Mustard and Radish Green Manure Use in a Wheat-Potato Rotation

Fort Hall Indian Reservation, Idaho
2002-2003

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The use of soil fumigants in the wheat-potato rotation on the Fort Hall Indian Reservation has been the standard practice for over twenty years. The consistent use of chemical fumigants is expensive for potato farmers and has resulted in soils with little biological diversity or activity. After the identification of nitrate and pesticide contaminated ground water on the Reservation, the Shoshone-Bannock Tribes initiated a demonstration project to explore alternative production practices and cropping sequences.

In this demonstration project, green manure crops were explored as possible alternatives to chemical fumigant treatment. Two green manures, mustard and radish, were selected for their biofumigant properties and ability to grow during the fall in between the wheat and potato crops. The green manure crops were each planted on forty acres in August 2002 following wheat harvest and incorporated into the soil in October 2002. Potato yields and quality, economic returns, soil biological parameters and plant and soil nutrient levels from soils amended with the mustard or radish were compared to nontreated, metam sodium and carbofuran treated soils. In April 2003, fields were planted to Russet Norkotah potatoes and harvested in September 2003.

Net yields from five acres of each treatment were highest in the carbofuran, mustard and metam sodium treated areas, respectively, while the nontreated control and radish produced fewer potatoes. The highest percent of US #1 potatoes were found in the mustard, metam sodium and carbofuran treated fields, respectively. Gross economic returns from a September 24, 2003 sale showed the best returns for the carbofuran, mustard and metam sodium treated fields, respectively. No major differences were found between treatments in soil beneficial or plant pathogenic nematodes, *Verticillium* levels or total fungal levels. A slight stimulation of total bacteria and predatory nematodes in mustard and radish amended soils was found. Sampling of potato petioles and soil nutrient levels showed that no nutrients were limiting.

This demonstration project tracked only a single rotation sequence of mustard and radish green manures compared to other soil chemical treatments, so some caution must be taken in placing significance on these findings. This project did show that it is feasible for farmers to add a mustard or radish green manure crop to their wheat-potato rotation on the Reservation. Mustard and radish crop management fits into the timing of fall activities of the operation. No overall stimulation of beneficial soil microorganisms was seen in the green manure amended soils. This may be an indication that several years of soil building with green manures is necessary to realize such a change. When soil sampling indicates that plant pathogenic organism levels are low, metam sodium treatment may be unnecessary. With the reduced production costs from not fumigating with metam sodium, the nontreated control provided a net return of $95 per acre more than metam sodium treatment. Mustard or radish can be grown for less than treating with metam sodium, due to the high cost of metam sodium. Consequently, if the mustard and radish crops produce yields similar to metam sodium, the green manure crops can be a viable economic alternative. Gross returns were greater from mustard, but less for radish as compared to metam sodium. In this demonstration project, net returns from mustard amendment resulted in $280 per acre more than metam sodium treatment, while radish amendment resulted in $240 per acre less than metam sodium treatment. Overall, this project indicated that adding a mustard green manure crop to the wheat-potato rotation and not fumigating is worth further consideration.

Introduction

Project Rationale

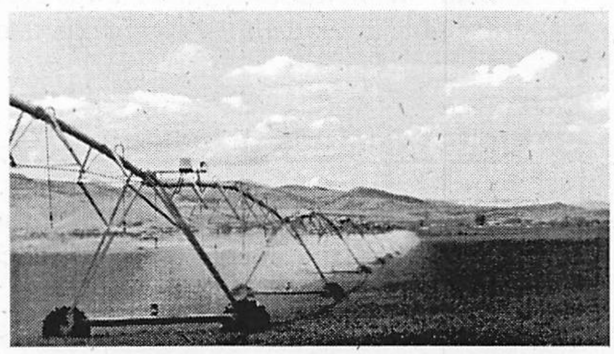
After the detection of nitrate and pesticide contaminated wells in the late 1980s on the Fort Hall Indian Reservation, a report of potential actions was prepared by the USDA Natural Resources Conservation Service (formerly the Soil Conservation Service) (USDA SCS, 1991). In this 1991 report, agricultural chemical usage was listed among the most likely contributing factors to the water quality problem. The potential for contamination of ground water with other agricultural chemicals was noted, due to the excess nitrates appearing in numerous Reservation wells. To address this potential future contamination source and reduce the threat, the 1991 study recommended that alternative crops and crop sequences be explored. In response to this recommendation, Tribal leaders initiated a demonstration field project on the Reservation to study the effectiveness and feasibility of alternative cropping practices. This report on the use of green manures in the conventional two-year wheat-potato crop rotation on the Fort Hall Indian Reservation is the first report on findings from the demonstration field.

