora infestans*, US8, A2

[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.

[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight

[4] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development

[5] Application dates: A= 23 Jun; B= 1 Jul; C= 8 Jul; D= 15 Jul; E= 22 Jul; F= 30 Jul; G= 3 Aug; H= 9 Aug; I= 17 Aug; J= 24 Aug; K= 30 Aug; L= 5 Sept.

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

Trial 4. Comparison of control of potato late blight (*Phytophthora infestans)* attained with Bravo ZN, Terranil ZN and program initiation with Bravo ZN or Quadris.

Introduction

Increasing and decreasing rates, and application of reduced rates of chlorothalonil ZN formulations at 5 application intervals were compared in this trial for the control of foliar blight. The effect of initiating programs with either Quadris or Bravo ZN was also evaluated.

Foliar disease (Table 4)

All fungicide programs with seven-day application intervals reduced the level of late blight foliar infection significantly compared to the untreated control. The programs with the least amount of late blight (percentage final foliar disease and RAUDPC) and most green leaf area at the end of the season were Quadris 80WDG alternated with Bravo ZN 6.25SC (full season), Quadris 80WDG (two applications, mid-season) alternated with Bravo ZN 6.25SC and Terranil ZN 6.25SC (both increasing and decreasing rates of application with the progress of the season) and with both 5 day, reduced rate applications of Bravo ZN 6.25SC and Terranil ZN 6.25SC. The program increasing the rate of Bravo ZN 6.25SC had three times as much foliar late blight compared with the equivalent Terranil ZN 6.25SC program. Phytotoxicity was not noted in any of the treatments.

Yield and Tuber disease

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

Conclusions and Recommendations

Bravo ZN and Terranil ZN should be recommended as effective fungicides for the control of foliar late blight applied at 1.5 pt/A on a 5 day schedule or at increasing and decreasing rates of application.

The effect of initiating the late blight control program with either Bravo ZN or Quadris had no effect on late blight development and it is recommended that the program could be started with either fungicide.

The effect of two applications of Quadris (0.31 lb/A) compared to four or five applications within the late blight control program had no effect on late blight development and therefore it is recommended that two applications of Quadris are adequate within a seven-day management strategy to control 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 4.

Treatment and rate/acre	final foliar disease (%) 32 dai [1]	green leaf area (%) 42 dai [2]	RAUDPC max = 100 0 - 32 dai[3]	Yield (cwt/acre)		% rotted tubers 90 das[4]
				US1	Total	
Bravo ZN 6.25 SC 1.0 pt (A,B)[5], 1.5 pt (C,D,E).......... 2.13 pt (F,G,H,I)	22.0 b[6]	35.0 bc	5.0 b	153 a	211 a	0 a
Quadris 80WDG 0.31 lb (A,C,E,G,I)............................ Bravo ZN 6.25SC 2.13 pt (B,D,F,H)	9.5 ab	62.5 ab	2.5 ab	101 a	199 a	0 a
Bravo ZN 6.25 SC 2.13 pt (A,C,E,G,I)........................ Quadris 80WDG 0.31 lb (B,D,F,H)	9.0 ab	72.5 a	3.0 ab	125 a	180 a	0 a
Quadris 80WDG 0.31 lb (A,C,E,G,I)............................ Bravo ZN 6.25 SC 1.75 pt (B,D,F,H)	12.3 ab	67.5 ab	3.0 ab	145 a	218 a	2 a
Bravo ZN 6.25 SC 1.75 pt (A,C,E,G,I)........................ Quadris 80WDG 0.31 lb (B,D,F,H)	9.8 ab	67.5 ab	2.5 ab	123 a	176 a	0 a
Bravo ZN 6.25 SC 2.13 pt (A,B,D,E,G,H,I)................ Quadris 80WDG 0.31 lb (C,F)	6.5 a	73.8 a	2.0 a	91 a	183 a	0 a
Terranil ZN 6.25 SC 1.0 pt (A,B), 1.5 pt (C,D,E)........ 2.13 pt (F,G,H,I)	6.3 a	81.3 a	2.3 ab	129 a	198 a	0 a
Terranil ZN 6.25 SC 2.13 pt (A,B), 1.5 pt (C,D,E)...... 1.0 pt (F,G,H,I)	8.5 ab	67.5 ab	2.3 ab	100 a	156 a	0 a
Bravo ZN 6.25 SC 1.5 pt (a,b,c,d,e,f,g,h,i,j,k,l,m,n)[7]...	12.0 ab	66.3 ab	3.8 ab	157 a	211 a	0 a
Terranil ZN 6.25 SC 1.5 pt (a,b,c,d,e,f,g,h,i,j,k,l,m,n).	8.3 ab	71.3 ab	2.8 ab	127 a	181 a	0 a
untreated..	100 c	0 c	29.7 c	76 a	166 a	0 a

[1] Days after inoculation with *Phytophthora infestans*, US8, A2

[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.

[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight

[4] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development

[5] Application dates: A= 23 Jun; B= 1 Jul; C= 8 Jul; D= 15 Jul; E= 22 Jul; F= 30 Jul; G= 7 Aug; H= 14 Aug; I= 21 Aug.

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

[7] 5-day schedule Application dates: a= 23 Jun; b= 28 Jun; c= 2 Jul; d= 7 Jul; e= 12 Jul; f= 17 Jul; G= 22 Jul; h= 28 Jul; i= 3 Aug; j= 8 Aug; k= 14 Aug l= 13 Aug; m= 18 Aug; n= 23 Aug; n= 28 Aug.

Trial 5. **Comparison of control of potato late blight (*Phytophthora infestans*) attained with Tattoo C and Acrobat MZ applied at reduced rates and at different timings within the late blight management program.**

Introduction

Reduced rates of Tattoo C and Acrobat MZ were compared to the standard Bravo WS program in this trial for the control of foliar blight.

Foliar disease (Table 5)

All fungicide programs with seven-day application intervals reduced the level of late blight foliar infection significantly compared to the untreated control. All programs had a similar amount of late blight (percentage final foliar disease and RAUDPC) and green leaf area at the end of the season. The reduced rate programs gave comparable control levels to the standard full rate programs. Phytotoxicity was not noted in any of the treatments.

Yield and Tuber disease

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

Conclusions and Recommendations

The standard programmed approach to late blight control with Tattoo C (applied immediately prior to canopy closure and again 14 days later, with the remainder applications, Bravo WS) could be recommended for control of late blight.

Tattoo C applied season long at about half and 3/4 the recommended full rate of application, or at half rate with additional Bravo gave similar levels of control to the standard programmed application of Tattoo C and the standard program, Bravo WS, full season.

The standard programmed approach to late blight control with Acrobat MZ (applied immediately prior to canopy closure and again as the final application, with the remainder applications, Bravo WS) could be recommended for control of late blight.

Acrobat MZ or Tattoo C applied at full rate at the standard early timing and with two half rates of application for the final two applications gave similar levels of control to the standard programmed application of Tattoo C and the standard program, Bravo WS, full season.

Acrobat MZ applied at half rate early season (first four applications) followed by Bravo WS to the end of the season gave similar levels of control to the standard programmed application of Tattoo C and the standard program, Bravo WS, full season.

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.

Treatment and rate/acre	final foliar disease (%) 32 dai [1]	green leaf area (%) 42 dai [2]	RAUDPC max = 100 0 - 32 dai[3]	Yield (cwt/acre) US1	Yield (cwt/acre) Total	% rotted tubers 90 das[4]
Bravo WS 6SC 1.5 pt (A,B,S,D,E,F,G,H,I)[5].........	10.8 a[6]	67.5 a	2.5 a	137 a	243 a	2 a
Bravo WS 6SC 1.5 pt (A,B,D,F,H,I)..................... Tattoo C 6.25SC 2.3 pt (C,E,G)	15.0 a	50.0 a	4.3 a	88 a	212 a	2.5 a
Bravo WS 6SC 1.5 pt (A,B,D,F,G,H,I)................. Tattoo C 6.25SC 2.3 pt (C,E)	16.3 a	51.3 a	4.0 a	126 a	252 a	0 a
Tattoo C 6.25SC 1.28 pt (A,B,S,D,E,F,G,H,I).......	16.3 a	42.5 a	5.0 a	100 a	209 a	0 a
Tattoo C 6.25SC 1.72 pt (A,B,S,D,E,F,G,H,I).......	12.0 a	58.4 a	4.5 a	100 a	209 a	0 a
Tattoo C 6.25SC 1.28 pt (A,B,S,D,E,F,G,H,I)....... + Bravo WS 6SC 0.83 pt	10.8 a	62.5 a	3.5 a	129 a	250 a	0 a
Bravo WS 6SC 1.5 pt (A,B,C,E,FG,H,I)................ Acrobat 69WP 2.25 lb (D,J)	16.3 a	38.8 a	5.0 a	117 a	259 a	0 a
Bravo WS 6SC 1.5 pt (A,B,D,E,FG,H,I)................ Acrobat 69WP2.25 lb (C),1.13 lb (J,K)	15.0 a	53.8 a	3.8 a	140 a	271 a	0 a
Acrobat 69WP 1.13 lb (A,B,C,I) .... Bravo WS 6SC 1.5 pt (D,E,F,G,H)	16.3 a	48.8 a	4.5 a	119 a	271 a	2 a
Tattoo C 6.25SC 1.28 pt (A,B,C).......................... Bravo WS 6SC 1.5 pt (D,E,F,G,H) Acrobat 69WP 1.13 lb (I,J)	15.0 a	41.3 a	4.5 a	114 a	248 a	0 a
Untreated...	100 b	0 b	36.0 b	81 a	214 a	0 a

[1]Days after inoculation with *Phytophthora infestans*, US8, A2

[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.

[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight

[4] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development

[5] Application dates: A= 23 Jun; B= 1 Jul; C= 8 Jul; D= 15 Jul; E= 22 Jul; F= 30 Jul; G= 7 Aug; H= 14 Aug; I= 21 Aug.

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

Trial 6. Comparison of control of potato late blight (*Phytophthora infestans*) attained with Curzate 60DF in combination with Bravo or Manzate and the novel fungicide KP481 within the late blight management program.

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. The efficacy of the novel fungicide KP481, famoxate, against late blight was also evaluated in this trial.

Foliar disease (Table 6)

All fungicide programs with seven-day application intervals reduced the level of late blight foliar infection significantly compared to the untreated control. All programs had a similar amount of late blight (percentage final foliar disease and RAUDPC) and green leaf area at the end of the season. The Curzate 60DF + Manzate 75DF program had about double the amount of disease in comparison with other programs. KP 481 50DF gave similar control to the Curzate 60DF + Bravo WS 6SC programs. Phytotoxicity was not noted in any of the treatments.

Yield and Tuber disease

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

Conclusions and Recommendations

Curzate 60DF applied in combination with Bravo WS and alternated with Bravo WS season long should be recommended for control of potato late blight.

The addition of Li700 to the Curzate 60DF applied in combination with Bravo WS and alternated with Bravo WS program season long made no difference to the level of control of late blight and should not be recommended as an adjuvant to this tank mixture.

Curzate 60DF applied in combination with Manzate and alternated with Bravo WS season long should be recommended for control of potato late blight under conditions that are less conducive for late blight development .

Curzate 60DF applied in combination with reduced amounts of Manzate and Bravo WS and alternated with Bravo WS season long should be recommended for control of potato late blight under conditions that are conducive for late blight development.

KP481 50DF alternated with Bravo WS season long or applied season long following two applications of Bravo WS should 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.

Treatment and rate/acre	final foliar disease (%) 32 dai [1]	green leaf area (%) 42 dai [2]	RAUDPC max = 100 0 - 32 dai[3]	Yield (cwt/acre)		% rotted tubers 90 das[4]
				US1	Total	
Bravo WS 6SC 1.5 pt (A,B,H,I)[5] .... Curzate 60DF + 0.21 lb (C,D,E,F,G) + Bravo WS 6SC 1.17 pt	7.0 a[6]	83.8 a	2.0 a	117 a	231 a	0 a
Bravo WS 6SC 1.5 pt (A,B,H,I)....................... Curzate 60DF + 0.21 lb (C,D,E,F,G) + Bravo WS 6SC 1.17 pt+ Li700 EC 0.11pt	9.3 a	76.3 a	2.8 a	114 a	273 a	1 a
Bravo WS 6SC 1.5 pt (A,B,H,I)....................... Curzate 60DF 0.21lb (C,D,E,F,G) + Manzate75DF 1.75 lb	20.8 a	61.3 a	4.3 a	108 a	235 a	4 a
Bravo WS 6SC 1.5 pt (A,B,H,I)....................... Curzate 60DF + 0.21 lb(C,D,E,F,G) + Bravo WS 6SC 0.75 pt + Manzate 75DF 1.33 lb	10.5 a	70.0 a	2.5 a	126 a	277 a	0 a
Bravo WS 6SC 1.5 pt (A,B,H,I)....................... KP481 50DF 0.5 lb (C,D,E,F,G)	10.0 a	70.0 a	2.5 a	101 a	207 a	0 a
Bravo WS 6SC 1.5 pt (A,B,H,I)....................... KP481 50DF 0.75 lb (C,D,E,F,G)	11.3 a	75.0 a	2.5 a	126 a	249 a	2.5 a
Bravo WS 6SC 1.5 pt (A,B)............................ KP481 50DF 0.75 lb (C,D,E,F,G,H,I)	9.5 a	75.0 a	2.5 a	124 a	268 a	0 a
Bravo WS 6SC 1.5 pt (A,B,C,D)..................... Curzate 60DF 0.21lb (E,F,G,H,I) + Bravo WS 6SC 1.17 pt	10.8 a	71.3 a	2.5 a	119 a	257 a	0 a
Bravo WS 6SC 1.5 pt (A,B,C,D)..................... Curzate 60DF 0.21 lb (E,F,G,H) + Bravo WS 6SC 1.17 pt Acrobat 69WP 2.25 lb (I)	7.0 a	81.3 a	2.3 a	94 a	218 a	0 a
Bravo WS 6SC 1.5 pt (A,B,C,D)..................... Curzate 60DF 0.21 lb (E,F,G,H) + Bravo WS 6SC 1.17 pt + Supertin 80WP 0.23lb (I)	8.8 a	78.8 a	2.5 a	108 a	220 a	0 a
Untreated...	100 b	0 b	28.2 b	64 a	218 a	2.5 a

[1] Days after inoculation with *Phytophthora infestans*, US8, A2
[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.
[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight
[4] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development
[5] Application dates: A= 23 Jun; B= 1 Jul; C= 8 Jul; D= 15 Jul; E= 22 Jul; F= 30 Jul; G= 7 Aug; H= 14 Aug; I= 21 Aug.
[6] Values followed by the same letter are not significantly different at p = 0.05 (Tukey Multiple Comparison).

Trial 7. Comparison of control of potato late blight (*Phytophthora infestans*) attained with Polyram and Curzate 60DF + Polyram in combination with adjuvants.

Introduction
This trial compared the contribution that different adjuvants made to late blight control when applied with a surface residual fungicide (Polyram 80DF) and with a translaminar/systemic fungicide (Curzate 60DF + Polyram 80DF).

Additional Methods
This trial block was not directly inoculated. The block was close to other trial blocks that had been inoculated as described in the general methods section.

Foliar disease (Table 7)
All fungicide programs with seven-day application intervals reduced the level of late blight foliar infection significantly compared to the untreated control. All fungicide programs with seven-day application intervals, reduced the amount of loss of green leaf area at the end of the growing season significantly compared to the untreated control. The addition of any of the adjuvants (Tactic, Li700, Activator 90) to Polyram 80DF and Curzate 60DF + Polyram 80DF did not significantly improve disease control, although a trend toward late blight reduction in the foliage was observed with their addition to fungicides. No significant difference was measured in the comparison of Curzate 60DF and Polyram 80DF with other contact (Bravo WS) and translaminar (Acrobat MZ) products. Phytotoxicity was not noted in any of the treatments.

Yield and Tuber disease
Total yields were very low in this block. Acrobat MZ 69WP had a significantly higher total yield than the untreated check. The Acrobat MZ 69WP, Polyram 80DF + Li700, Polyram 80DF + Tactic, Curzate 60DF + Polyram 80DFand Curzate 60DF + Polyram 80DF + Li700 programs had significantly higher US1 size grade yield than the untreated check 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.

Conclusions and Recommendations
Curzate 60DF applied in combination with Polyram 80DF gave good control of late blight and could be recommended for control of potato late blight under moderately conducive late blight conditions.

Polyram 80DF gave good control of late blight and could be recommended for control of potato late blight.

The addition of Tactic, Li700 or Activator 90 to Curzate 60DF + Polyram 80DF or Polyram 80DF programs season long made no significant difference to the level of control of late blight and their addition is not justified for late blight control, however, their addition did tend to reduce the level of foliar 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.

Treatment and rate/acre	Final foliar disease (%) 32 dai[1]	Green leaf area (%)[2] 42 dai	RAUDPC[3] max = 100 0 - 32 dai	Yield (cwt/acre) US1	Yield (cwt/acre) Total	% rotted tubers 90 das[4]
Bravo WS 6SC 1.5 pt (A,B,C,D,E,F,G,H,I)[5]	18.8 a[6]	37.5 a	6.5 a	119 abc	263 ab	0 a
Acrobat MZ 69WP 2.25 lb (A,B,C,D,E,F,G,H,I)	15.0 a	42.3 a	4.3 a	177 a	328 a	1 a
Polyram 80DF 2.0 lb (A,B,C,D,E,F,G,H,I) + Supertin 80WP 0.16 lb	14.5 a	42.5 a	5.8 a	90 bc	212 ab	1 a
Polyram 80DF 2.0 lb (A,B,C,D,E,F,G,H,I)	18.3 a	56.3 a	4.3 a	119 abc	299 ab	1 a
Polyram 80DF 2.0 lb + Tactic SC 0.25 pt (A,B,C,D,E,F,G,H,I)	14.3 a	66.3 a	2.3 a	150 ab	255 ab	0 a
Polyram 80DF 2.0 lb + Li700SC 0.25 pt (A,B,C,D,E ,F,G,H,I)	13.0 a	67.5 a	2.3 a	167 ab	312 ab	0 a
Polyram 80DF 2.0 lb + Activator 90SC 0.25 pt (A,B,C,D,E ,F,G,H,I)	20.8 a	57.5 a	3.3 a	110 ab	229 ab	0 a
Curzate 60DF 0.21lb (A,B,C,D,E,F,G,H,I) + Polyram 80DF 1.5 lb	26.8 a	53.8 a	4.5 a	147 ab	290 ab	0 a
Curzate 60DF 0.21lb (A,B,C,D,E,F,G,H,I) + Polyram 80DF 1.5 lb + Tactic SC 0.25 pt	16.8 a	57.5 a	3.0 a	107 ab	226 ab	0 a
Curzate 60DF 0.21lb + Polyram 80DF 1.5 lb (A,B,C,D,E,F,G,H,I) + Li700 SC0.25 pt	19.5 a	57.5 a	3.0 a	146 ab	306 ab	0 a
Curzate 60DF 0.21lb + Polyram 80DF 1.5 lb (A,B,C,D,E,F,G,H,I) + Activator 90SC 0.25 pt	18.8 a	57.5 a	3.0 a	153 ab	265 ab	0 a
Untreated	100 b	0 b	26.8 b	76 c	204 b	0 a

[1] days after inoculation with *Phytophthora infestans*, US8, A2

[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.

[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight

[4] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development

[5]Application dates: A= 23 Jun; B= 1 Jul; C= 8 Jul; D= 15 Jul; E= 22 Jul; F= 30 Jul; G= 7 Aug; H= 14 Aug; I= 21 Aug.

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

Trial 8. Comparison of control of established potato late blight (*Phytophthora infestans*) attained with fungicides.

Introduction

This trial compared the efficacy of various fungicides with applied after late blight had started to develop within the crop. Three timings were evaluated, fungicide programs initiated (5 day interval, 3 applications) at a) 72 h after inoculation, b) when 1% and c) when 5% of the foliage showed late blight symptoms. Previous trials from 1995 - 1997 have shown that at infection levels above 5% foliar infection, no fungicides can contain the infection under continued conducive late blight conditions.