Project Question

Is a mustard or radish green manure an effective and economical alternative to chemical fumigant use in a wheat-potato rotation on the Fort Hall Indian Reservation?

This report addresses the following factors, which were monitored during the addition of a green manure crop to the conventional wheat–potato rotation on the Fort Hall Indian Reservation.

- ✓ soil health
- ✓ plant health
- ✓ economics



Project Background

After a period of growth, green manure crops are turned into soil to improve soil fertility and overall soil characteristics. Leguminous green manure crops are selected for their ability to build soil nitrogen, while other crops are selected for their ability to suppress diseases, pests and weeds or to stimulate beneficial bacterial and fungal populations. Of particular concern to Idaho potato growers is *Verticillium dahliae*, which is suppressed by a number of different green manure crops (Davis et al., 1994; Davis et al., 1996). Green manures are grown for different lengths of time; some grow all season, while others are utilized only during the spring or fall.

Due to Reservation potato growers' interest in maintaining the existing two-year wheat-potato rotation, green manures that could be added to the current rotation without extending the rotation were selected. Two green manures crops, mustard and radish, were selected for their ability to grow during the cooler temperatures and shorter days of fall in southeastern Idaho (Finnigan et al., 2003).

Radish, cultivar Colonel, was selected for use in this demonstration project due to its biomass accumulation during fall and suppression of plant-parasitic nematodes. Idaho farmers have been adding radish to their sugar beet rotations for years, while potato farmers have recently begun utilizing radish in their cropping sequence. The radish green manure has been shown to be an effective control of cyst nematode in sugar beets. When turned into the soil, radish suppresses the cyst nematode by stimulating cyst nematode egg hatching, but not supporting cyst nematode growth (Hafez, 1999). Radish has also been shown to reduce Columbia root-knot nematode levels and increase potato yields and quality compared to fallow (Al-Rehiayani and Hafez, 1998).

Mustard green manure crops have been grown by potato farmers in Washington state. Recent studies by Washington State University Cooperative Extension Educator, Andrew McGuire, and a central Washington potato farmer have documented the use of mustard as an alternative to metam sodium (McGuire, 2002; McGuire, 2003). The mustard improved soil quality as determined by higher infiltration rates and produced yields similar to fields treated with metam sodium. While Russet Norkotah was grown in the Washington state study and is considered susceptible to *Verticillium dahliae* (potato early dying), yields were not reduced by early dying.

Project Goal and Objectives

The goal of this demonstration project was to determine whether radish and mustard green manures are viable alternatives to chemical fumigant use in potato production on the Fort Hall Indian Reservation.

The specific objectives of this study were to determine if mustard and radish green manures

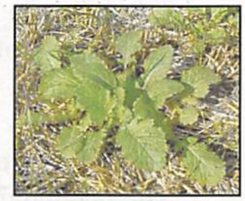
- grow sufficiently under the climatic conditions on the Reservation,
- suppress early dying,
- suppress plant-parasitic nematodes,
- enhance beneficial soil microorganism population levels,
- fit timing of fall management required in a wheat-potato rotation,
- produce potatoes of similar yields and quality as treatment with chemical fumigant, and
- offer an economically viable alternative to chemical fumigant use.

Project Design and Methods

Treatments

The effects of five different soil treatments were assessed.

1. Mustard green manure – *Sinapis alba* and *Brassica juncea* blend Calięnte Brand 119
   Forty acres of mustard were planted in August 2002. After 9 weeks of growth, the mustard was chopped and incorporated into the soil. Mustard was selected for its biofumigant properties as it releases glucosinolates when chopped and disced into soil.



2. Radish green manure – *Raphanus sativus* cv. Colonel
   Forty acres of radish were planted in August 2002. After 9 weeks of growth, the radish was chopped and incorporated into the soil. Radish was selected for its soil pathogen suppressing properties.

3. Vapam (Metam sodium)
   Forty acres were soil-injected with 38 gallons per acre in late October 2002. Metam sodium was selected for use as a contact fumigant, insecticide and nematicide for potatoes.

4. Furadan 4F (Carbofuran)
   Thirty acres were treated with 2 quarts per acre along with the starter fertilizer at potato planting markout in spring 2003. Carbofuran was selected for use by the farm manager as a systemic insecticide and nematicide in potatoes.

5. Nontreated control
   Ten acres were not treated with metam sodium, carbofuran or planted with a green manure crop.

Field Layout and Sampling Sites

The five treatments were located under a single center irrigation pivot on a160-acre field. Soil samples were collected from 32 sampling sites, which were marked using GPS. Eight sampling sites were located in each of the metam sodium, radish and mustard treatments and four sampling sites were located in each of the nontreated control and carbofuran treatments.

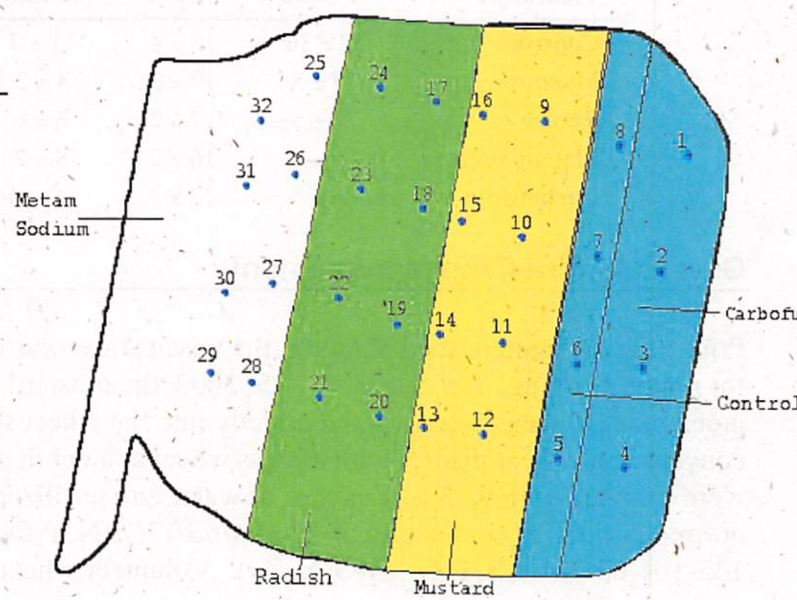


Figure 1. The location of the five treatments on the 160-acre field.

Climate

The following climatic information was obtained from an AgriMet weather station located three miles north of Fort Hall on the Fort Hall Indian Reservation. The information was gathered online and is based on AgriMet data between 1996 and 2003 (http://www.usbr.gov/pn/agrimet/).

The frost-free growing season averages 125 days, typically between May 10 and September 15. The mean daily temperatures from April through September are the following: April – 45 F; May – 54 F; June – 61 F; July – 69 F; August – 69 F; September – 59 F. The annual precipitation varies between 8–12 inches.

The average heat-units or growing degree-days (GDDs) in Fort Hall between April 1 and September 1, 1996 through 2003 was 1722 GDDs (50 F base). For comparison, Parma, Idaho averaged 2699 GDDs and Hermiston, Oregon averaged 2402 GDDs during the same time period.

Soil Characteristics

The 160-acre field is located north of Fort Hall on the Gibson Bench in Zone 1 of the Reservation, as designated by the Shoshone-Bannock Tribes. The soils are Sheepskin-Magallon Variant-Bartonflat Variant Complex 0 to 3% slopes with a few small areas of Sheepskin Loamy Fine Sand 3 to 5% slopes as identified by a 1994 NRCS soil survey. The soil textural classes were determined by the hydrometer method for each treatment area and found to be loamy sand to sandy loam.