Additional Methods

The variety planted in this trial was Onaway, which is more susceptible to late light than cv. Snowden. Fungicides were applied on a 5 day interval for 15 days (3 applications). Fungicide applications were initiated at 3different timings a) 72 h after inoculation, b) when plants were 1% infected and c) when plants were 3 - 5% infected. The first timing began on 26 July, the second on 1 Aug and the third on 3 Aug 1998.

Foliar disease (Table 8)

Late blight developed rapidly during August and untreated controls reached 85 - 95% foliar infection by 14 Aug. Partial control of late blight was achieved when some of the fungicides were applied 72 hour after inoculation. No fungicide treatments gave control of late blight when the initiation of the control programs were delayed until 1 or 5% foliar infection.

Bravo WS6SC, Acrobat MZ 69WP, Tattoo C 6.25SC, Curzate 60DF + Bravo WS 6SC, Penncozeb 75DF + Supertin 8-WF, Acrobat 50DF + Banol (propamocarb) 6.65SC and Acrobat 50DF + Supertin 80WP programs all had significantly less late blight than the untreated control (RAUDPC). All other programs were not significantly different from the untreated plots. The programs listed above were not significantly different from each other.

Conclusions and Recommendations

Bravo WS6SC, Acrobat MZ 69WP, Tattoo C 6.25SC, Curzate 60DF + Bravo WS 6SC, Penncozeb 75DF + Supertin 8-WF, Acrobat 50DF + Banol (propamocarb) 6.65SC and Acrobat 50DF + Supertin 80WP programs applied 72 h after inoculation contributed to a reduction in late blight development. These fungicides could be recommended for control of potato late blight under conducive late blight conditions after infection is known to have occurred.

Non-preventative application of any fungicide for late blight control should not be considered for management of 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 8

Treatment and rate/acre	RAUDPC[1] timing[2] Difference of means at each timing[4] 72 hai[5] 37.1A[6]		1% foliar infection 50.0 B		5% foliar infection 56.3 C	
Bravo WS 6SC 1.5 pt (A,B,C);(D,E,F),(G,H,I)[7].............	32.5	abc[8]	50.7	a	56.8	a
Acrobat MZ 69WP 2.25 lb (A,B,C);(D,E,F),(G,H,I)......	33.8	abc	41.2	a	56.0	a
Tattoo C 6.25SC 2.3 pt (A,B,C);(D,E,F),(G,H,I)............	32.5	abc	49.0	a	55.0	a
Curzate 60DF 0.21 lb + (A,B,C);(D,E,F),(G,H,I)........... Bravo WS 6SC1.5 pt	30.5	ab	51.5	a	56.8	a
Penncozeb 75DF 2.0 lb + (A,B,C);(D,E,F),(G,H,I)......... Supertin 80WP 0.23 lbs	35.5	abc	51.5	a	54.7	a
Acrobat 50WP 0.4 lb + (A,B,C);(D,E,F),(G,H,I)............ Banol 6.65SC 1.08 pt	38.5	abcd	51.5	a	56.8	a
Acrobat 50WP 0.4 lb + (A,B,C);(D,E,F),(G,H,I)............ Supertin 80WP 0.23 lbs	32.0	abc	51.7	a	58.2	a
Acrobat 50WP 0.40 lb (A,B,C);(D,E,F),(G,H,I)..........	43.5	cde	45.5	a	56.0	a
Untreated..	51.0	e	53.2	a	57.0	a

[1] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight

[2] Three different application timings initiated at a) 72 hours after inoculation, b) when plants were 1% infected and c) when plants were 3 - 5% infected. Applications were at 5 day intervals.

[3] The data were for all timings were combined and the average RAUDPC for each treatment was calculated

[4] The error term describes the variance between the three timings regardless of treatment

[5] Hours after inoculation with *Phytophthora infestans*, US8, A2

[6] Values followed by the same upper case letter across the row are not significantly different at p = 0.05 (Tukey Multiple Comparison)

[7] Application dates: A= 26 Jul; B= 31 Jul; C= 4 Aug; D= 1 Aug; E= 6 Aug; F= 11 Aug; G= 3 Aug; H= 8 Aug; I= 13 Aug.

[8] Values followed by the same lower case letter down the columns are not significantly different at p = 0.05 (Tukey Multiple Comparison)

Trial 9. Comparison of control of potato late blight (*Phytophthora infestans)* attained with Tattoo C and Acrobat MZ applied at reduced rates in programs initiated at the accumulation of 10 and 15 disease severity values (predicted by Blitecast).

Introduction

Reduced rates of Tattoo C and Acrobat MZ were compared to the standard Bravo WS program in this trial for the control of foliar blight. The initiation of the programs were started when either 10 or 15 disease severity values (DSV) had accumulated according to the Blitecast model. The weather station was situated within the canopy of the trial block.

Additional methods

Two sets of program initiations were compared, the first was started when 10 DSV had accumulated and the second set, when 15 DSV had accumulated. DSV were calculated from the Blitecast model from weather data collected by an in-crop weather station (Sensor Instruments).

Foliar disease (Table 9)

The accumulation of 10 (1 Jul.) and 15 DSV (8 Jul.) occurred within 7 days. All fungicide programs with seven-day application intervals reduced the level of late blight foliar infection significantly compared to the untreated control. All programs had a similar amount of late blight (percentage final foliar disease and RAUDPC) and green leaf area at the end of the season. Full rate Bravo WS 6SC programs had less late blight than the reduced rate Acrobat 69MZ or Tattoo C 6.25SC programs initiated at either 10 or 15 DSV. Phytotoxicity was not noted in any of the treatments.

Yield and Tuber disease

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

Conclusions and Recommendations

The standard programmed approach to late blight control with Bravo WS initiated at either 10 or 15 DSV could be recommended for control of late blight.

Tattoo C applied season long at half and 3/4 the recommended full rate of application initiated at either 10 or 15 DSV, gave similar levels of control to the standard program of Bravo WS, and could be recommended for control of late blight.

Acrobat MZ applied season long at half and 3/4 the recommended full rate of application initiated at either 10 or 15 DSV, gave similar levels of control to the standard program of Bravo WS, and could be recommended for control of 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.

Treatment and rate/acre	Final foliar disease (%) 32 dai[1]	Green leaf area (%)[2] 42 dai	RAUDPC[3] max = 100 0 - 32 dai	Yield (cwt/acre)		% rotted tubers 90 das[4]
				US1	Total	
Bravo WS 6SC 1.5 pt (A,B,C,D,E,F,G,H)[5].....	6.5 a[6]	73.8 a	1.8 a	129 a	282 a	1 a
Tattoo C 6.25SC 1.15 pt (A,B,C,D,E,F,G,H)...	14.5 a	58.8 a	2.0 a	99 a	250 a	1 a
Tattoo C 6.25SC 1.75 pt (A,B,C,D,E,F,G,H)...	10.3 a	66.3 a	2.8 a	116 a	275 a	1 a
Acrobat 69WP 1.13 lb (A,B,C,D,E,F,G,H)......	13.8 a	57.5 a	2.5 a	123 a	278 a	0 a
Acrobat 69WP1.69 lb (A,B,C,D,E,F,G,H).......	12.0 a	65.0 a	3.0 a	134 a	293 a	0 a
Bravo WS 6SC 1.5 pt (B,C,D,E,F,G,H)...........	5.8 a	76.3 a	1.5 a	146 a	298 a	1 a
Tattoo C 6.25SC 1.15 pt (B,C,D,E,F,G,H).......	9.8 a	62.3 a	6.8 ab	109 a	253 a	0 a
Tattoo C 6.25SC 1.75 pt (B,C,D,E,F,G,H).......	15.0 a	63.8 a	2.5 a	101 a	248 a	0 a
Acrobat 69WP 1.13 lb (B,C,D,E,F,G,H)..........	14.3 a	58.8 a	5.5 ab	106 a	273 a	0 a
Acrobat 69WP1.69 lb (B,C,D,E,F,G,H)...........	10.5 a	65.0 a	2.0 a	128 a	295 a	0 a
Untreated..	100 b	0 b	15.3 b	83 a	252 a	1 a

[1] Days after inoculation with *Phytophthora infestans*, US8, A2. Plots were not directly inoculated, secondary spread from adjacent plots.
[2] Green leaf area remaining, *Botrytis cinerea* caused considerable green leaf area loss toward the end of the season.
[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation of late blight.
[4] Yield is expressed as a percentage of the untreated plot, the value (cwt/acre) is shown. To convert to actual yield multiply the percentage yield by the actual yield and divide by 100.
[5] Days after introduction of tubers into storage at 49°F. 25 tubers/plot (100 per treatment) are incubated in plastic bags to encourage late blight development
[6] Application dates: A= 1 Jul; B= 8 Jul; C= 15 Jul; D= 22 Jul; E= 30 Jul; F= 7 Aug; G= 14 Aug; H= 21 Aug. (A initiated @ 10 disease severity values; B initiated @ 15 disease severity values
[7] Values followed by the same letter are not significantly different at P = 0.05 (Tukey Multiple Comparison).

Appendix 1. Weather data and disease indices for the Muck Farm 1998.

Date	Average Air Temperature		P-values early blight		DSV late blight		Air pressure Average	Average Daily Wind Speed	Rain		
	∘C	∘F	daily	cum.[1]	daily	cum.	Bar	mph	mm	in	cum.
06/22/98	21.0	69.8	16.9	17	1	1	739.7	0.6	0.51	0.02	0.02
06/23/98	24.6	76.2	20.5	37	1	2	740.0	0.7	1.60	0.06	0.08
06/24/98	22.7	72.9	18.6	56	2	4	740.4	0.7	6.70	0.27	0.35
06/25/98	22.8	73.1	18.7	75	0	4	739.1	0.9	0.00	0.00	0.35
06/26/98	20.3	68.6	16.2	91	1	5	737.8	0.8	2.10	0.08	0.44
06/27/98	16.9	62.3	12.8	104	0	5	739.6	0.4	0.00	0.00	0.44
06/28/98	20.0	68.1	15.9	120	1	6	742.5	0.5	1.77	0.07	0.51
06/29/98	21.4	70.6	17.3	137	2	8	743.4	0.4	4.32	0.17	0.68
06/30/98	20.9	69.6	16.8	154	1	9	741.1	0.8	0.00	0.00	0.68
07/01/98	21.1	70.0	17.0	171	1	10	738.5	0.4	0.50	0.02	0.70
07/02/98	22.4	72.3	18.3	189	0	10	740.6	0.7	0.00	0.00	0.70
07/03/98	21.4	70.5	17.3	206	1	11	740.4	1.0	2.29	0.09	0.79
07/04/98	20.3	68.6	16.2	223	2	13	740.1	0.8	7.11	0.28	1.08
07/05/98	16.9	62.3	12.8	235	0	13	744.3	0.4	0.00	0.00	1.08
07/06/98	20.0	68.1	15.9	251	1	14	740.9	0.5	4.56	0.18	1.26
07/07/98	21.4	70.6	17.3	269	0	14	738.5	0.4	0.50	0.02	1.28
07/08/98	20.9	69.6	16.8	285	1	15	737.8	0.8	0.50	0.02	1.30
07/09/98	21.0	69.7	16.9	302	0	15	739.6	0.4	0.00	0.00	1.30
07/10/98	19.5	67.1	15.4	318	0	15	742.5	0.7	0.00	0.00	1.30
07/11/98	16.8	62.3	12.7	330	0	15	743.4	0.4	0.00	0.00	1.30
07/12/98	18.7	65.7	14.6	345	0	15	741.1	0.6	0.00	0.00	1.30
07/13/98	19.6	67.2	15.5	360	0	15	739.8	0.6	0.00	0.00	1.30
07/14/98	22.0	71.5	17.9	378	1	16	740.0	0.8	1.77	0.07	1.37
07/15/98	23.4	74.1	19.3	398	2	18	740.0	0.6	4.32	0.17	1.54
07/16/98	23.7	74.7	19.6	417	0	18	738.7	0.7	0.00	0.00	1.54
07/17/98	19.9	67.8	15.8	433	1	19	739.2	1.0	0.50	0.02	1.56
07/18/98	18.5	65.4	14.4	447	0	19	739.3	0.4	0.00	0.00	1.56
07/19/98	23.0	73.3	18.9	466	1	20	736.4	1.2	2.03	0.08	1.64
07/20/98	24.1	75.3	20.0	486	0	20	737.7	0.9	0.00	0.00	1.64
07/21/98	23.9	75.0	19.8	506	2	22	736.5	2.0	3.81	0.15	1.80
07/22/98	23.0	73.5	18.9	525	1	23	738.1	1.0	0.25	0.01	1.81
07/23/98	20.1	68.2	16.0	541	4	27	737.4	1.3	25.91	1.04	2.84
07/24/98	15.1	59.3	11.0	552	1	28	741.9	0.6	2.29	0.09	2.93
07/25/98	16.0	60.9	11.9	564	1	29	744.4	0.3	0.75	0.03	2.96
07/26/98	16.9	62.4	12.8	577	0	29	743.8	0.6	0.00	0.00	2.96
07/27/98	19.3	66.7	15.2	592	2	31	738.7	1.3	4.32	0.17	3.14
07/28/98	21.2	70.1	17.1	609	0	31	736.6	1.3	0.00	0.00	3.14
07/29/98	21.9	71.3	17.8	627	0	31	737.9	1.1	0.00	0.00	3.14
07/30/98	19.0	66.3	14.9	642	0	31	740.2	0.4	0.00	0.00	3.14
07/31/98	18.1	64.6	14.0	656	1	32	745.4	0.5	7.87	0.31	3.45
08/01/98	17.2	62.9	13.1	669	0	32	749.0	0.4	0.00	0.00	3.45
08/02/98	18.5	65.3	14.4	683	0	32	747.0	0.4	0.00	0.00	3.45
08/03/98	19.2	66.5	15.1	698	3	35	744.7	0.4	12.45	0.50	3.95
08/04/98	17.2	62.9	13.1	711	0	35	749.0	0.4	0.00	0.00	3.95
08/05/98	20.4	68.8	16.3	728	1	36	743.5	0.8	1.27	0.05	4.00
08/06/98	22.3	72.1	18.2	746	2	38	741.0	0.7	9.14	0.37	4.37
08/07/98	23.4	74.0	19.3	765	1	39	741.6	0.7	1.02	0.04	4.41
08/08/98	23.6	74.4	19.5	785	2	41	743.5	0.8	2.28	0.09	4.50

Appendix 1cont.

Date	Average Air Temperature		P-values early blight		DSV late blight		Air pressure Average	Average Daily Wind Speed	Rain		
	∘C	∘F	daily	cum.[1]	daily	cum.	Bar	mph	mm	in	cum.
08/10/98	21.2	70.1	17.1	820	3	47	738.6	0.5	12.95	0.52	5.63
08/11/98	18.6	65.5	14.5	834	1	48	741.1	0.7	0.76	0.03	5.67
08/12/98	17.2	63.0	13.1	848	0	48	745.4	0.4	0.25	0.01	5.68
08/13/98	17.2	63.0	13.1	861	0	48	744.2	0.2	0.25	0.01	5.69
08/14/98	18.2	64.8	14.1	875	2	50	739.5	0.4	5.33	0.21	5.90
08/15/98	19.9	67.8	15.8	891	0	50	737.9	0.3	0.25	0.01	5.91
08/16/98	20.4	68.8	16.3	907	0	50	741.4	0.5	0.00	0.00	5.91
08/17/98	21.4	70.5	17.3	924	2	52	740.1	0.7	14.72	0.59	6.50
08/18/98	18.9	66.0	14.8	939	0	52	743.7	0.7	0.25	0.01	6.51
08/19/98	13.7	56.6	9.6	949	0	52	747.8	0.4	0.00	0.00	6.51
08/20/98	17.4	63.4	13.3	962	0	52	746.2	0.7	0.25	0.01	6.52
08/21/98	23.1	73.6	19.0	981	2	54	744.6	0.5	9.15	0.37	6.88
08/22/98	22.3	72.1	18.2	999	0	54	743.2	0.4	0.25	0.01	6.89
08/23/98	25.6	78.0	21.5	1021	0	54	736.4	1.7	0.00	0.00	6.89
08/24/98	26.1	78.9	22.0	1042	0	54	733.1	1.6	0.00	0.00	6.89
08/25/98	22.2	72.0	18.1	1061	2	56	734.9	1.1	12.18	0.49	7.38
08/26/98	18.2	64.8	14.1	1075	0	56	741.1	0.5	0.25	0.01	7.39
08/27/98	19.8	67.6	15.7	1090	0	56	743.2	0.3	0.00	0.00	7.39
08/28/98	19.3	66.7	15.2	1106	1	57	741.0	0.4	0.76	0.03	7.42

[1] Cumulative

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

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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 of this pathogen to metalaxyl and the potential loss of some currently effective protective fungicides, compounds the serious nature of this problem. The economics of crop production demand that cost effective crop protection is a prime concern for the whole industry. Public pressure to reduce crop production inputs without compromising crop quality is 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 such as those 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 in 1997 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. The experimental design was modified in 1998. After interpretation of the previous results it was clear that successful protection against late blight could only be achieved by prophylactic applications of fungicides at a 7 day interval. The trials conducted in 1998 focused on the application of fungicides applied with managed application amounts in combination with potato varieties and advanced breeding lines with different levels of late blight susceptibility. A broad range of cultivars and advanced breeding lines were evaluated in the absence of fungicide for their reaction to the US8 biotype of potato late blight.

MATERIALS AND METHODS

Potato transplants were planted at the Michigan State University Muck Soils Experimental Station, Bath, MI on 5 June into two-row by 6-foot plots (9-inch between plants, 34-inch row spacing) replicated four times in a randomized complete block design. Seed pieces were planted for the varieties FL 1533 and FL 1625. 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. All plants were inoculated (100 ml/25-foot row) with a zoospore suspension of *Phytophthora infestans* US8 (insensitive to metalaxyl, A2 mating type) genotype (10^3 zoospores/ml) on 23 Jul. Fungicides were applied 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 Dual 8E (2 pt/A on 5 Jun), Basagran (2 pt/A on 15 Jun and 5 Jul) and Poast (1.5 pt/A on 23 Jul). Insects were controlled with Admire 2F (20 fl oz/A at planting on 26 Jun), Sevin 80S (1.25 lb on 1 and 23 Jul), Thiodan 3EC (2.33 pt/A on 1 and 21 Aug) and Pounce 3.2EC (8 oz/A on 23 Jul). Plots were rated visually for percentage foliar area affected by late blight on 23, 31 Jul, 7, 14 and 23 Aug

Potato plants were generated by tissue culture and transplanted into soil when the plants were established and had well developed root systems. Well sprouted seed pieces were planted for the varieties FL 1533 and FL 1625 on 5 Jun . The fungicides chlorothalonil (Bravo WS 6SC) and fluazinam 5SC were applied at 33, 67 and 100% of the recommended field application rates.

Chemical treatments were begun before inoculation with the US8-A2 biotype of *P. infestans* (three applications). Foliar disease was assessed at various points after inoculation, with 32 days after inoculation (dai) taken as a key reference point. The average amount of disease that developed over the disease progress period was expressed as the relative area under the disease progress curve (RAUDPC). The area under the disease progress curve (AUDPC) was calculated by adding the area under the linear progression of disease between each successive estimation of disease from inoculation to 32 days after inoculation. The RAUDPC is calculated by dividing the measured AUDPC by the maximum AUDPC (100 x duration of the epidemic, from inoculation to 100% plant death). The RAUDPC was expressed with a maximum value of 100. The RAUDPC of each program and variety combination was re-expressed relative to the RAUDPC of an industry standard variety and protectant fungicide common in Michigan i.e. cv. Atlantic protected season long with Bravo WS 6SC applied at 100% of the recommended rate. Data were analyzed by three-way analysis of variance and means compared at $P = 0.05$ level of significance by a multiple range comparison of means (Tukey, SAS).

Varietal Evaluations

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 23 Jul when foliage was vigorous and healthy. Foliar disease was assessed frequently after`inoculation (minimum 5 days) and RAUDPC (see above) was calculated to evaluate disease development over the season until 28 days after inoculation.

RESULTS, 1998 FIELD SEASON:

The varieties had significantly different responses to the inoculation of *P. infestans*, US8 biotype (Figure 1A - F), 0 rate of fungicide application). The commercial varieties classified as most susceptible to late blight in the untreated controls were Atlantic, Snowden and FL1533. The advanced breeding lines classified as most susceptible to late blight in the untreated controls were E230-6, G007-1, G297-4, G141-3 and E018-1. The commercial varieties and advanced breeding lines classified as moderately resistant to late blight in the untreated controls were A091-1, C103-2, Picasso, Matilda, E246-5 and FL 1625 (cv. Atlantic is included for reference in Figure 1 C - F). The commercial varieties and advanced breeding lines classified as most resistant to late blight in the untreated controls were Lily, Zarevo and G274-3.

The component graphs, Figure 1A and B are grouped as the most susceptible varieties, Figure 1C and D, moderately resistant varieties and Figure 1E and F the most resistant varieties. Fungicide application rates of 33, 67 and 100% of both chlorothalonil and fluazinam significantly decreased the RAUDPC in all the most susceptible varieties and the moderately resistant varieties in comparison with the untreated control varieties (Figure 1A, B, C and D). The RAUDPC at full application rate of either chlorothalonil or fluazinam resulted in RAUDPC values close to 2 in all varieties and advanced breeding lines except E018-1 (Figure 1A - F). The application of either chlorothalonil or fluazinam at 33, 67 or 100% of the full recommended rates did not significantly reduce the RAUDPC in the group of varieties that were described as most resistant in the untreated control (Figure 1E and F). In the most susceptible variety grouping, the 33% rate of application of both chlorothalonil and fluazinam reduced the RAUDPC to a level not significantly different from the 67and 100% application rates (Figure 1A and B). Advanced breeding line G141-3 was the least responsive of the varieties to either fungicide at each application rate. The fungicides chlorothalonil and fluazinam were not significantly different from each other in reducing the RAUDPC in any of the variety groupings (Figure 1A- F) but G141-3 was less responsive to chlorothalonil than to fluazinam and E018-1 was less responsive to fluazinam than chlorothalonil.
The RAUDPC expressed relative to the industry standard (cv. Atlantic, full rate of chlorothalonil, 7 day schedule = 100) showed that in most varieties an RAUDPC of 100 - 200% of the standard could be achieved at application rates between 33 and 67% rate chlorothalonil and 33% fluazinam (Figure 2A - F). The RAUDPC expressed relative to the industry standard at full application rate of either chlorothalonil or fluazinam was 100 - 200% of the standard (Figure 2A - F).

Variety Trial
Late blight disease was high following inoculation. RAUDPC of selected varieties and advanced breeding lines are summarized in Table 1. Susceptible varieties reached 100% foliar infection within three weeks. The majority of the entries tested in this experiment were classified into the susceptible category (RAUDPC >20). Thirty eight lines and varieties with reduced susceptibility had slower disease progress (RAUDPC 10 - 20) but had 50 -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 (RAUDPC 5 - 10) and had 20 - 50% foliar late blight at the end of the season. Only the breeding lines LBR8, LBR9, G274-3, Q237-25 and B0692-4 were classified into the category defined as most resistant to potato late blight (RAUDPC < 5, % foliar late blight less than 20% at the end of the season).

Discussion
Combination of varietal resistance with chemical applications can provide effective disease control. This can be accomplished at lower rates of application with a conventional fungicide e.g chlorothalonil (Bravo WS 6SC) or with the novel fungicide fluazinam with a lower amount of active ingredient. In this study, reduced amounts of both chlorothalonil and fluazinam were effective at all application rates tested on all varieties in comparison with the untreated controls. Although some varieties required only 33% of the full recommended rate of application of either fungicide, others

required 67%. No further reduction in disease was measured by application at the full recommended rate of either fungicide in any variety or advanced breeding line. The least susceptible varieties e.g. G274-3 and Zarevo did not respond to application of rates greater than 33% of the full recommended rate of either fungicide. This suggests that reductions below 33% of recommended rate may be effective for the control of late blight in varieties and advanced breeding lines that are categorized as most resistant to *P. infestans* (RAUDPC, untreated control < 5).

Trials conducted in 1997, suggested that an application interval of 10 days only resulted in acceptable disease control in the least susceptible varieties and advanced breeding lines treated with 100% of the recommended rate of chlorothalonil. The efficacy of fluazinam at an application interval of 10 days at reduced application rates was not evaluated. The similarity in efficacy against late blight between chlorothalonil and fluazinam in the 1998 trials suggests that fluazinam may not be effective at reduced application rates beyond a 7-day application interval. The activity of fluazinam at reduced rates of application and decreased frequency of application interval against late blight needs to be determined in the varieties that were least susceptible to late blight. The opportunity for reduction of fungicide applications by managing the rate of application of traditional fungicides and novel fungicides with lower amounts of active ingredient in varieties less susceptible to late blight is clear. More critical dose response studies are required for new chemicals to establish effective rates of application for the control of late blight. The efficacy of reduced rates of these fungicides against other potato pathogens such as Alternaria solani (early blight) has not been established and may prove to be a major constraint in the adoption of managed rate fungicide applications.

Three advanced breeding lines from the MSU Potato Breeding Project in the late blight resistance group classified as most resistant (RAUDPC < 5), were determined to have acceptable agronomic qualitites, determined from agronomic variable studies e.g. specific gravity, yield potential, susceptibility to common scab. These lines with moderate resistance will be candidates for variety x fungicide management profiles in 1999. Only eight lines were determined to be within the moderately resistant and resistant groupings (RAUDPC < 10). The MSU advanced selection, G274-3, was the advanced breeding line with the most outstanding foliar resistance in the trial. G-274-3 also has good horticultural characteristics.G274-3 will continue to be used as a parent to transfer resistance to other genetic backgrounds and be developed as a commercial line. The varieties falling into the moderately susceptible category may be protected with reduced application rates of protectant fungicides and some of these lines will be evaluated in 1999 in the managed fungicide application trial.

Some of the lines that are most resistant to late blight will be used as parental material in the MSU Potato Breeding Project. This group included many unadapted varieties and breeding lines.

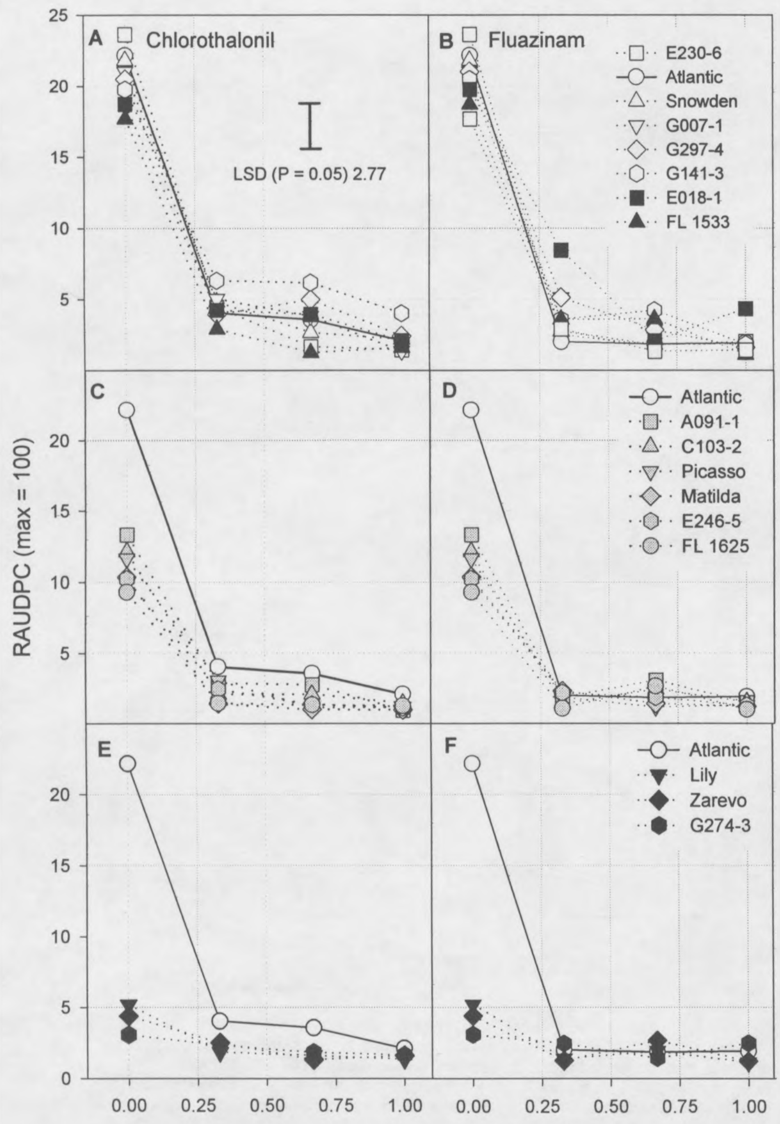

Figure 1A - F. Relative area under the disease progress curve (max = 100) in potato varieties and advanced breeding lines inoculated with *P. infestans* (US8, A2) and protected with reduced rates of chlorothalonil or fluazinam. Most suceptible varieties (in untreated control) treated with A, chlorothalonil B, fluazinum; moderately resistant varieties C, chlorothalonil, D, fluazinam; most resistant varieties E, chlorothalonil, F, fluazinam.

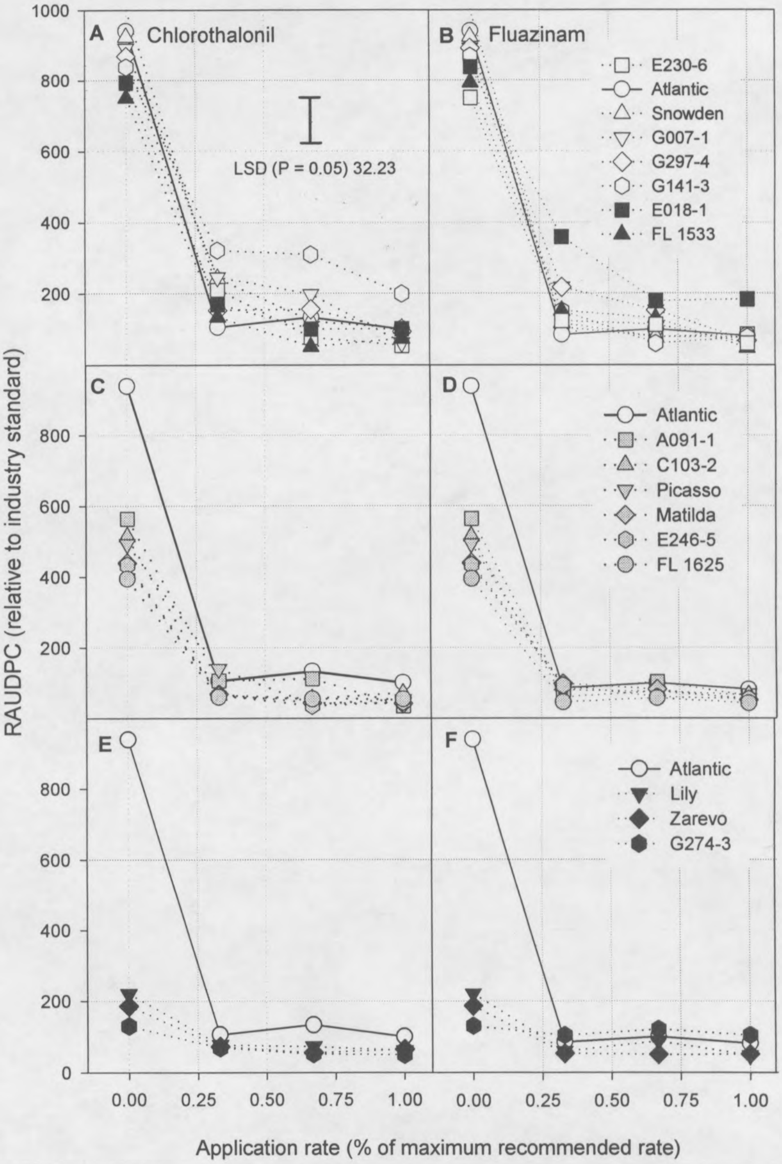

Figure 2 A - F. Relative area under the disease progress curve relative to an industry standard (cv. Atlantic, full rate chlorothalonil) in potato varieties and advanced breeding lines inoculated with *P. infestans* and protected with full and reduced rates of chlorothalonil and fluazinam. Most susceptible varieties (in untreated control) treated with A, chlorothalonil, B, fluazinam; moderately resistant varieties C, chlorothalonil, D, fluazinam; most resistant varieties E, chlorothalonil, F, fluazinam.

Table 1. Percent foliar disease and foliar RAUDPC values of potato varieties and advanced breeding lines after inoculation with *P. infestans* (US8 biotype).

Variety or Advanced Breeding Line[1]	Foliar infection (%)		RAUDPC[3] (max = 100)	Variety or Advanced Breeding Line	Foliar infection (%)		RAUDPC (max = 100)
	22 dai[2]	28 dai		varieties cont. from previous column	22 dai	28 dai	
LBR8	0.0	5.7	1	B1004-8	76.7	100.0	27
LBR9	0.7	9.0	1.33	LBR3_TBR	75.0	98.3	27.3
G274-3	5.0	20.0	4	G124-8P	68.3	91.7	27.7
Q237-25	8.7	35.0	5	H018-3	71.7	85.0	27.7
B0692-4	16.7	15.0	5	G050-2	71.7	93.3	28
AWN86514-2	13.3	21.7	5.33	TURBO	73.3	88.3	28.3
B0718-3	12.3	36.7	8	MATILDA	70.0	88.3	28.7
LBR0	10.0	55.0	8.33	G104-6	71.7	96.7	29
BZURA	18.3	56.7	10.3	MIRAKEL	75.0	96.7	29
ROBIJN	31.7	53.3	12	C103-2	71.7	93.3	29.3
B0288-17	41.7	58.3	14.3	ND5084-3R	73.3	95.0	29.7
ZAREVO	35.0	80.0	16.0	W1355-1	73.3	100.0	29.7
ELBA	43.3	66.7	17	GOLDRUSH	76.7	100.0	30
STOBRAWA	43.3	76.7	17.3	AF1753-16	75.0	100.0	30.3
LBR5	48.3	83.3	18	F373-8	76.7	93.3	31.3
ND02438-7R	41.7	88.3	19	H392-1	76.7	95.0	31.3
A084275-3	50.0	71.7	19.3	F099-3	78.3	100.0	31.3
LBR1R2R3R4	40.0	88.3	19.7	E018-1	76.7	95.0	31.7
DORITA	55.0	85.0	19.7	A7961-1	78.3	100.0	31.7
BERTITA	50.0	76.7	20.3	H380-3Y	78.3	100.0	31.7
ARS4219-1	55.0	70.0	20.3	W1151RUS	80.0	100.0	31.7
GRETA	51.7	81.7	21	H308-2	76.7	100.0	32
A080432-1	58.3	85.0	21	B076-2	78.3	100.0	32
A84118-3	60.0	90.0	21.3	DALI	71.7	91.7	32.3
LBR7	65.0	78.3	21.7	W1348RUS	76.7	96.7	32.3
B0811-13	58.3	100.0	22	ND2470-27	76.7	100.0	32.3
LBR2	60.0	100.0	24	NORVALLEY	81.7	100.0	32.3
A082611-7	58.3	93.3	24.3	AF1808-18	81.7	100.0	32.3
NORDONNA	66.7	98.3	25	MN17572	85.0	100.0	32.3
PICASSO	58.3	96.7	25.3	C120-1Y	76.7	100.0	32.7
B9922-11	65.0	100.0	25.3	ERNTESTOLZ	78.3	98.3	32.7
P88-5-12	63.3	91.7	25.7	NY112	78.3	100.0	32.7
LILY	66.7	91.7	26	MN17922	73.3	100.0	33
F105-10	66.7	91.7	26.7	B107-1	75.0	93.3	33
A091-1	68.3	90.0	26.7	B0178-34	80.0	100.0	33
H120-1	63.3	80.0	27	R_BURBANK	81.7	98.3	33
LBRY	71.7	100.0	27	F420-1	85.0	100.0	33
PIKE	73.3	100.0	27	F349-1	81.7	100.0	33.7
LSD (P = 0.05)	3.59	2.68	2.46	LSD (P = 0.05)	3.59	2.68	2.46

Table 1 (cont.)

Variety or Advanced Breeding Line	Foliar infection (%)		RAUDPC (max = 100)	Variety or Advanced Breeding Line	Foliar infection (%)		RAUDPC (max = 100)
varieties cont. from previous column	22 dai	28 dai		varieties cont. from previous column	22 dai	28 dai	
FAMBO	83.3	100.0	33.7	MS401-1	95.0	100.0	38.3
F060-6	85.0	100.0	33.7	B040-3	93.3	100.0	38.7
G119-1RD	81.7	100.0	34	E149-5Y	91.7	100.0	39
F019-11	85.0	100.0	34	NY115	91.7	100.0	39
NY119	88.3	100.0	34.3	C148-A	95.0	100.0	39
G139-1	81.7	98.3	34.7	E230-6	90.0	100.0	39.3
ATLANTIC	81.7	100.0	34.7	G088-6	90.0	100.0	39.3
E228-9	88.3	100.0	34.7	E263-10	95.0	100.0	39.3
H381-6Y	91.7	100.0	34.7	SHEPODY	91.7	100.0	39.7
G007-1	81.7	100.0	35	SUPERIOR	96.7	100.0	39.7
MN16966	83.3	100.0	35	A8495-1	93.3	100.0	40
SNOWDEN	85.0	100.0	35	ACCENT	95.0	100.0	40.7
E245-B	85.0	100.0	35	A097-1Y	91.7	98.3	41.7
E274-A	86.7	98.3	35	B094-1	98.3	100.0	41.7
F020-23	90.0	100.0	35	ND4093-4RUS	100.0	100.0	41.7
NT-2	83.3	100.0	35.3	P84-9-8	88.3	100.0	42
E080-4	86.7	100.0	35.3	SAG_GOLD	95.0	98.3	42.3
W1313	90.0	100.0	35.3	E040-6RY	96.7	100.0	42.3
MN16478	88.3	100.0	35.7	E030-4	93.3	100.0	42.7
E221-1	91.7	100.0	35.7	G141-3	95.0	100.0	43
H321-1	85.0	100.0	36	E226-4Y	93.3	100.0	43.3
H418-1	86.7	100.0	36	H112-6	95.0	100.0	43.3
Y_GOLD	88.3	100.0	36	F313-3	95.0	100.0	43.7
G297-4	86.7	96.7	36.3	F059-1	98.3	100.0	43.7
AF1475-20	85.0	100.0	37	E226-5	98.3	100.0	43.7
ONAWAY	93.3	100.0	37	E192-8RUS	98.3	100.0	44
E222-5Y	86.7	100.0	37.3	C086-3	98.3	100.0	44
H106-2	86.7	100.0	37.3	C122-1	100.0	100.0	44
H018-4	86.7	100.0	37.3	ARS4152-1	100.0	100.0	44.3
E228-1	90.0	100.0	37.3	E011-11	100.0	100.0	44.3
AF1763-2	93.3	100.0	37.7	E033-1RD	98.3	100.0	45.7
B106-7	88.3	100.0	38	H351-6	96.7	100.0	47.7
NT-1	91.7	98.3	38	P83-11-5	98.3	100.0	48.3
R_NORKOTAH	95.0	100.0	38.3	E011-14	100.0	100.0	50.3
LSD (P = 0.05)	3.59	2.68	2.46	LSD (P = 0.05)	3.59	2.68	2.46

[1] Ranked in order of RAUDPC, lines indicate susceptibility to *P. infestans* (< 5, most resistant; 5 -10 moderately resistant; 10 - 20 moderately susceptible; > 20 most susceptible).

[2] days after inoculation.

[3] Relative area under the disease progress curve (maximum value = 100).

Appendix 1. Weather data and disease indices for the Muck Farm 1998.

Date	Average Air Temperature		P-values early blight		DSV late blight		Air pressure Average	Average Daily Wind Speed	Rain		
	°C	°F	daily	cum.[1]	daily	cum.	Bar	mph	mm	in	cum.
06/22/98	21.0	69.8	16.9	17	1	1	739.7	0.6	0.51	0.02	0.02
06/23/98	24.6	76.2	20.5	37	1	2	740.0	0.7	1.60	0.06	0.08
06/24/98	22.7	72.9	18.6	56	2	4	740.4	0.7	6.70	0.27	0.35
06/25/98	22.8	73.1	18.7	75	0	4	739.1	0.9	0.00	0.00	0.35
06/26/98	20.3	68.6	16.2	91	1	5	737.8	0.8	2.10	0.08	0.44
06/27/98	16.9	62.3	12.8	104	0	5	739.6	0.4	0.00	0.00	0.44
06/28/98	20.0	68.1	15.9	120	1	6	742.5	0.5	1.77	0.07	0.51
06/29/98	21.4	70.6	17.3	137	2	8	743.4	0.4	4.32	0.17	0.68
06/30/98	20.9	69.6	16.8	154	1	9	741.1	0.8	0.00	0.00	0.68
07/01/98	21.1	70.0	17.0	171	1	10	738.5	0.4	0.50	0.02	0.70
07/02/98	22.4	72.3	18.3	189	0	10	740.6	0.7	0.00	0.00	0.70
07/03/98	21.4	70.5	17.3	206	1	11	740.4	1.0	2.29	0.09	0.79
07/04/98	20.3	68.6	16.2	223	2	13	740.1	0.8	7.11	0.28	1.08
07/05/98	16.9	62.3	12.8	235	0	13	744.3	0.4	0.00	0.00	1.08
07/06/98	20.0	68.1	15.9	251	1	14	740.9	0.5	4.56	0.18	1.26
07/07/98	21.4	70.6	17.3	269	0	14	738.5	0.4	0.50	0.02	1.28
07/08/98	20.9	69.6	16.8	285	1	15	737.8	0.8	0.50	0.02	1.30
07/09/98	21.0	69.7	16.9	302	0	15	739.6	0.4	0.00	0.00	1.30
07/10/98	19.5	67.1	15.4	318	0	15	742.5	0.7	0.00	0.00	1.30
07/11/98	16.8	62.3	12.7	330	0	15	743.4	0.4	0.00	0.00	1.30
07/12/98	18.7	65.7	14.6	345	0	15	741.1	0.6	0.00	0.00	1.30
07/13/98	19.6	67.2	15.5	360	0	15	739.8	0.6	0.00	0.00	1.30
07/14/98	22.0	71.5	17.9	378	1	16	740.0	0.8	1.77	0.07	1.37
07/15/98	23.4	74.1	19.3	398	2	18	740.0	0.6	4.32	0.17	1.54
07/16/98	23.7	74.7	19.6	417	0	18	738.7	0.7	0.00	0.00	1.54
07/17/98	19.9	67.8	15.8	433	1	19	739.2	1.0	0.50	0.02	1.56
07/18/98	18.5	65.4	14.4	447	0	19	739.3	0.4	0.00	0.00	1.56
07/19/98	23.0	73.3	18.9	466	1	20	736.4	1.2	2.03	0.08	1.64
07/20/98	24.1	75.3	20.0	486	0	20	737.7	0.9	0.00	0.00	1.64
07/21/98	23.9	75.0	19.8	506	2	22	736.5	2.0	3.81	0.15	1.80
07/22/98	23.0	73.5	18.9	525	1	23	738.1	1.0	0.25	0.01	1.81
07/23/98	20.1	68.2	16.0	541	4	27	737.4	1.3	25.91	1.04	2.84
07/24/98	15.1	59.3	11.0	552	1	28	741.9	0.6	2.29	0.09	2.93
07/25/98	16.0	60.9	11.9	564	1	29	744.4	0.3	0.75	0.03	2.96
07/26/98	16.9	62.4	12.8	577	0	29	743.8	0.6	0.00	0.00	2.96
07/27/98	19.3	66.7	15.2	592	2	31	738.7	1.3	4.32	0.17	3.14
07/28/98	21.2	70.1	17.1	609	0	31	736.6	1.3	0.00	0.00	3.14
07/29/98	21.9	71.3	17.8	627	0	31	737.9	1.1	0.00	0.00	3.14
07/30/98	19.0	66.3	14.9	642	0	31	740.2	0.4	0.00	0.00	3.14
07/31/98	18.1	64.6	14.0	656	1	32	745.4	0.5	7.87	0.31	3.45
08/01/98	17.2	62.9	13.1	669	0	32	749.0	0.4	0.00	0.00	3.45
08/02/98	18.5	65.3	14.4	683	0	32	747.0	0.4	0.00	0.00	3.45
08/03/98	19.2	66.5	15.1	698	3	35	744.7	0.4	12.45	0.50	3.95
08/04/98	17.2	62.9	13.1	711	0	35	749.0	0.4	0.00	0.00	3.95
08/05/98	20.4	68.8	16.3	728	1	36	743.5	0.8	1.27	0.05	4.00
08/06/98	22.3	72.1	18.2	746	2	38	741.0	0.7	9.14	0.37	4.37
08/07/98	23.4	74.0	19.3	765	1	39	741.6	0.7	1.02	0.04	4.41
08/08/98	23.6	74.4	19.5	785	2	41	743.5	0.8	2.28	0.09	4.50

Appendix 1cont.

Date	Average Air Temperature		P-values early blight		DSV late blight		Air pressure Average	Average Daily Wind Speed	Rain		
	◦C	◦F	daily	cum.[1]	daily	cum.	Bar	mph	mm	in	cum.
08/10/98	21.2	70.1	17.1	820	3	47	738.6	0.5	12.95	0.52	5.63
08/11/98	18.6	65.5	14.5	834	1	48	741.1	0.7	0.76	0.03	5.67
08/12/98	17.2	63.0	13.1	848	0	48	745.4	0.4	0.25	0.01	5.68
08/13/98	17.2	63.0	13.1	861	0	48	744.2	0.2	0.25	0.01	5.69
08/14/98	18.2	64.8	14.1	875	2	50	739.5	0.4	5.33	0.21	5.90
08/15/98	19.9	67.8	15.8	891	0	50	737.9	0.3	0.25	0.01	5.91
08/16/98	20.4	68.8	16.3	907	0	50	741.4	0.5	0.00	0.00	5.91
08/17/98	21.4	70.5	17.3	924	2	52	740.1	0.7	14.72	0.59	6.50
08/18/98	18.9	66.0	14.8	939	0	52	743.7	0.7	0.25	0.01	6.51
08/19/98	13.7	56.6	9.6	949	0	52	747.8	0.4	0.00	0.00	6.51
08/20/98	17.4	63.4	13.3	962	0	52	746.2	0.7	0.25	0.01	6.52
08/21/98	23.1	73.6	19.0	981	2	54	744.6	0.5	9.15	0.37	6.88
08/22/98	22.3	72.1	18.2	999	0	54	743.2	0.4	0.25	0.01	6.89
08/23/98	25.6	78.0	21.5	1021	0	54	736.4	1.7	0.00	0.00	6.89
08/24/98	26.1	78.9	22.0	1042	0	54	733.1	1.6	0.00	0.00	6.89
08/25/98	22.2	72.0	18.1	1061	2	56	734.9	1.1	12.18	0.49	7.38
08/26/98	18.2	64.8	14.1	1075	0	56	741.1	0.5	0.25	0.01	7.39
08/27/98	19.8	67.6	15.7	1090	0	56	743.2	0.3	0.00	0.00	7.39
08/28/98	19.3	66.7	15.2	1106	1	57	741.0	0.4	0.76	0.03	7.42

[1] Cumulative

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Potato Varietal Response to Novel Agrochemicals: Plant Growth Regulators and Mycorrhizal Stimulants

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ABSTRACT

In the first year of a multi-year study, three commercial potato varieties (Atlantic, Snowden and Russet Burbank) received various treatments of three novel agrochemicals: an auxin-based growth regulator (AuxiGro), a gibberellin-based growth regulator (Early Harvest) and an isoflavonoid-based mycorrhizal symbiont stimulator (Myconate). The treatments consisted of varying rates, dosages and timings of applications. Plants were measured for rate of emergence, plant biomass, yield and specific gravity. For each chemical, there were no significant differences between the treatments. Although the varieties examined showed significant differences in emergence, biomass and yield, these differences were düe to differential seed lot quality. The varieties tended to respond differently to the various chemical/treatment combinations, but these differences were not consistently significant.

Introduction

With increased demand for zero-defect produce in North American potato markets, agrochemical supplements which can subtly alter or "fine tune" the pattern of growth and development of potato plants are seen as important niche products. While treatments such as fertilizers, pesticides, irrigation and soil pH amendments alter gross morphology, growth and yield, agrochemical supplements have traditionally included micronutrient supplements, growth regulators or other chemicals designed to modify more subtle secondary growth responses. Research into potato physiology, soil microbiology and cell biochemistry can guide the development of new agrochemical supplements. Improved understanding of the sequence of potato plant growth and development continues to improve the method and timing of application of these chemicals to ensure maximal efficacy.

The objectives of this study were to compare the response of potato plants a) of three commercial varieties to b) various formulations and applications of novel supplemental agrochemicals, including an auxin-based growth regulator, a gibberellin-based growth regulator and an isoflavonoid-based stimulator of a fungal soil symbiont.

Materials and Methods

Potato seed tubers of Atlantic, Snowden and Russet Burbank were obtained from the MSU Potato Breeding Program. These tubers were planted at the Montcalm Research Farm (MRF). Each treatment replicate consisted of 25 plants, spaced 12". Each treatment was replicated four times. The treatments were applied based on plant development characteristics. The critical timings were a) planting (0 days after planting, DAP), b) tuber initiation with stems 6" high (21 DAP), c) 67% row closure (40 DAP) and d) full closure (49 DAP).

The auxin-based growth regulator (AuxiGro, a product of Auxien Corp.) treatments consisted of two formulations and was applied in split foliar application as three treatments. Dosages and timings for all treatments are given in Table 1. The first treatment (AuxiGro-1) applied the commercial formulation split between tuber initiation and 67% canopy closure. The second treatment (AuxiGro-2) applied the commercial formulation split between 67% canopy closure and full closure. The third treatment (AuxiGro-3) applied a modified formulation split between 67% canopy closure and full closure.

The gibberellin-based growth regulator (Early Harvest, a product of Griffen Corp.) treatments consisted of two concentrations and was applied in split tuber and foliar applications. A seed treatment was applied immediately before planting. The low (Early Harvest low) and high (Early Harvest high) concentration foliar applications were split between tuber initiation and 67% canopy closure.

The isoflavonoid-based mycorrhizal fungal stimulant (Myconate, a product of Vamtech Inc.) treatments consisted of four concentrations (Myconate 5ppm, 10ppm, 17.5ppm and 25ppm) applied as a foliar and soil drench at the time of tuber initiation.

Treatments were examined for emergence beginning 21 days after planting (DAP), and for canopy development at 32 DAP. The relative area under the emergence curve (RAUEC) was calculated for each replicated treatment based on five (5) emergence assessments. Tuber yield and quality were taken. The relative area under the emergence curve (RAUEC) was calculated for each replicated treatment based on five (5) emergence assessments. Tuber yield and quality were taken.

Canopy volume was calculated by an ellipsoidal approximation. The volume of an ellipsoid is derived as: $V=(4/3)(\pi)(ABC)$, where A, B an C are the semiaxes of the ellipsoid. In a potato plant, A=plant height (h) and B=C=radius of plant at ground level (r). The volume of the individual plant is therefore derived as: $V_{plant}=(4/3)(\pi)(hr^2)$. The average plant estimation is derived from and average of the two largest and the two smallest emerged plants. Total treatment canopy volume is the average single plant volume for each treatment multiplied by the number of emerged plants. Treatments were harvested after approximately 100 days. Tubers were sorted by size (B and A+oversize). The fractional yield (% B) was calculated. Specific gravity was measured for a sample of tubers from each treatment (approximately 50 tubers). Data were examined with one-way analysis of variance (ANOVA).

Results

The three varieties showed different emergence and stand density. The Atlantic and Russet Burbank plantings showed markedly poorer emergence, typically 40-50% vs. 95-100% for Snowden. This difference between varieties arising from seed lot issues prevented meaningful combined analysis of the data across varieties.

Within varieties, there were no significant differences between the different formulations and/or applications of the chemicals examined.

Discussion

The results from the first year of this multi-year study showed no differences between the formulations and/or applications of the chemicals examined. In part, this was due to poor growing conditions at the MRF resulting from drought in 1998. The major perturbing factor in the 1998 phase of this study was the poor seed lot quality of the Atlantic and Russet Burbank seed. This difference overwhelmed the more subtle differences that may have otherwise resulted. This study is continuing and future implementations will address the limitations observed in this first year of the study.

Notice: Mention of a product and/or brand name does not constitute an endorsement.

Table 1. Dosage and timing of chemical applications on Atlantic, Russet Burbank and Snowden potatoes, Montcalm Research Farm.

CHEMICAL	%Active or Lb/Gal	Formulation	Rate of formulation	Rate Active	Spray Schedule	Company	Rate (lb/A or pt/A)
Untreated							
Myconate 5ppm	5 %	SC	0.22 Pints/A	0.14 lb/A	21 dap (3L on 3 varieties)	Vamtech	0.22
Myconate 10ppm	5 %	SC	0.45 Pints/A	0.28 lb/A	21 dap (3L on 3 varieties)	Vamtech	0.45
Myconate 17.5ppm	5 %	SC	0.78 Pints/A	0.49 lb/A	21 dap (3L on 3 varieties)	Vamtech	0.78
Myconate 25ppm	5 %	SC	1.12 Pints/A	0.70 lb/A	21 dap (3L on 3 varieties)	Vamtech	1.12
AuxiGro-1	60 %	WP	0.31 Lbs/A	0.19 lb/A	21, 40 dap (3L on 3 varieties)	Auxien	0.3125
AuxiGro-2	60 %	WP	0.31 Lbs/A	0.19 lb/A	40, 49 dap (3L on 3 varieties)	Auxien	0.3125
AuxiGro-3	60 %	WP	0.31 Lbs/A	0.19 lb/A	40, 49 dap (3L on 3 varieties)	Auxien	0.3125
Early Harvest low	0.165 %	SC	0.20 Pints/A	0.00 lb/A	21, 40 dap (3L on 3 varieties)	Griffen	0.1
Early Harvest high	0.165 %	SC	0.20 Pints/A	0.00 lb/A	21, 40 dap (3L on 3 varieties)	Griffen	0.2

Table 2. Varietal response to an auxin-based growth regulator (AuxiGro, a product of Auxien Corp.).

		Canopy Volume (cc)			Yield (lbs)				Approx.	Specific
Treatment	Variety	Single plant	Treatment	RAUEC	B	A+oversize	Total	%B	CWT/Acre	Gravity
Control	Atlantic	6461	70271	0.220	2.0	37.7	39.7	5.1%	238.2	1.079
AuxiGro-1	Atlantic	5341	50426	0.190	1.5	27.8	29.2	5.0%	175.5	1.077
AuxiGro-2	Atlantic	4069	34699	0.167	1.2	27.7	28.9	4.1%	173.3	1.079
AuxiGro-3	Atlantic	6192	52653	0.170	2.0	35.6	37.5	5.5%	225.1	1.076
Control	R. Burbank	12096	147091	0.277	6.5	22.3	28.8	22.5%	173.0	1.066
AuxiGro-1	R. Burbank	7438	75403	0.226	6.2	23.7	30.0	21.3%	179.7	1.074
AuxiGro-2	R. Burbank	5704	69375	0.261	7.5	27.1	34.6	22.2%	207.6	1.065
AuxiGro-3	R. Burbank	6290	75617	0.269	6.3	18.9	25.2	24.6%	151.1	1.067
Control	Snowden	8706	159681	0.423	7.8	38.3	46.1	17.0%	276.4	1.076
AuxiGro-1	Snowden	6224	113279	0.378	8.3	36.0	44.3	18.9%	265.7	1.075
AuxiGro-2	Snowden	11235	225331	0.456	9.2	31.1	40.3	22.6%	241.6	1.075
AuxiGro-3	Snowden	9480	159806	0.384	7.9	40.4	48.3	16.5%	289.9	1.075

Table 2. Varietal response to an gibberellin-based growth regulator (Early Harvest, a product of Griffen Corp.).

		Canopy Volume (cc)			Yield (lbs)				Approx.	Specific
Treatment	Variety	Single plant	Treatment	RAUEC	B	A+oversize	Total	%B	CWT/Acre	Gravity
Control	Atlantic	6461	70271	0.220	2.0	37.7	39.7	5.1%	238.2	1.079
Early Harvest low	Atlantic	8413	47309	0.131	1.6	28.2	29.8	5.2%	178.8	1.078
Early Harvest high	Atlantic	3900	30763	0.121	1.4	24.6	25.9	5.8%	155.6	1.076
Control	R. Burbank	12096	147091	0.277	6.5	22.3	28.8	22.5%	173.0	1.066
Early Harvest low	R. Burbank	11675	151168	0.293	7.2	24.9	32.1	22.7%	192.5	1.067
Early Harvest high	R. Burbank	6062	81478	0.279	8.8	23.8	32.5	26.9%	195.1	1.068
Control	Snowden	8706	159681	0.423	7.8	38.3	46.1	17.0%	276.4	1.076
Early Harvest low	Snowden	7939	156583	0.416	8.4	35.8	44.2	18.5%	265.1	1.077
Early Harvest high	Snowden	9699	165236	0.444	6.5	29.3	35.9	18.3%	215.2	1.076

Table 3. Varietal response to an isoflavonoid-based mycorrhizal fungal stimulant (Myconate, a product of Vamtech Inc.).

		Canopy Volume (cc)			Yield (lbs)				Approx.	Specific
Treatment	Variety	Single plant	Treatment	RAUEC	B	A+oversize	Total	%B	CWT/Acre	Gravity
Control	Atlantic	6461	70271	0.220	2.0	37.7	39.7	5.1%	238.2	1.079
Myconate 5ppm	Atlantic	5061	37638	0.154	1.3	24.4	25.6	5.2%	153.8	1.077
Myconate 10ppm	Atlantic	5716	39638	0.121	1.5	30.2	31.7	4.6%	189.9	1.077
Myconate 17.5ppm	Atlantic	7656	66691	0.160	1.3	28.9	30.2	4.3%	181.0	1.078
Myconate 25ppm	Atlantic	8178	45602	0.110	1.6	35.6	37.2	4.2%	223.1	1.079
Control	R. Burbank	12096	147091	0.277	6.5	22.3	28.8	22.5%	173.0	1.066
Myconate 5ppm	R. Burbank	9549	132939	0.293	7.7	26.0	33.6	23.6%	201.6	1.067
Myconate 10ppm	R. Burbank	7193	104470	0.302	7.2	21.4	28.5	25.4%	171.1	1.068
Myconate 17.5ppm	R. Burbank	5007	58571	0.277	8.3	20.8	29.1	28.6%	174.4	1.066
Myconate 25ppm	R. Burbank	7234	76239	0.236	8.2	19.8	27.9	30.4%	167.6	1.066
Control	Snowden	8706	159681	0.423	7.8	38.3	46.1	17.0%	276.4	1.076
Myconate 5ppm	Snowden	9660	190342	0.454	9.6	36.6	46.1	21.5%	276.7	1.075
Myconate 10ppm	Snowden	8664	161365	0.391	8.4	32.4	40.7	21.0%	244.3	1.076
Myconate 17.5ppm	Snowden	9811	181071	0.435	9.3	40.0	49.3	19.4%	295.6	1.077
Myconate 25ppm	Snowden	7521	143308	0.418	9.2	36.5	45.6	20.0%	273.8	1.076

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Susceptibility of Potato (*Solanum tuberosum*) Foliage and Tubers to the US8 Biotype of *Phytophthora infestans*

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ABSTRACT
Commercial varieties and advanced breeding lines of potato (*Solanum tuberosum*) were examined for foliar and tuber susceptibility to the US8 biotype of potato late blight (*Phytophthora infestans*) to determine the extent to which these factors are related. In advanced potato breeding material, foliar and tuber susceptibility varied significantly among 19 breeding lines , but did not differ among 4 commercial varieties. In the potato material examined, foliar and tuber susceptibility to potato late blight were not correlated. Low tuber susceptibility was associated both with extremely low (e.g. G274-3) and high (e.g. E202-3Rus) foliar susceptibility. This implies that the biophysical mechanisms controlling foliar and tuber susceptibility are distinct from each other in the potato material examined. In research programs addressing varietal response to modern biotypes of *P. infestans*, foliar and tuber susceptibility should be regarded as separate agronomic characteristics.

Introduction
Potato late blight (*Phytophthora infestans* (Mont.) de Bary) has re-emerged as a significant threat to potato (*Solanum tuberosum* L.) production worldwide in recent years (Andviron 1995; Fry and Goodwin 1995). *P. infestans* causes severe defoliation and may also infect potato tubers after sporangia or zoospores move through the soil water and penetrate the tuber periderm (Campbell and Madden 1989; Lacey, 1977). Economic losses due to late blight therefore result from tuber as well as foliar susceptibility. Severe storage losses can occur after tubers infected with *P. infestans* are held for processing at temperatures in excess of 7°C (Kirk et al., 1997). Although the production of late blight resistant varieties is a priority for potato breeding programs, no commercial varieties with good foliar resistance to modern biotypes of *P. infestans* are currently available (Douches et al. 1997). The biophysical mechanisms controlling late blight susceptibility in potato varieties are complex, and can involve differences in leaf and tuber cell defense biochemistry, as well as canopy structure, leaf anatomical variation and vine maturation rates (Douches et al., 1997; Gees and Hohl 1987; Kirk et al., 1997). Studies examining foliar and tuber susceptibility are inconclusive regarding the strength of association between these characteristics (Platt and Tai, 1998; Stewart et al., 1992; Stewart et al., 1994). The metalaxyl-insensitive US8 biotype, A2 mating type, has supplanted the metalaxyl-sensitive US1 biotype, A1 mating type, as the dominant biotype in much of North America (Fry and Goodwin, 1995.). The population structure of *P. infestans* in North America is continuing to change as new biotypes emerge (Fry and Goodwin, 1995.). The objective of this study was to examine tuber and foliar susceptibility of commercial potato varieties and advanced breeding lines to an aggressive isolate of the US8 biotype of *P. infestans* to determine the strength of the association between these agronomic characteristics.

Materials and Methods
Plant material
The commercial varieties included Atlantic, Onaway, Snowden and Yukon Gold and advanced breeding lines obtained from the Michigan State University potato breeding program: A091-1, B040-

3, B073-2, B076-2, C103-2, E018-1, E202-3Rus, E221-1, E228-11, E230-6, E246-5, F099-3, F373-8, G007-1, G050-2, G227-2, G274-3, NY101 and NY103. Tuber material was produced in 1997 field plots which were maintained with a chlorothalonil-based fungicide program. Tubers were determined to be disease-free and stored at 8°C, 90% relative humidity for 3 months prior to testing. Ten matured tubers from each variety/breeding line were surface sterilized by soaking in a 10% bleach solution for 30 minutes and rinsed 5x with distilled water.

Tubers were inoculated with *P. infestans* isolate 97-2 (US8, A2 mating type). Axenic cultures of *P. infestans* 97-2 were grown on rye agar plates for 14 days at 18°C in the dark (Dhingra and Sinclair, 1985). A mycelial homogenate was prepared from the mature culture (Schmitthenner and Bhat, 1994). Approximately 0.1ml of the mycelial homogenate was injected into the apical end of each tuber. The homogenate was injected 3-5 mm into the tuber periderm, 1-2cm from the apical meristem. Tubers were transferred to controlled environment chambers (12°C, 95% relative humidity) and stored in the dark for 40 days. Inoculated tubers were removed from storage and surface development of disease was visually rated on a 1-9 scale (Table 1). The tubers were then sectioned transversely, exposing the apical, middle and terminal regions of the internal tuber tissue. The internal surfaces were digitally scanned and computer image analysis was used to quantify internal disease (Niemira et al., 1998). The average reflective intensity (ARI) of the apical, middle and terminal regions yielded the Apical, Middle and Terminal disease metrics, respectively. These metrics were averaged to produce Mean ARI, a metric of overall tuber disease severity. Data were analyzed with ANOVA ($P<0.05$) to detect differences between varieties. The experiment was performed twice. Data for the first trial is presented in Table 2.

Seed tubers of the described varieties/breeding lines were stored at 10C, 90% r.h. for at least 8 weeks. Seed tubers were cut and planted in field plots as part of larger variety trials at the MSU Muck Soils Research Station in 1997 and 1998. Plots consisted of five cut seed tubers planted in May of each year. The seed piece size varied among the breeding lines due to tuber size; each see piece had at least three eyes. Tubers were planted 0.25m apart and at 1m spacing between rows. Within rows, varieties were separated by 0.5m. The varieties were arranged in a complete randomized block design and replicated in three blocks (n=3). Plants were hilled immediately after emergence. No foliar fungicides were applied. Weeds were controlled by hilling and with metolachlor at 2.3 l/ha 10 dap (days after planting), bentazon salt at 2.3 l/ha, 20 and 40 dap and sethoxydim at 1.8 l/ha, 58 - 60 dap. Insects were controlled with imidacloprid at 1.4 kg/ha at planting, carbaryl at 1.4 kg/ha, 31 and 55 dap, endosulfan at 2.7 l/ha, 65 and 87 dap and permethrin at 0.56 kg/ha, 48 dap. The dates of application were similar for 1997 and 1998. Immediately prior to row closure, the foliage was sprayed with a suspension of zoospores of the previously described US8 biotype of *P. infestans*. The volume of inoculum applied was calibrated to deliver approximately 1000 zoospores per plant based on the canopy density of a typical variety, e.g. Snowden. In order to promote disease, rainfall was supplemented with mist sprinkler irrigation to maintain high humidity within the canopy. Visual foliar disease ratings were taken every 5 to 7 days beginning immediately following inoculation until approximately 30 days after inoculation. The relative area under the disease progress curve (RAUDPC) was calculated for each plot. Data were analyzed with ANOVA for differences between varieties. The experiment was performed twice. Data for the first (1997) trial is presented in Table 2.

The field foliar susceptibility trial examined approximately 150 varieties and breeding lines in addition to those presented. To identify possible sampling bias, a chi-square analysis was performed on the quartile rankings of the identified varieties and breeding lines within the 170 varieties in the entire 1997 field trial.

The ratings of tuber and foliar infection were analyzed with Pearson's product moment correlation test to determine the strength of relation between these characteristics. The rank order by tuber susceptibility for each tuber disease metric was compared with the rank order by foliar susceptibility using chi-square analysis. Varieties and breeding lines were described as Susceptible (S), Moderately Susceptible (MS), Moderately Resistant (MR) or Resistant (R) according to defined criteria for each susceptibility metric. The criteria for each category are presented in Table 3.

Results

Tuber susceptibility of the varieties examined was significantly different ($P<0.05$) only between the most susceptible (e.g. G050-2) and least susceptible (e.g. G274-3) breeding lines (Table 2). The visual rating of tuber surface disease development is significantly ($P<0.05$) correlated with the digital ratings of internal disease development. The correlation between the surface and internal disease metrics are moderate (Table 2). By the surface disease rating metric, there were significant differences among the breeding lines ($P<0.05$), but commercial varieties did not differ. The digital measures of internal late blight severity indicated significant ($P<0.05$) differences among commercial varieties in the Apical and Mean ARI metrics. The Apical, Middle, Terminal and Mean ARI metrics showed significant differences ($P<0.05$) among the breeding lines. As a result of the apical inoculation site, ARI ratings from apical sections generally tended to be lower (more disease) than ARI from middle or terminal sections. In some lines, this difference was more pronounced (e.g. E221-1, G227-2), while in others this difference was minimal (e.g. A091-1, E228-11). The results from each run of the experiment were similar.

The breeding line G274-3 had a foliar susceptibility (RAUDPC) rating significantly ($P<0.05$) lower than most other breeding lines (Table 2). All other varieties and breeding lines did not differ from each other. The results from each run of the experiment were similar. The breeding lines and varieties examined for tuber susceptibility were distributed evenly among the quartiles of the foliar susceptibility rankings of the larger foliar susceptibility trial based on chi-square analysis, indicating that there was no selection bias in the varieties chosen for tuber susceptibility studies.

Foliar susceptibility ratings are not correlated with any tuber susceptibility metric (Table 2). Chi-square analysis of the rank orders showed that the ranking by foliar susceptibility did not match the ranking by any tuber susceptibility metric. The classification by susceptibility class is generally consistent between the tuber susceptibility metrics, while the foliar susceptibility metric classifies most varieties as Susceptible, with F373-8 as Moderately Susceptible and G274-3 as Resistant (Table 3).

Discussion

In this study, foliar and tuber susceptibility were not correlated. The rank of a given breeding line or variety with regard to one type of susceptibility allowed no reliable inference to be drawn regarding the other type of susceptibility. The two breeding lines with the lowest tuber susceptibility had the lowest (G274-3) and the highest (E202-3Rus) foliar susceptibility. The breeding lines and varieties examined were classified variously based on the tuber susceptibility metrics, but nearly all were classified as Susceptible based on foliar susceptibility. This also suggests that foliar and tuber susceptibility are governed by different mechanisms. This has implications for the process of breeding a late blight resistant potato variety, in that the two types of susceptibility must be assessed independently. The overwhelming categorization of the 23 breeding lines and varieties examined as Susceptible indicates that more research and breeding is required to produce a commercially acceptable variety with resistance to late blight.

The association between tuber and foliar susceptibility to late blight is a matter of ongoing research. Dorrance and Inglis (1998) concluded that foliar and tuber susceptibility were not correlated, while a separate report indicated that a strong correlation exists (Platt and Tai, 1998). The isolates of *P. infestans* used in these studies included older biotypes such as US1 (Platt and Tai, 1998; Stewart et al., 1992; Stewart et al., 1994) and modern biotypes such as US8 (Dorrance and Inglis, 1998). This also suggests that the pathogen response to resistance mechanisms may be biotype specific. The mechanisms by which late blight development is slowed are different in tubers vs. foliage. These mechanisms may be related to histological and/or cytological variations in the tuber or canopy, biochemical defense responses or a combination of these and other factors (Gees and Hohl, 1987.). The interactions of these underlying mechanisms may change with changes in plant maturity related to canopy development, tuber development and maturation of tubers in storage (Plissey, 1993; Rowe and Secor, 1993).

It is clear that more work is needed to fully elucidate the association between foliar and tuber susceptibility. Potato lines which have been genetically engineered to express anti-fungal agents, such as glucose oxidase (Wu et al., 1995), may have a more tightly coupled response to late blight development if the same anti-fungal agent is expressed both in foliage and tubers. Research is ongoing to determine the extent to which genetically modified potato plants which systemically express glucose oxidase demonstrate changes in foliar and tuber susceptibility to late blight (K. Walters, MSU, personal communication). Foliar and tuber resistance that is native to a breeding line results from different native biophysical mechanisms. Development and implementation of systemically expressed genetic constructs should address the extent to which the introduced resistance mechanism may augment or supercede native resistance mechanisms, both in foliage and tubers. In assigning a variety to a class such as Susceptible or Moderately Resistant, care should be taken, therefore, to specify whether the description is based on foliar or tuber susceptibility.

The North American population of *P. infestans* is evolving, with new biotypes such as US11 increasing in prominence (Fry and Goodwin, 1995.). The role that sexual recombination may play in future population dynamics of *P. infestans* is not fully understood. In light of the emergence of new biotypes and the increasing complexity of the North American *P. infestans* population, susceptibility screening of breeding material and introduced commercial varieties should include tests using modern biotypes of *P. infestans* in order to maximize the utility of the information for breeding and genotype development programs.

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Additional Keywords

Late blight, breeding, variety

Literature cited

Andviron R. 1995. Comparison of race structure and diversity in populations of *Phytophthora infestans*, 1966-1993. pp 71 - 76, *in* L.J. Dowley, E. Bannon, L.R. Cooke, T.Keane and E.O. Sullivan (eds.) Phytophthora infestans 150. Boole Press, Dublin.

Campbell, C.L. and Madden, L.V. 1989. Ch.6 (pp. 107-128) *in* Introduction to Plant Disease Epidemiology. John Wiley and Sons, New York, NY.

Dhingra, O.D. and Sinclair, J.B. 1985. Ch.2 (p.29) *in* Basic Plant Pathology Methods. CRC Press, Boca Raton, FL.

Dorrance, A.E. and Inglis, D.A. 1998. Assessment of laboratory methods for evaluating potato tubers for resistance to late blight. Plant Dis. 82:442-446.

Douches, D.S., Kirk, W.W., Jastrzebski, K., Long, C. and Hammerschmidt, R. 1997. Susceptibility of potato varieties and advanced breeding lines (*Solanum tuberosum* L.) To *Phytophthora infestans* (Mont.) de Bary in greenhouse screenings. Amer. Potato J 74:75-86.

Fry, W.E. and Goodwin, S.B. 1995. Recent migrations of *Phytophthora infestans*. pp 89-95, *in* L.J. Dowley, E. Bannon, L.R. Cooke, T.Keane and E.O. Sullivan (eds.) Phytophthora infestans 150. Boole Press, Dublin.

Gees, R. and Hohl, H.R. 1987. Cytological comparison of specific (R3) and general resistance to late blight in potato leaf tissue. Phytopath. 78:350-357.

Kirk, W.W., Niemira, B.A., Kitchen, B., Stein, J.M. and Hammerschmidt, R. 1997. Digital assessment of late blight (*Phytophthora infestans*) in tubers of three susceptible varieties as influenced by storage temperature (abstr.). p. 09 in Proceedings of 81st Annual Meeting of the Potato Association of America, August, 1997, Charlottetown, PEI, Canada.

Lacey, J. 1977. The role of water in the spread of *Phytophthora infestans* in the potato crop. Annals of Applied Biology, 59:245 - 255.

Niemira, B.A., Kirk, W.W. and Stein, J.M. 1998. Screening for late blight susceptibility in potato tubers by digital analysis of cut tuber surfaces. Plant Dis. (in press).

Platt, H.W. and Tai, G. 1998. Relationship between resistance to late blight in potato foliage and tubers of cultivars and breeding selections with different resistance levels. Amer J of Potato Res. 75:173-178.

Plissey, E.S. 1993. Maintaing tuber health during harvest, storage, and post-harvest handling, pp. 41-54 *in* Rowe, R.C. (Ed) Potato Health Management. APS Press, St. Paul, MN.

Rowe, R.C. and Secor, G.A. 1993. Managing potato health from emergence to harvest, pp. 35-40 *in* Rowe, R.C. (Ed) Potato Health Management. APS Press, St. Paul, MN.

Schmitthenner, A.F. and Bhat, R.G. 1994. Useful methods for studying *Phytophthora* in the laboratory. p. 7. Ohio Agricultural Research and Development Center, Ohio State University, Wooster, OH.

Stewart, H.E., Wastie, R.L., Bradshaw, J.E. and Brown, J. 1992. Inheritance of resistance to late blight in foliage and tubers of progenies from parents differing in resistance. Potato Res. 35:313-319.

Stewart, H.E., Bradshaw, J.E. and Wastie, R.L. 1994. Correlation between resistance to late blight in foliage and tubers in potato clones from parents of contrasting resistance. Potato Res 37:429-434.

Wu, G. Shortt, B.J. Lawrence, E.B. Levine, E.B., Fitzsimmons, K.C. and Shah, D.M. 1995. Disease resistance conferred by expression of a gene encoding H_2O_2-generating glucose oxidase in transgenic potato plants. Plant cell. 7(9):1357-1368.

Table 1. Visual rating scale for late blight (*Phytophthora infestans*) in potato tubers (reprinted from Niemira et al., 1998)

Rating	Visual disease symptoms of whole tubers inoculated with *P. infestans*			
	Skin discoloration (% of surface)	Sprout damage (% total sprouts)	Sporulation (% of surface)	Physical degradation (% of surface)
1	0	0	0	0
2	<10	0	0	0
3	>10	0-5	0	0
4	>25	>5	<10	0
5	>25	>5	10-50	<10 (spots <1cm in diameter)
6	>25	>5	50-75	10-25 (spots >1cm in diameter)
7	>25	>5	>75	25-50 (spots >1cm in diameter)
8	>25	>5	>75	50-75, loss of internal structure
9	>25	>5	>75	75-100, complete physical breakdown

Table 2. Susceptibility of potato foliage and tubers of advanced breeding lines and commercial varieties to potato late blight, (*Phytophthora infestans*) US8 biotype.

Variety	Tuber disease					Foliar disease
	Surface	Internal rating[b]				RAUDPC[d]
	Rating[a]	Apical	Middle	Terminal	Mean ARI[c]	
Atlantic[e]	4.5 cdef[f]	160.21 abcde	189.69 ab	184.13 abc	178.01 abcd	0.455 a
Onaway	4.8 abcdef	145.65 bcde	153.43 bc	148.82 c	149.30 cd	0.516 a
Snowden[e]	4.3 def	173.34 abcde	185.56 ab	194.01 abc	184.30 abcd	0.386 a
Yukon Gold[e]	4.3 cdef	176.95 ab	202.44 a	210.06 abc	196.48 ab	0.506 a
A091-1	6.0 abcde	142.32 bcde	146.94 bc	146.37 c	145.21 c	0.444 a
B040-3	4.0 ef	163.41 abcde	174.69 abc	162.15 abc	166.75 abcd	0.411 a
B073-2[e]	5.4 abcdef	154.49 abcde	176.88 abc	174.32 abc	168.56 abcd	0.492 a
B076-2[e]	6.2 abce	137.27 cde	156.40 bc	150.46 c	148.04 d	0.409 a
C103-2	6.4 abce	151.69 abcde	172.31 abc	185.89 abc	169.30 abcd	0.452 a
E018-1	4.8 bcdef	176.45 abc	190.21 a	191.42 abc	186.03 abc	0.381 a
E202-3 Rus[e]	3.9 f	186.06 a	200.53 a	213.03 a	199.87 a	0.518 a
E221-1	6.0 abcdef	128.00 e	147.67 bc	175.00 abc	150.22 cd	0.517 a
E228-11	4.5 cdef	184.01 a	184.40 abc	186.77 abc	185.06 abc	0.515 a
E230-6	4.4 cdef	164.48 abcde	178.26 abc	178.60 abc	173.78 abcd	0.359 a
E246-5	4.5 cdef	172.79 abcd	178.89 abc	189.78 abc	180.49 abcd	0.397 a
F099-3	4.5 cdef	171.17 abcd	170.37 abc	--- ---	170.77 abcd	0.482 a
F373-8	4.1 cdef	149.33 abcde	170.78 abc	167.80 abc	162.63 bcd	0.272 ab
G007-1[e]	5.1 abcdef	167.77 abcde	184.03 abc	182.26 abc	178.02 abcd	0.471 a
G050-2[e]	7.1 ab	160.86 abcde	156.63 bc	162.56 bc	160.02 cd	0.408 a
G227-2	4.6 bcdef	145.95 abcde	155.91 bc	176.37 abc	159.41 cd	0.458 a
G274-3[e]	3.9 f	156.77 abcde	183.41 abc	187.74 abc	175.97 abcd	0.041 b
NY101[g]	4.0 f	152.38 abcde	164.30 abc	156.31 c	157.66 cd	0.507 a
NY103[g]	5.7 abcdef	136.05 de	143.67 c	148.53 c	142.75 d	0.508 a

Correlation coefficient (P<0.05)					
Surface rating	-0.355	-0.404	-0.285	-0.384	NS[h]
Apical		0.736	0.537	0.834	NS
Middle			0.758	0.936	NS
Terminal				0.884	NS
Mean ARI					NS

a Surface ratings are 1 (no disease) to 9 (heavy disease)

b Internal ratings are Average Reflective Intensity (ARI) based on digital scan of internal tuber tissue. Lower value = darker image = more disease

c Mean ARI = (Apical + Middle + Terminal)/3

d RAUDPC = Relative Area Under Disease Progress Curve, based on % diseased foliage (max=1)

e Values for this variety reprinted from Niemira et al., 1998

f Numbers in a given column with different letters are significantly different (P<0.05, Tukey) by ANOVA

g Breeding material produced by Cornell University, obtained through MSU potato breeding program

h NS = no significant correlation (P<0.05, Pearson's product moment)

Table 3. Ranking of varieties and breeding lines according to susceptibility.

Variety	Tuber disease					Foliar disease
	Surface Rating[a]	Internal rating[b]				RAUDPC[d]
		Apical	Middle	Terminal	Mean ARI[c]	
Susceptible (S)	>5	<150	<150	<150	<150	>0.35
Moderately susceptible (MS)	4-4.99	150-164.9	150-164.9	150-164.9	150-164.9	0.20-0.349
Moderately resistant (MR)	3-3.99	165-179.9	165-179.9	165-179.9	165-179.9	0.05-0.199
Resistant (R)	<3	>180	>180	>180	>180	<0.05
Atlantic	MS	MS	R	R	MR	S
Onaway	MS	S	MS	S	S	S
Snowden	MS	MR	R	R	R	S
Yukon gold	MS	MR	R	R	R	S
A091-1	S	S	S	S	S	S
B040-3	MS	MS	MR	MS	MR	S
B073-2	S	MS	MR	MR	MR	S
B076-2	S	S	MS	MS	S	S
C103-2	S	MS	R	R	MR	S
E018-1	MS	MR	R	R	R	S
E202-3 Rus	MR	R	R	R	R	S
E221-1	S	S	S	MR	MS	S
E228-11	MS	R	R	R	R	S
E230-6	MS	MS	MR	MR	MR	S
E246-5	MS	MR	MR	R	R	S
F099-3	MS	MR	MR	NA	MR	S
F373-8	MS	S	MR	MR	MS	MS
G007-1	S	MS	R	R	MR	S
G050-2	S	MS	MS	MS	MS	S
G227-2	MS	S	MS	MR	MS	S
G274-3	MR	MS	R	R	MR	R
NY101	MS	MS	MS	MS	MS	S
NY103	S	S	S	S	S	S

a Surface ratings are 1 (no disease) to 9 (heavy disease)

b Internal ratings are Average Reflective Intensity (ARI) based on digital scan of internal tuber tissue. Lower value = darker image = more disease

c Mean ARI = (Apical + Middle + Terminal)/3

d RAUDPC = Relative Area Under Disease Progress Curve, based on % diseased foliage (max=1)

Funding: Industry

The Role of Select Fungicides within a Potato Late Blight (Phytophthora infestans) Control Program. Antisporulation and Tuber Blight Aspects

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INTRODUCTION

Potato late blight (*Phytophthora infestans*) is the most important potato pathogen in the United States. Control of late blight is achieved by cultural practices and foliar fungicide based control programs. In Michigan the standard control program consists of regular preventative applications of chlorothalonil (e.g. Bravo WS) or EBDC (e.g. Manzate) based fungicides. The initiation of fungicide application typically occurs prior to row closure. Spray program factors may be partly based upon weather conditions. When late blight is present, or when weather conditions are conducive to disease, additional or alternative fungicides may be employed. These fungicides may also have properties (e.g. antisporulation or curative) that allow for the specific positioning of the product at certain points within the season and under certain conditions.

Field trials were conducted in the presence of late blight in order to evaluate the optimal placement of select fungicides within a chlorothalonil based foliar fungicide control program. Specifically , in respect to foliar disease levels, sporangia (spore) production, and tuber rotting.

METHODS

Cut potato seed (cv. Onaway) was planted at the Michigan State University Muck Soils Experimental Station, Bath, MI on 27 May 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 unplanted row. Plots were irrigated as needed with sprinklers and were hilled immediately before sprays began. Plots were inoculated (100 ml/25-foot row) with a zoospore suspension of *Phytophthora infestans* US8 biotype (insensitive to metalaxyl, A2 mating type) at 10^3 spores/ml on 22 Jul. Fungicides were applied weekly from 7 July to 25 or 31 Aug (7 or 8 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 5 Jun), two applications of Basagran (2 pt/A on 15 Jun and 5 Jul) and one application of Poast (1.5 pt/A on 23 Jul). Insects were controlled with applications of Admire 2F (20 fl oz/A at planting on 26 June), Sevin 80S (1.25 lb on 1 and 23 Jul), Thiodan 3EC (2.33 pt/A on 1 and 21 Aug) and Pounce 3.2EC (8 oz/A on 23 Jul). Plots were rated visually for percentage foliar area affected by late blight on 22, 31 Jul, 7, 17 and 23 Aug. The foliar assessment on 31 Jul represents the initial development of lesion upon the leaves. The relative area under the disease progress curve was calculated for each treatment. Leaves with active lesions were sampled on 3 Aug and the lesion size (cm^2) and number of sporangia per lesion area and per acre was calculated for each treatment. The number of sporangia per acre was calculated using the number of sporangia per cm^2 lesion and the percent foliar infection for the date of lesion sampling. The percent foliar infection is assumed to be an average across the acre. Vines were killed with Diquat 2EC (1 pt/A on 28 Aug and 4 Sep). Tuber and rotted tuber number was determined on 20 Aug by destructive plant harvests. Plots were harvested on 15 Oct. and individual treatments were graded, counted and weighed.

Fungicide programs are listed in Tables 1 and 2. Each program was based on chlorothalonil (Bravo WS) applications on a 7 day spray interval and consisted of replacing two of the standard applications with an alternative fungicide. Four basic types of replacement programs were examined.

The first consisted of the replacement of the Bravo sprays with the alternative fungicide before and after inoculation . The second consisted of two applications of the alternative previous to dessication. The third employed one alternative fungicide application immediately previous to and after dessication. Finally, the fourth employed one alternative fungicide application previous to inoculation and one previous to dessication. Additionally, an untreated control and a full-season chlorothalonil program were present for comparison purposes. The applications rates of the fungicides have been altered for proper statistical analysis and are based upon the amount of mancozeb in a Acrobat MZ 69WP application at the rate of 2.25lb/acre.

RESULTS

The number of emerged plants per experimental plot did not differ significantly. The foliar and sporulation results are in Table 1. The level of foliar infection at the first sign of lesion production was relatively uniform. The only program that differed significantly (LSD $\alpha = 0.05$) from the untreated control consisted of a type four program with an application of Penncozeb + SuperTin. The type one program using a Penncozeb + SuperTin did not differ from the untreated control. No experimental program had significantly lower initial disease than the Bravo WS standard. At the final foliar infection assessment only the type one program consisting of two applications of Acrobat 50WP 0.04lb/acre previous to the inoculation did not differ significantly from the untreated control. None of the programs differed significantly from the Bravo WS standard. The season long measure of disease, the relative area under the disease progress curve (RAUDPC), had results similar to the final foliar disease assessment. All of the programs had a lower RAUDPC than the untreated control. The only program that had a significantly higher RAUDPC than the chlorothalonil standard was the type one Acrobat 50WP program. The number of sporangia produced per cm^2 lesion tissue did not differ between any of the programs or the untreated control. The average number of sporangia per cm^2 lesion was around 30,000. The number of sporangia produced per acre for each program did not vary significantly. None of the programs varied significantly from the untreated control.

Tuber and yield results are in Table 2. The number of tubers per plant at the first assessment (20 Aug) did not vary significantly between programs or the untreated control. All of the spray programs had significantly less rotted tubers per plant than the untreated control at the first assessment. The programs did not differ from each other. For the final tuber number the only programs that had significantly more tubers per plant that the untreated control were the type three Penncozeb, type three Acrobat MZ, type one Manex C8/Penncozeb, and type two Acrobat 50/SuperTin programs. Of these programs only the type three Acrobat MZ program had significantly more tubers per plant than the Bravo WS standard. The final number of rotted tubers per plant did not differ significantly between any of the treatments or the untreated control. The yield of marketable tubers varied significantly between treatment. Only about half of the programs had yields that were larger than the untreated control. Only the type three Acrobat MZ, type one Penncozeb/SuperTin, and type three Manex C8/Penncozeb programs had significantly high yield than both the Bravo WS standard and the untreated control. The remaining programs did not differ from the Bravo WS control.

DISCUSSION

All of the programs that employed the use of an alternative fungicide at full application rate were as effective or more effective at controlling late blight than the standard Bravo WS program for all of the foliar parameters tested. The programs using early season Acrobat 50WP and Acrobat 50WP/SuperTin applications were higher in foliar infection than the Bravo standard because of the low amount of actual fungicide applied. Acrobat 50WP contains only dimethomorph and the amount applied as Acrobat 50WP was equal to the amount applied as Acrobat MZ. Acrobat MZ also contains a substantial amount of mancozeb and this additional fungicide was involved in disease control. At the initial development of lesions the number of sporangia produced per lesion area and per acre with even an extremely low level of foliar infection is very large. The lack of sporulation difference between any of the treatments is most likely attributable to sampling error as fungicide application does not guarantee complete plant coverage. Unprotected leaves that develop lesions may skew results.

The lack of variation between tuber number per plant at the initial sampling point indications that any difference in tuber number or yield at the end of the season is attributable only to the interaction between late blight and the fungicide programs. The initial sampling point was at the onset of disease development. The number of tubers rotting per plant at the first tuber sampling indicates that late blight may begin to affect tuber health early in the disease progress. The examination of *Phytophthora infestans* as the causal agent of the tuber rot itself was not directly confirmed and the pathogen may be increasing rot via a mechanism such as plant stress. Tuber infections with *P. infestans* may be a less important factor in highly organic soils, but may be of greater importance under different soil conditions. Tuber number per plant for the final harvest did not yield any applicable results as only three programs were significantly different than the untreated control. A lack of significant difference in final rotted tuber number is probably due to the inability of the infected tubers to remain solid enough to be successfully harvested. Marketable tuber yield per plot was not correlated to tuber number per plant. The programs that were significantly different than the untreated control in yield usually represented a mancozeb containing product, Penncozeb, Acrobat MZ, and Penncozeb/SuperTin being examples. Of the four types of alternating programs employed none, of the programs regularly reduced disease or increased crop yield.

Both alternative fungicide used and the type of alternation program failed to cause any significant difference from the chlorothalonil standard for most of the parameters measured. It is currently not recommended to deviate from a chlorothalonil based program for foliar disease control. However, for increased tuber yield the alternation of chlorothalonil and EBDC based fungicides (e.g. mancozeb) is recommended. It is important to note that recent pesticide regulatory activities show a movement towards the reduction in the use of chlorothalonil and EBDC fungicides. Therefore, fungicides with lower levels of active ingredient and reduced biological risk may eventually replace the products currently in use. It is beneficial to determine beforehand which product(s) will be most effective at each specific point in the season and at different points in the late blight disease cycle. Continuing research will address these remaining questions.

Table 1.

Treatment and rate/acre	foliar disease sample #2[1] (%) 9 dai [2]	final foliar disease (%) 27 dai	RAUDPC max = 100 0 - 27 dai[3]	Sporangia per cm^2 lesion[4] 12 dai	Sporangia per acre 12 dai
Untreated	1.00 abc[6]	100.0 a	41.86 a	18726 a	1.7E+09 a
Bravo WS 6SC 0.75 pt (A)[7] Bravo WS 6SC 1.20 pt (B,C,D,E,F,G)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (D,E,F,G) Acrobat 50WP 0.40 lb (B,C)	0.75 abcd	73.5 abc	22.79 bc	23375 a	1.9E+09 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E) Acrobat 50WP 0.40 lb (F,G)	0.47 cd	42.5 cde	15.92 bcd	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E,F) Acrobat 50WP 0.40 lb (G,H)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (C,D,E,F) Acrobat 50WP 0.40 lb (B,G)	0.25 cd	48.8 cde	9.54 d	17360 a	2.1E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (D,E,F,G) Penncozeb 75DF 1.80 lb (B,C)	0.25 cd	29.5 e	7.54 d	10681 a	3.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E) Penncozeb 75DF 1.80 lb (F,G)	0.47 cd	43.8 cde	7.86 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E,F) Penncozeb 75DF 1.80 lb (G,H)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (C,D,E,F) Penncozeb 75DF 1.80 lb (B,G)	0.25 cd	32.5 de	6.55 d	24911 a	5.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (D,E,F,G) Acrobat MZ 69WP 2.25lb (B,C)	0.50 bcd	37.5 de	7.08 d	11305 a	5.0E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E) Acrobat MZ 69WP 2.25lb(F,G)	0.47 cd	37.5 de	7.57 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E,F) Acrobat MZ 69WP 2.25lb(G,H)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (C,D,E,F) Acrobat MZ 69WP 2.25lb(B,G)	0.50 bcd	41.3 cde	10.91 cd	15496 a	8.0E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (D,E,F,G) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (B,C)	0.25 cd	43.3 cde	8.13 d	14750 a	3.5E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (F,G)	0.47 cd	53.8 bcde	15.78 bcd	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (B,C,D,E,F) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (G,H)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A) Bravo WS 6SC 1.20 pt (C,D,E,F) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (B,G)	0.00 d	40.8 de	11.38 cd	20885 a	0.0E+00 a

[1] Percent foliar infection at the first post-inoculation visual assessment.
[2] Days after inoculation with Phytophthora infestans, US8, A2
[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation
[4] Number of sporangia/cm^2 lesion area on lesions at the date of sampling (3 Aug)
[5] Estimated number of sporangia/acre with a foliar infection level of < 1%. This number is specific to a situation in which the area is uniformly infected and is producing its initial crop of visually notable sporulating lesions.
[6] Values followed by the same letter are not significantly different at p = 0.05 (Fisher's LSD)
[7] Application dates: A= 7 Jul; B= 14 Jul; C= 24 Jul; D= 4 Aug; E= 11 Aug; F= 18 Aug; G= 25 Aug; H= 31 Aug;

Table 1 continued.

Treatment and rate/acre	foliar disease sample #2[1] (%) 9 dai [2]	final foliar disease (%) 27 dai	RAUDPC max = 100 0 - 27 dai[3]	Sporangia per cm^2 lesion[4] 12 dai	Sporangia per acre 12 dai
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Fluazinam 5XX 0.60 pt (B,C)	0.25 cd	47.5 cde	8.96 d	30357 a	5.3E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Fluazinam 5XX 0.60 pt (F,G)	0.47 cd	43.5 cde	14.36 bcd	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Fluazinam 5XX 0.60 pt (G,H)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Fluazinam 5XX 0.60 pt (B,G)	0.50 bcd	55.0 bcde	13.14 cd	38877 a	1.1E+09 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Tattoo C 6.25SC 2.30 pt (B,C)	0.75 abcd	37.5 de	7.65 d	19394 a	2.0E+09 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Tattoo C 6.25SC 2.30 pt (F,G)	0.47 cd	37.0 de	7.24 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Tattoo C 6.25SC 2.30 pt (G,H)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Tattoo C 6.25SC 2.30 pt (B,G)	1.00 abc	37.0 de	7.91 d	30716 a	1.4E+09 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (B,C)	0.25 cd	46.3 cde	10.61 cd	20712 a	2.3E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (F,G)	0.47 cd	38.3 de	7.21 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (G,H)	0.47 cd	40.9 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (B,G)	0.75 abcd	40.8 de	13.15 cd	20627 a	5.2E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (B,C)	0.25 cd	62.3 bcd	18.53 bcd	28229 a	4.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (F,G)	0.47 cd	43.8 cde	8.55 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (G,H)	0.47 cd	35.0 de	9.72 d	21260 a	7.8E+08 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (B,G)	1.00 abc	37.5 de	8.17 d	33000 a	2.6E+09 a

[1] Percent foliar infection at the first post-inoculation visual assessment.
[2] Days after inoculation with Phytophthora infestans, US8, A2
[3] RAUDPC, relative area under the disease progress curve calculated from the day of inoculation to the last evaluation
[4] Number of sporangia/cm^2 lesion area on lesions at the date of sampling (3 Aug)
[5] Estimated number of sporangia/acre with a foliar infection level of < 1%. This number is specific to a situation in which the area is uniformly infected and is producing it's initial crop of visually notable sporulating lesions.
[6] Values followed by the same letter are not significantly different at p = 0.05 (Fisher's LSD)
[7] Application dates: A= 7 Jul; B= 14 Jul; C= 24 Jul; D= 4 Aug; E= 11 Aug; F= 18 Aug; G= 25 Aug; H= 31 Aug;

Table 2.

Treatment and rate/acre	sample #1[1] 29 dai[2] tuber number[3]	sample #1[1] 29 dai[2] number rotted[4]	final harvest[5] US1 55 dai tuber number	final harvest[5] US1 55 dai number rotted	Yield (cwt/acre) US1
Untreated...	9.66 a[6]	0.34 a	3.39 abc	0.00 a	67.22 fg
Bravo WS 6SC 0.75 pt (A)[7]................ Bravo WS 6SC 1.20 pt (B,C,D,E,F,G)	8.53 a	0.01 b	4.45 abcdef	0.75 a	99.42 cdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Acrobat 50WP 0.40 lb (B,C)	8.94 a	0.00 b	5.07 bcdefg	0.75 a	116.94 abcd
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Acrobat 50WP 0.40 lb (F,G)	9.31 a	0.06 b	3.99 abcd	0.50 a	90.86 defg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Acrobat 50WP 0.40 lb (G,H)	8.53 a	0.01 b	3.78 abcd	0.25 a	89.22 defg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Acrobat 50WP 0.40 lb (B,G)	9.56 a	0.00 b	3.94 abcd	0.50 a	86.54 defg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Penncozeb 75DF 1.80 lb (B,C)	9.13 a	0.06 b	4.44 abcdef	0.00 a	106.78 bcde
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Penncozeb 75DF 1.80 lb (F,G)	9.25 a	0.00 b	4.32 abcdef	0.00 a	106.28 bcde
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Penncozeb 75DF 1.80 lb (G,H)	8.53 a	0.01 b	5.09 cdefg	0.00 a	111.94 bcde
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Penncozeb 75DF 1.80 lb (B,G)	10.44 a	0.00 b	5.14 defg	1.00 a	128.82 abc
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Acrobat MZ 69WP 2.25lb (B,C)	11.00 a	0.00 b	4.46 abcdef	1.25 a	119.66 abcd
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Acrobat MZ 69WP 2.25lb(F,G)	10.44 a	0.00 b	3.77 abcd	0.00 a	95.92 cdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Acrobat MZ 69WP 2.25lb(G,H)	8.53 a	0.01 b	6.66 g	0.00 a	152.78 a
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Acrobat MZ 69WP 2.25lb(B,G)	10.63 a	0.00 b	4.95 bcdef	0.50 a	121.02 abcd
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (B,C)	11.94 a	0.00 b	4.96 bcdefg	0.50 a	136.84 ab
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (F,G)	9.69 a	0.00 b	4.28 abcdef	0.25 a	105.7 bcde
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (G,H)	8.53 a	0.01 b	4.23 abcde	0.75 a	100.44 bcdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Penncozeb 75DF 1.80 lb + SuperTin 80WP 0.16 lb (B,G)	10.69 a	0.06 b	4.9 bcdef	0.00 a	121.92 abcd

Destructive sample of 4 plants per replicate on 20 Aug
[2] Days after inoculation with Phytophthora infestans, US8, A2
[3] Tuber number and number rotted represent the average number per plant for each treatment
[4] Rotted tubers represent the number of tubers per plant with any visually detectable soft rot, leak, or late blight.
[5] Final harvest occurred on 15 Sep and consisted only of tubers at marketable size or larger
[6] Values followed by the same letter are not significantly different at p = 0.05 (Fisher's LSD)
[7] Application dates: A= 7 Jul; B= 14 Jul; C= 24 Jul; D= 4 Aug; E= 11 Aug; F= 18 Aug; G= 25 Aug; H= 31 Aug;

Table 2 Continued.

Treatment and rate/acre	sample #1[1] 29 dai[2] tuber number[3]	number rotted[4]	final harvest[5] US1 55 dai tuber number	number rotted	Yield (cwt/acre) US1
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Fluazinam 5XX 0.60 pt (B,C)	9.38 a	0.00 b	4.97 bcdefg	0.25 a	95.16 cdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Fluazinam 5XX 0.60 pt (F,G)	9.5 a	0.00 b	4.36 abcdef	0.00 a	95.54 cdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Fluazinam 5XX 0.60 pt (G,H)	8.53 a	0.01 b	3.84 abcd	0.50 a	88.2 defg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Fluazinam 5XX 0.60 pt (B,G)	8.69 a	0.00 b	3.73 abcd	0.25 a	99.82 bcdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Tattoo C 6.25SC 2.30 pt (B,C)	12.19 a	0.06 b	4.06 abcde	0.25 a	96.44 cdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Tattoo C 6.25SC 2.30 pt (F,G)	10.56 a	0.00 b	5.02 bcdefg	0.50 a	122.92 abcd
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Tattoo C 6.25SC 2.30 pt (G,H)	8.53 a	0.01 b	4.01 abcde	0.00 a	92.76 cdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Tattoo C 6.25SC 2.30 pt (B,G)	9.44 a	0.00 b	4.91 bcdef	1.00 a	111.6 bcde
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (B,C)	11.5 a	0.00 b	5.96 fg	0.25 a	114.3 bcde
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (F,G)	9.38 a	0.00 b	3.38 ab	0.25 a	88.08 defg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (G,H)	8.53 a	0.01 b	4.19 abcde	0.13 a	138.91 ab
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Manex C8 72 WP 1.50 lb + Penncozeb 75DF 0.52 lb (B,G)	10.38 a	0.06 b	4.1 abcde	0.50 a	101.2 bcdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (D,E,F,G) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (B,C)	8.38 a	0.00 b	3.97 abcd	0.00 a	100.1 bcdefg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (F,G)	9.00 a	0.00 b	5.7 efg	0.75 a	122.52 abcd
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (B,C,D,E,F) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (G,H)	8.53 a	0.01 b	3.49 abcd	0.25 a	86.68 defg
Bravo WS 6SC 0.75 pt (A)................. Bravo WS 6SC 1.20 pt (C,D,E,F) Acrobat 50 WP 0.40 lb + SuperTin 80WP 0.16 lb (B,G)	10.06 a	0.00 b	2.88 a	0.00 a	65.18 fg

[1] Destructive sample of 4 plants per replicate on 20 Aug
[2] Days after inoculation with Phytophthora infestans, US8, A2
[3] Tuber number and number rotted represent the average number per plant for each treatment
[4] Rotted tubers represent the number of tubers per plant with any visually detectable soft rot, leak, or late blight.
[5] Final harvest occurred on 15 Sep and consisted only of tubers at marketable size or larger
[6] Values followed by the same letter are not significantly different at p = 0.05 (Fisher's LSD)
[7] Application dates: A= 7 Jul; B= 14 Jul; C= 24 Jul; D= 4 Aug; E= 11 Aug; F= 18 Aug; G= 25 Aug; H= 31 Aug;

Funding: MPIC

Influence of Storage Temperature on Rate of Potato Tuber Tissue Infection Caused by Different Biotypes of *Phytophthora infestans* (Mont.) de Bary

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Introduction

Late blight of potato (*Phytophthora infestans* (Mont.) De Bary) has recently reemerged as a major factor in potato production in North America (5). Prior to 1992 populations of *P. infestans* were predominantly the metalaxyl-sensitive A_1 mating type, a strain easily controlled by applications of metalaxyl-based fungicides. The efficacy of fungicide control of this pathogen and the rarity of late blight outbreaks may have contributed to the *P. infestans*-susceptible nature of most commercial potato varieties (4). Biotypes of *P. infestans* that have become dominant since 1992 can infect tubers more effectively than biotypes of the fungus present in North America prior to 1992 (5,15). The foliage of all currently available commercial varieties is highly susceptible to current populations of *P. infestans* (4,11).

The influence of temperature on the development and growth of *P. infestans* on and within potato foliage has been well documented (7). Different stages in the life cycle of *P. infestans* have different optimal temperature ranges (7,9). In foliage, the optimal temperature for hyphal growth varies among cultivars and is between 15 - 20°C (8,9). The development and growth of hyphae of *P. infestans* within tuber tissue are optimal at 10°C (12, 20, 21). The lower temperature limit for hyphal growth in foliar tissue has not been determined. *P. infestans* is an obligate pathogen and the base temperature for disease development may be related to that for potato leaf and sprout development, i.e., 4°C (14). Studies of the development of *P. infestans* on potato tuber tissue have focused on sporangial development. The minimum temperatures investigated have supported a decreased rate of sporangial development in comparison with the optimal temperature of 10°C (12, 20). An estimate of the base temperature for hyphal growth within tuber tissue has not been reported. Studies of tuber tissue degradation in whole tubers due to late blight infection have concentrated on the pathogenicity of biotypes as affected by tuber age and duration of storage periods (7).

Colonization by *P. infestans* of the tissue of individual tubers held in storage for processing is potentially of greater economic importance than the spread of the disease in storage by disseminated sporangia. Potato tubers stored for the processing industries are conventionally held at temperatures of about 10°C for up to six months to minimize accumulation of reducing sugar (1). The long duration of storage at 10°C may encourage tissue infection caused by *P. infestans*. The objective of this study was to evaluate the influence of storage temperature and variety on the rate of tuber tissue infection by *P. infestans.*

MATERIALS AND METHODS

The experiment was carried out in temperature-controlled environments. Tubers of cvs. Russet Burbank, Superior and Snowden were inoculated with different biotypes of *P. infestans* and stored at different temperatures. Assessments of the disease severity in the tubers were made following various times in storage. Rates of tuber tissue infection by *P. infestans* were calculated. Run A was started in October 1996, two weeks after harvest. Run B was started in December 1996 using the same tuber lot as run A. Prior to inoculation, the tubers were stored at 3°C in the dark at 90% relative humidity.

Tubers. Tubers for the experiments were obtained from commercial potato stores in Michigan. Examination for visual disease symptoms indicated that the tubers were free from late blight. Samples of tubers from each lot (n = 100) were tested with the ELISA immuno-diagnostic Alert Multi-well kit (Alert Multiwell Kit - *Phytophthora sp.* Neogen Corporation, Lansing, MI). *P. infestans* was not detected in any of the tubers. Tubers for all the experiments were selected within the size grade range 50 - 100 mm diameter (any plane).

Pathogens. The isolates of *P. infestans* used for inoculations were *P.i.*-US1 (US1 biotype, WI93-13, phenylamide-sensitive, A_1 mating type, Stevenson, WI) and *P.i.*-US8 (US8 biotype, PAI 95-7, phenylamide-insensitive, A_2 mating type, MI)(6).

Tuber preparation, inoculum production and inoculation. Prior to inoculation, tubers were washed in distilled H_2O to remove soil. The tubers were then surface sterilized by soaking in 2% Clorox solution for four hours. Tubers were dried in a controlled environment with continuous air flow at 15°C in dry air (30% relative humidity) for four hours prior to inoculation. Both biotypes of *P. infestans* were propagated on rye agar (3) for 14 days in the dark at 15°C. Sporangia were harvested from the petri dishes by rinsing the mycelium/sporangia mat in cold (4°C) sterile, distilled H_2O and scraping the agar surface with a rubber policeman. The mycelium/sporangia suspension was stirred with a magnetic stirrer for 1 hour. The suspension was strained through four layers of cheesecloth and sporangia concentration was adjusted to about 1×10^6 sporangia ml^{-1} and measured with a hemacytometer. The washed, surface-sterilized tubers were inoculated by a sub-peridermal injection of a sporangia suspension of 2×10^{-5} ml (delivering about 20 sporangia inoculation^{-1}) injection using a hypodermic syringe and needle at the apical end of the tuber about 1 cm from the dominant sprout to a maximum depth of 1 cm.

Controlled environments and experimental design. Tubers for the experiments were stored at 3, 7, 10, and 15°C. The temperatures were selected to represent typical storage temperatures for both seed and processing practices. For all experiments, relative humidity was maintained at 90% within each of the chambers. Tubers were stored in the dark in net bags, with a separate bag used for the tubers for each sampling date. As disease development rates within tubers in relation to storage temperature were unknown, sampling dates were planned at the same frequency at all storage temperatures. Sample size was n = 10 for each sampling date.

Disease assessment. Inoculated and untreated tubers were incubated in the controlled environments. The tubers were cut transversely across the center and 1 cm from the apex and base of each tuber. A sharp knife was used to ensure a smooth cut face. The amount of disease on each of the three surfaces (apical, middle and basal) was assessed by digital image analysis using a flatbed scanner controlled by a personal computer, according to the method of Niemira et al. (1998). The average reflective intensity (ARI) of each cut tuber surface was measured and the amount of tuber tissue infected was estimated by averaging the infected area of the three sections. The sample tubers were assessed at regular intervals, 5 sampling dates (7 - 39 days after inoculation) in run A and 6 in run B (14 - 49 days after inoculation).

Data analysis. The percent disease tuber^{-1} for all treatments, at each evaluation timing, was expressed relative to the average (n = 10) amount of percent disease tuber^{-1} at 3°C, inoculated with *P.i.*-US1. The relative amounts of disease were calculated for each cultivar. It was expected that tubers stored at the lowest temperature and inoculated with the less aggressive biotype of *P. infestans* would provide the most consistent baseline. This normalization allowed comparison of data among all treatment combinations and between the two runs of the experiment.

The rate of tuber disease development for each variety/biotype combination, at each storage temperature, was determined by linear regression of the percent diseased tuber tissue (raw data) as a function of time in storage. The rates were plotted against the storage temperatures (Figure 2). Sigmoidal curves (Equation 1) were derived for each variety/biotype combination. The rate of tuber tissue of infection (R_i) was expressed as a function of storage temperature (t) from the minimum storage temperature (t_o) with a and b as constants. The point of inflection, where the rate increased to >0.01 percent tuber tissue infected day^{-1}, was estimated to be approximately equal to the base temperature for *P. infestans* for that variety/biotype combination.

(1) $$R_i = a/[1+e^{-((t-t0)/b)}]$$

RESULTS

Tuber decay did not increase with time in storage in any of the varieties inoculated with either biotype of *P. infestans* and stored at 3°C (Figure 1). The amount of tuber decay increased with time in most other combinations of variety, temperature and biotype. *P.i.*-US8 generally caused more decay than *P.i.*-US1 (Figure 1). The varieties Russet Burbank and Superior were more susceptible to *P.i.*-US1 than Snowden in both runs and to *P.i.*-US8 in run B (Figure 1). In run A there was no difference between any of the varieties in response to inoculation with *P.i.*-US8. All varieties developed less disease in run B than in run A.

The percent diseased tissue was greatest at 10 and 15°C in most of the treatment combinations in both runs. This was especially pronounced at the later sampling dates (Figure 1). The amount of diseased tissue in tubers stored at 10°C was greater than that at 15°C in some treatment combinations. The percent diseased tissue was least at 3 and 7°C at all evaluations in all treatment combinations (Figure 1). Russet Burbank and Superior inoculated with *P.i.*-US1 and stored at 7°C had lower relative amounts of tuber infection in run A than in run B.

The rate of development of tuber tissue infection following inoculation with *P.i.*-US8 vs. *P.i.*-US1 was greater at all storage temperatures in run A, but only at 15°C in run B. In run A, the maximum rate of development of tuber tissue infection in stored tubers of all three varieties inoculated with *P.i.*-US8 was at 10°C (about 2% tuber tissue day^{-1}) (Figure 2). In run B, the maximum rate of all three varieties inoculated with *P.i.*-US8 was at 15°C (about 1% tuber tissue day^{-1}). In both runs, the rate of infection development at 7°C was about 0.2 - 0.5% tuber tissue day^{-1} in all three varieties following inoculation with *P.i.*-US8. In both runs, the rate of infection development at 3°C was about 0% tuber tissue day^{-1}, in all three varieties following inoculation with *P.i.*-US8 (Figure 2).

In run B, the rate of infection development at 7°C was similar in tubers of all three varieties, regardless of the biotype of *P. infestans*. At 10 and 15°C, the rate of infection development increased in tubers inoculated with *P.i.*-US8 in cvs. Russet Burbank and Superior but not in Snowden.

The estimated base temperatures in tuber tissue for the development of *P. infestans* infection of tuber tissue were higher in run A than in run B. The estimated base temperatures in run A were about 6°C for *P.i.*-US8 infection for all three varieties and about 7°C for *P.i.*-US1 infection in Russet

Burbank and Superior (Table 1). The *P.i.*-US1 base temperature could not be calculated for Snowden due to the limited disease development in this treatment combination (Figure 1). Estimated base temperatures in run B were similar in Russet Burbank and Superior tubers for either biotype (about 3°C). In Snowden, the base temperature was about 3°C for *P.i.*-US8, and about 5°C for *P.i.*-US1.

DISCUSSION

The US8 biotype of *P. infestans* used in this study caused faster tuber degradation than the US1 biotype. Different biotypes vary in aggressiveness and virulence in foliar infections (16). This study supports the view that the US8 biotype is more virulent than the clonal lineages isolated prior to 1994 (13).

The varieties tested in this study were representative of commercial varieties currently grown in North America. Few commercial varieties have substantive field resistance to foliar infection caused by US8 biotypes of *P. infestans* (4,11). While foliar and tuber susceptibility to US1 biotypes of *P. infestans* are reported to be well correlated (19), this correlation does not hold for the US8 biotypes (17). In this study, differences between the varieties in response to infection caused by the two biotypes of *P. infestans* were apparent. In the first run of the experiment, cv. Snowden developed very little disease at any of the storage temperatures after inoculation with the US1 biotype of P. infestans and only at 10 and 15°C in run B. Both cvs. Russet Burbank and Superior were susceptible to both biotypes of P. infestans, and differed only in degree of response to the biotypes. All three varieties were susceptible to *P.i.*-US8, but again cv. Snowden was the least infected of the three varieties in both runs.

This study used three of the current standard temperatures used in commercial practice in the North America. Seed potato tubers and table stock tubers are stored at about 3°C and processing tubers are stored at 7 to 10°C depending on the end use. The maximal development of *P. infestans* at 10°C in run A and 15°C in run B suggests that tubers which are stored at these higher temperatures may be more at risk of storage losses than those stored at lower temperatures.

The base temperatures for the development of *P. infestans* infection of tuber tissue estimated in run A were consistent between varieties and differed only slightly between *P.i.*-US8 (about 6°C) and *P.i.*-US1 (about 7°C). The base temperatures estimated in run B were also consistent between varieties, about 3°C for both biotypes. However, estimated base temperatures differed between the two runs. The difference between the runs may be a result of the physiological age of the tubers used in the experiment. As the tubers were stored for an additional 60 days at 3°C for the second run, the tubers were physiologically more mature than the tubers used in the first run. Potato tubers have been shown to decrease in susceptibility to the US1 biotype of *P. infestans* as they aged physiologically. This response is variety-dependent (2). These results suggest that tubers may change in susceptibility to both biotypes with time in storage, possibly due to physiological aging, incomplete temperature equilibration or a combination of these. Tubers are therefore at greatest risk from infection by *P. infestans*, and perhaps other primary and secondary pathogens, immediately after harvest and also into the first few weeks of storage.

The results of this study show that tuber disease does not develop in tuber storage environments which are maintained at 3°C (and sometimes 7°C) when low initial inoculum levels of *P. infestans* are present in tubers. To reduce initial inoculum levels in tubers going into storage, growers may consider modifying harvest and storage techniques. Tubers harvested prior to cold, wet periods in late fall are at reduced risk of exposure to soil- and water-borne *P. infestans* sporangia. More rapid equilibration of the tubers from the soil temperature to the cooler storage temperature may reduce the time period during which late blight could develop internally. As tubers age in storage, late blight susceptibility may decrease. These results suggest that chipping varieties which can be cooled quickly and stored at lower temperatures would be at a greatly reduced risk of losses due to late blight in storage.

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Literature Cited

1. Burton,W.G. 1992. The physics and physiology of storage. In: The Potato Crop, second edition (P.M. Harris ed.), Chapter 13: 608 - 727. Chapman Hall, London.
2. Bhatia, S.K. and Young, R.J. 1985. Reaction of potato tuber slices to Phytophthora infestans in relation to physiological age. ,American Potato Journal 62:459 - 470.
3. Deahl, K.L., DeMuth, S.P., Sinden, S.L. and Rivera-Pena, A. (1995). Identification of mating types and metalaxyl resistance in North America Populations of Phytophthora infestans. American Potato Journal 72:35 - 50.
4. Douches, D.S., Kirk W.W., Jastrzebski, K., Long, C. and Hammerschmidt, R. (1997) Susceptibility of potato varieties and advanced breeding lines (*Solanum tuberosum* L.) to *Phytophthora infestans* (Mont.) de Bary in greenhouse screenings. American Potato Journal 74:75-86.
5. Fry, W.E. and Goodwin, S.B. 1997. Resurgence of the Irish potato famine fungus. BioScience 47: 363 - 371.
6. Goodwin, S.B., Schneider, R.E., and Fry W.E.. 1995. Use of cellulose-acetate electrophoresis for rapid identification of allozyme genotypes of *Phytophthora infestans*. Plant Disease 79:1181-1185
7. Grinberger, M., Kadish, D. and Cohen, Y. 1995. Infectivity of metalaxyl-sensitive and -resistant isolates of *Phytophthora infestans* to whole potato tubers as affected by tuber aging and storage. Phytoparasitica 23(2): 165 - 175.
8. Harrison, J.G. 1992. Effects of the aerial environment on late blight of potato foliage - a review. Plant Pathology 41:384-416.
9. Harrison, J.G. and Lowe, R. (1989). Effects of humidity and air speed on sporulation of *Phytophthora infestans* on potato leaves. Plant Pathology 38:585-591
10. Harrison, J.G., Lowe, R., Williams, N.A.; (1994) Effects of temperature and light on non-race-specific resistance of potato leaflets to late blight. Plant Pathology 43:733-739.
11. Inglis, D.N., Johnson, D.A., Legard D.E., Fry W.E., and Hamm P.B. 1996. Relative resistance of potato clones in response to new and old populations of *Phytophthora infestans*. Plant Disease 80:575 578
12. Kadish, D.; Cohen, Y. 1992. Over seasoning of metalaxyl-sensitive and metalaxyl-resistant isolates of *Phytophthora infestans* in potato tubers. Plant Disease 82:887-889.
13. Kato, M., Mizubuti, E.S., Goodwin, S.B. and Fry, W.E. 1997. Sensitivity to protectant fungicides and pathogenic fitness of clonal lineages of *Phytophthora infestans* in the United States. Phytopathology 87: 973 - 978.
14. Kirk W.W. and Marshall B. 1992. The influence of temperature on leaf development and growth in potatoes in controlled environments. Annals of Applied Biology, 120, 511 - 525.
15. Lambert, D.H. and Currier, A.I..1997. Differences in tuber rot development for North American clones of *Phytophthora infestans*. American Potato Journal 74:39-43
16. Miller, J.S., Johnson, D.A. and Hamm, P.B. 1995. Aggressiveness of *Phytophthora infestans* isolates in the Pacific Northwest (abstr.) Phytopathology 85: 1127.
17. Niemira, B.A., Kirk, W.W., Douches, D. and Stein, J.M. 1998. Tuber susceptibility of advanced breeding lines to Phytophthora infestans in storage. Proceedings of The Potato Association of America Conference, Fargo, ND. P21.

18. Niemira, B.A., Kirk, W.W., Kitchen, B.J., and Stein, J.M. 1998. Quantification of late blight (*Phytophthora infestans* (Mont.) de Bary) by digital scanning of tuber tissue. [in preparation for Plant Disease 1998].
19. Platt, H.W. and Tai, G. 1998. Relationship between resistance to late blight in potato foliage and tubers of cultivars and breeding selections with different resistance levels. Amer. J. Potato Res. 75:173-178.
20. Walker, A.S.L. and Cooke, L.R. 1988. The survival of phenylamide-resistant strains of *Phytophthora infestans* in potato tubers. Brighton Crop Protection Conference - Pests and Diseases. 1988 4C-1: 353 - 358.
21. Walker, A.S.L. and Cooke, L.R. 1990. The survival of *Phytophthora infestans* in potato tubers - the influence of phenylamide resistance. Brighton Crop Protection Conference - Pests and Diseases 1990 9C-1: 1109 - 1114.

Table 1. Estimated base temperatures (°C) of the rate of development of *Phytophthora infestans* in three varieties of potatoes.

Potato variety	Biotype of P. infestans	Estimated base temperature (°C) Run A	r^2	Run B	r^2
Russet Burbank	US1	7.6	0.997[a]	3.2	0.982
Superior		6.7	0.997	3.0	0.934
Snowden		nc[b]		4.8	0.998
Russet Burbank	US8	6.4	0.934	3.0	0.999
Superior		5.9	0.934	3.0	0.999
Snowden		6.0	0.765	3.0	0.849

a r^2 values of sigmoidal curves fitted to estimate base temperature
b nc - base temperature could not be assessed from the data set

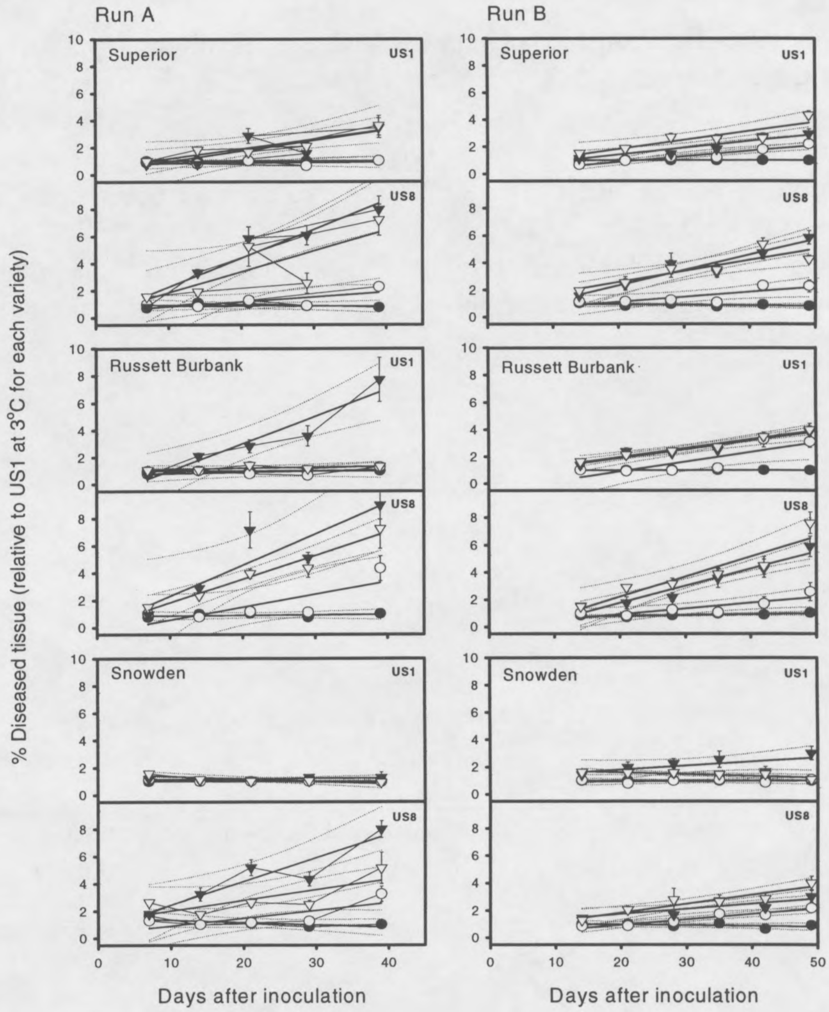

Fig. 1. Percent diseased tissue in tubers of cvs. Superior, Russet Burbank and Snowden inoculated with either US1 or US8 biotypes of *Phytophthora infestans*. The amount of tuber decay in all treatment combinations for each variety is expressed relative to the average amount of tuber decay caused by *P.i.*-US1 at 3°C (n=10). Solid lines (–) are linear regression, dotted lines (···) are 95% confidence intervals for each storage temperature. Storage temperatures: ● 3°C, ○ 7°C, ▼ 10°C and ▽ 15°C.

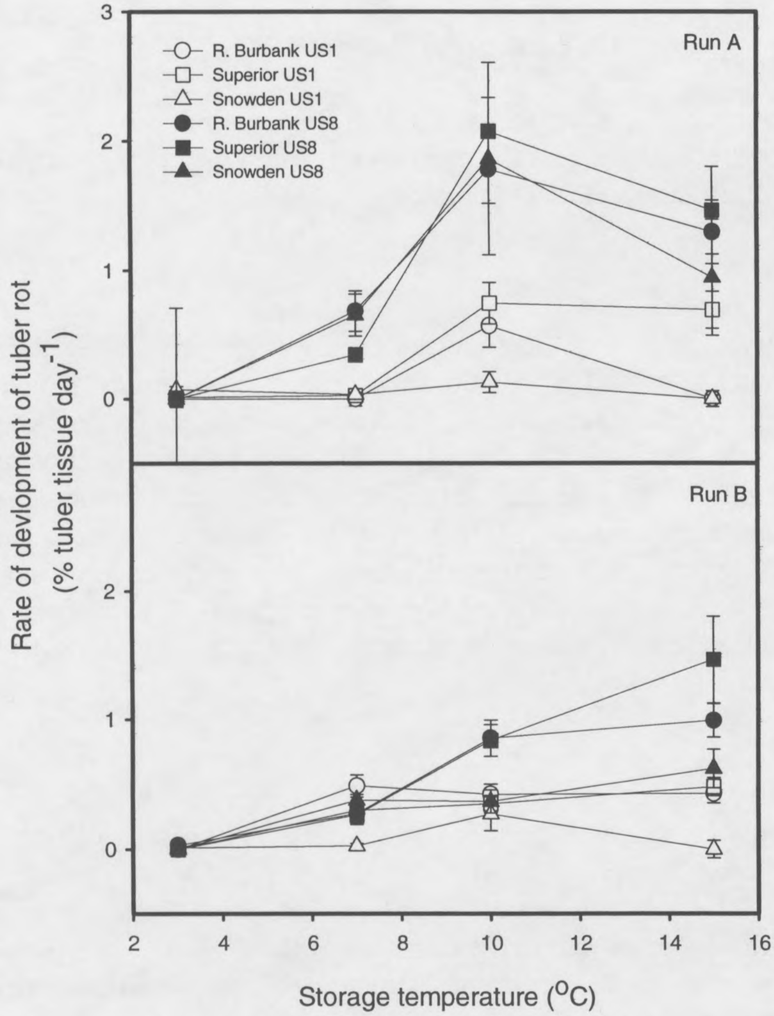

Fig. 2. The rates of development of potato tuber tissue infection caused by different biotypes of *Phytophthora infestans* stored at different incubation temperatures in three potato varieties. Bars indicate standard error (n=10). The black symbols represent US8 biotype of *P. infestans* and the white symbols the US1 biotype. Run A and Run B of experiment.

Funding: MPIC

Development of a Low-Cost, Real-Time, On-Site Electronic Nose System for Rapid and Early Detection of Spoilage in Stored Potatoes. Part 1: Laboratory Model

1998 Progress Report

Principal Investigator: Evangelyn C. Alocilja, Agricultural Engineering
Collaborators: Drs. Roger Brook, Agricultural Engineering; Arthur Cameron, Horticulture; and Raymond Hammerschmidt, Botany and Plant Pathology

ABSTRACT
Potatoes are stored at harvest to supply the country's food requirement during the whole year. Potato processing contributes almost $2 billion dollars a year to the economy. However, a major problem in potato storage is soft rot disease caused by the organism *Erwinia carotovora*. Disease losses in storage may be as high as 30%. Currently the managers of the potato bins measure odor and wetness to determine rot. By the time this sort of damage is detected, rotting has progressed to such an advanced stage that economic loss is potentially significant. The ethanol detection system (EDS) developed at Michigan State University monitors the presence of the gas emitted from potato tubers at concentrations far below the human threshold of 30 ppm. Early detection of the bacterial infection can lead to early management and marketing interventions, thereby greatly reducing economic loss and food waste.

INTRODUCTION
In today's farming industry, potatoes are stored in large bins for periods of time before they are shipped out to their various destinations for food processing. A common difficulty in potato storage stems from the tuber's high susceptibility to soft rot disease caused by *Erwinia carotovora*. Disease losses of potatoes in storage may be as high as 30%.[1] As potato processing contributes almost $2 billion dollars a year to the economy,[2] this is a significant problem. During tuber infection, *E. carotovora* breaks down the structure of the vegetative cells, causing anaerobic conditions in the underlying cells and producing a layer of wet 'slime' outside of the tuber. As the spoilage spreads, the infected potato releases increased amounts of ethanol. The presence of rising ethanol in the bins, therefore, indicates the initiation of rotting. Currently, the managers of the potato bins measure odor and wetness to determine rot. By the time this sort of damage is detected, however, rotting has progressed to such an advanced stage that economic loss is potentially significant.

OBJECTIVE
The long-term objective of the experiment is to develop a cost-effective, real-time, on-site, electronic nose system to monitor the spread of soft rot disease in potato storage piles by detection of ethanol. The research focus in 1998 was to develop a laboratory model for the detection of ethanol in Snowden potatoes resulting from *Erwinia carotovora* infection.

METHODOLOGY

[1] The Grower, May 1980; "A Mechanical 'Nose' Sniffs out Potato Trouble.", pp. 8
[2] Http:/www.sunspiced.com/pstorage.html #4

1. Detection System

Alcohol and relative humidity sensors are connected to a multi-channel data acquisition system. The output of the alcohol sensor is changed into an electronic signal. This signal is read by the computer and given a number between 1 and 5 volts. The output of the humidity sensor is read similarly. The computer system allows for a real-time graphical presentation of the voltage outputs to give a constantly updated picture of the concentration of the ethanol gas and relative humidity. The sampling units are built using airtight mason jars. Holes are drilled to provide air flow and needle ports for gas sampling. The ethanol detection system shall be referred hereafter as the Potato Sniffer.

2. Measurement of the Ethanol Standard by the Sniffer

The sensor output was calibrated with several ethanol concentrations. A series of ethanol concentrations were made, using doubly distilled water and 99.99% pure ethanol with density of 0.789 mg/ml. The headspace concentration the liquid ethanol standards would produce was found by using the following equation[3]:

$$C_{headspace} = 0.01442\left(2.316^{\frac{T}{10}}\right)S$$

where

S = Concentration (ppm) of solution

T = 20.9°C (ambient temperature of environment controlled room)

The solutions were placed inside the sampling jars, covered, and allowed to sit overnight, to reach equilibrium. Data collection was done for 24 hours, after equilibrium. One of the Sniffers was designated the control, and measured only the output from doubly distilled water. The data was logged and analyzed. The ethanol concentrations were simultaneously measured with a gas chromatograph to double-check the standards.

3. Measurement of the Ethanol Standard by Gas Chromatography

A Gas Chromatograph was then used to measure the standard ethanol solutions. A 0.1 ml gas sample was extracted through the needle port of the mason jars, once the solution had achieved headspace equilibrium. The gas was then inserted into the GC needle port. The chart-spikes resulting from each sample were measured and tabulated.

4. Volatile Measurement of Infected Potatoes

The *Erwinia carotovora* cell culture (obtained from Dr. R. Hammerschmidt, Botany and Plant Pathology) was diluted with $MgSO_4$ solution to approximately 10^8 cell concentration. The cell concentration was verified using a mass spectrometer. Snowden potatoes (obtained from Dr. R. Hammerschmidt) were then inoculated with *E. carotovora* by pipetting 0.1 ml of the fluid culture and stabbed into the center of the potato. The pipette tips were left in place in the potato. Once inoculated, the infected potatoes were placed into the sampling jars and covered. The controls

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[3] Smyth, A.B., P.C. Talasila, and A.C. Cameron. 1999. An Ethanol Biosensor Can Detect Low O_2 Injury in Modified Atmosphere Packages. Submitted to the PostHarvest Biology and Technology Journal.

were potatoes that had been stabbed with an empty pipette. Infection was allowed to proceed for 48 hours, after which time gas measurement by the Sniffer was initiated.

Results and Discussion

Measurement of the Ethanol Standard by the Sniffer

The experiment revealed a linear correlation between the voltage output of the sensor and the headspace concentration of the standard ethanol. The zero of the ethanol sensor ranged between 0.3 to 0.6 volts. After 300 ppm, the data became less linear. As the ethanol produced by *Erwinia carotovora* is in much smaller quantities, this should not have a detrimental effect on the system. Figure 1 shows a linear relationship between 0 and 110 ppm, with an R^2 value of 0.9403.

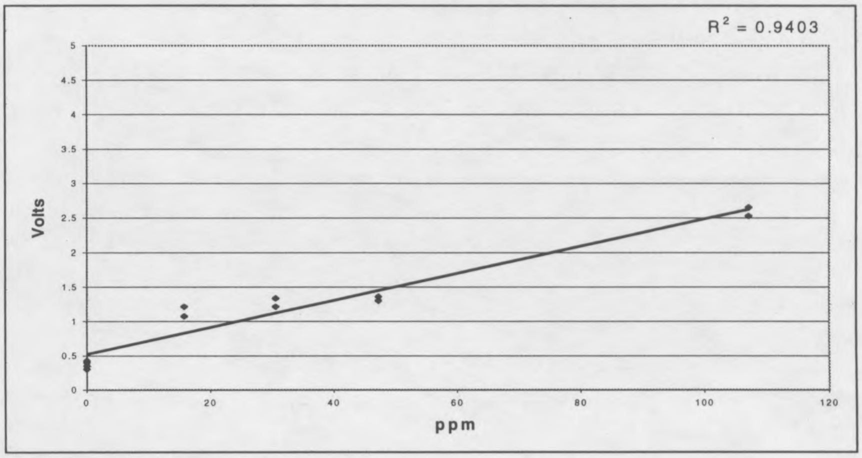

Figure 1. Voltage reading of ethanol standards (average of 24 hours)

Measurement of the Ethanol Standard by Gas Chromatography

The GC readings correlated well with the ethanol standards; showing a linear relationship between the height of the peak and the concentration of the solution with an R^2 value of 0.9218. (Figure 2).

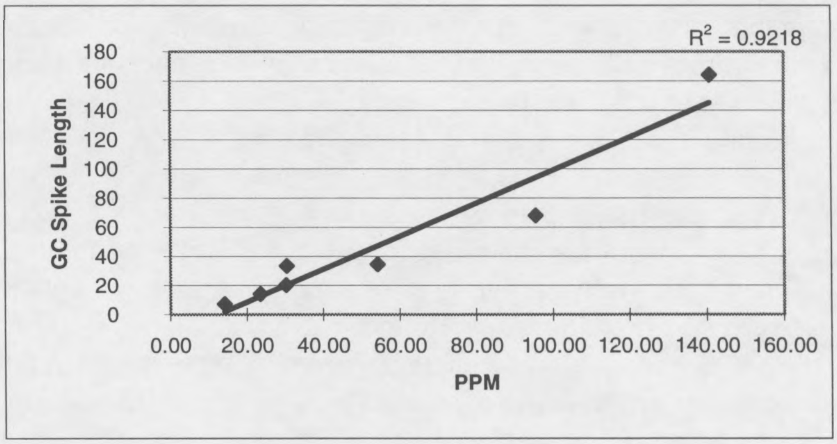

Figure 2. Gas chromatograph length of the spike (cm) vs. ethanol concentrations

Volatile Measurement of Infected Potatoes

Figure 3 is a pictorial comparison between soft rot infected potatoes and control. The infected tubers show no visible symptoms on the outside, however, the infected potatoes produced significantly more ethanol than the controls, as shown in Figure 4.

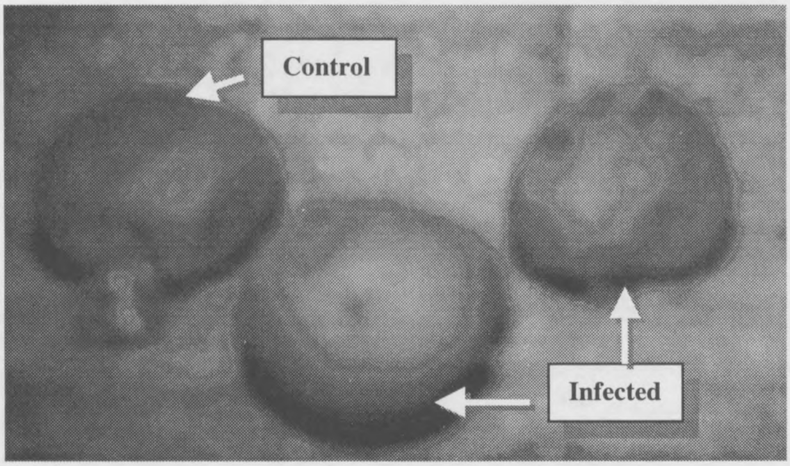

Figure 3. Exterior of soft rot infected and control potato tubers

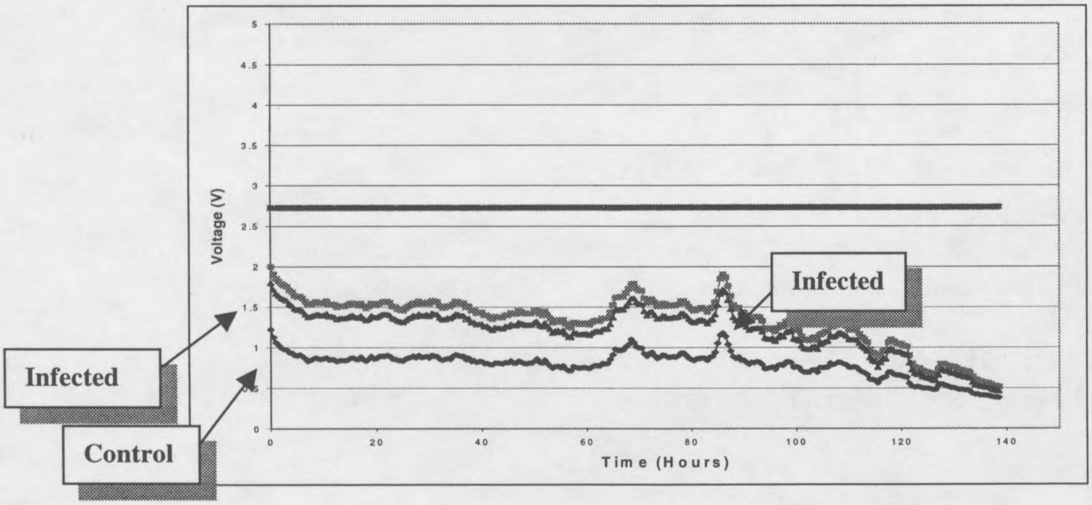

Figure 4. Voltage reading from potato samples over 139 hours (6 days).

When the electronic reading for ethanol reaches 2 volts, a light and a buzzer switch ON to warn storage operators of the onset of rotting. This warning system was adopted in lieu of the artificial neural network pattern recognition algorithm because of the very obvious results. The difference in output of the infected tubers versus the controls is significant enough that a computerized intelligence would be redundant.

CONCLUSION

Results from these measurements show that the Potato Sniffer is able to continuously detect volatile emissions in real time, measure 0-300 ppm headspace ethanol, differentiate healthy and infected potatoes before any visible symptoms occur, and demonstrate stability over a continuous sampling period. The Potato Sniffer will save time, money, and waste by providing a low-cost electronic nose system that will allow for a rapid, continuous monitoring of ethanol production. Early detection of the bacterial infection can lead to early management and marketing interventions, thereby potentially reducing economic loss and food waste. The Sniffer is automated and requires no expertise to operate. At this time, the Sniffer is working well at the laboratory level. Continued experimentation could produce a valuable tool for potato storage operators, with the possibility of expanding its utilization into other areas.

RECOMMENDATIONS FOR FURTHER RESEARCH

The Sniffer can be expanded and used to help extend potato storage. For example, the Sniffer can be used to monitor and pinpoint the end of suberization and epidermis formation by monitoring the gases produced during these stages. Subsequently, cooling of the storage bin to its holding temperature can be initiated as soon as possible, thereby minimizing the time in which the potatoes are exposed to conditions conducive to bacterial growth. The Sniffer can also be used to monitor the onset of senescence. Such information is critical to storage operators to facilitate intervention and management strategies.

Some recommendations for further study include:

1. Validate the following information: types of volatiles emitted with and without soft-rot infection and long-term stability of the Sniffer.
2. Evaluate the response time of the Sniffer in a continuous flow system.
3. Determine the effect of changing temperature and relative humidity on the sensing capability of the Sniffer.
4. Test the Sniffer in a mini storage facility.
5. Measure volatiles produced by *E. carotovora* organism in pure culture.
6. Include additional gas sensors to monitor other volatiles.

ACKNOWLEDGMENT

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