Table 1. Percent sand, silt and clay and corresponding soil textural classes for the five treatment areas.

Treatment	% Sand	% Silt	% Clay	Textural Class
Control	72 ± 10	18 ± 4	11 ± 7	Loamy Sand to Sandy Loam
Mustard	78 ± 5	17 ± 3	4 ± 3	Loamy Sand to Sandy Loam
Radish	77 ± 5	17 ± 2	6 ± 6	Loamy Sand to Sandy Loam
Metam Sodium	75 ± 4	16 ± 2	8 ± 2	Loamy Sand to Sandy Loam
Carbofuran	66 ± 5	22 ± 2	13 ± 4	Sandy Loam

Green Manure Crop Management

Prior to green manure seed planting, the wheat straw was chopped as usual to prepare the ground for potato planting. On August 14–15, 2002, the mustard (12 lb/acre) and radish (25 lb/acre) green manure seeds were planted directly into the wheat stubble with a John Deere 455 conventional wheat planter with a press wheel at a depth of ¼ - ½ inch. The mustard and radish were irrigated with 9.35 acre-inches of water and fertilized with 113-58 (N, S) plus the farmer's normal fall potato application of 22-104-60-12-7 (N, P_2O_5, K_2O, S, Zn) for a total application of 135-104-60-70-7 (N, P_2O_5, K_2O, S, Zn). Volunteer wheat was treated with Assure II herbicide.

- On October 17, 2002, following nine weeks of growth and 1129 GDDs (40 F base), the mustard and radish were chopped, disced and rolled. The mustard biomass was estimated at 5800 lbs per acre dry weight based upon comparisons to measured biomass levels of the 2003 mustard green manure crop on the demonstration field. Radish biomass levels were less. NRCS staff measured soil residue levels in fall 2002 and spring 2003 and found that the mustard and radish cropping systems had a total erosion rate of 3.2 and 4.7 tons of soil per acre per year, respectively. These erosion rates were within the USDA guidelines for compliance with the conservation plan.

Potato Crop Management

The 160-acre field was prepared for potato planting as usual and planted with standard Russett Norkotah potatoes on April 16, 2003. Standard Russett Norkotah potatoes were chosen because of their susceptibility to *Verticillium*, so the project could determine the effectiveness of the green manures in controlling *Verticillium*. Potato plants in the five treatments on the 160-acre field were managed the same. Irrigation water and precipitation were monitored with rain gauges and four soil moisture sensors tracked soil moisture levels. The soil moisture conditions were similar between treatments and not a limiting factor. Petiole nutrient samples were collected weekly for six weeks from June 18 – July 23 and used in planning fertilization application rates. The potato plants were fertilized with a total of 336-197-150-140-11 (N, P_2O_5, K_2O, S, Zn). Ridamil® was applied at labeled rates at planting for the control of tuber rot. One application of Bravo® was used for early blight. Potato plants grew for 114 days after planting. Potato plants were rolled and sprayed with Reglone (diquat) on August 8 and harvested on September 3-5, 2003.

Sampling Protocols

Potato Yield and Quality
Yields were measured by harvesting approximately five acres from each of the five treatment areas. All truckloads from each treatment were weighed separately and tare measurements were conducted. The salable tubers were sold September 24, 2003 through Wada Farms Potatoes located in Pingree, Idaho. Tuber quality was inspected and graded by an USDA inspector. Yield variability was assessed at harvest by hand digging tubers in five-foot sections of windrowed potatoes (5 foot by 4 rows, or 60 ft^2) at each of the 32 sampling sites.

Soil Biology, Beneficial and Plant Parasitic Nematodes, Early-Die Complex
Soil samples were collected for assessment of total soil fungi, total soil bacteria, protozoa, actinomycetes, and beneficial and plant parasitic nematode communities prior to green manure planting, following green manure incorporation, at mid-potato root growth, and following potato harvest. The corresponding sampling dates were August 7, 2002, March 21, June 18, and September 6, 2003. Soil samples were pulled in the same locations using GPS. Each sample represented the composite of five cores collected within a 50 foot radius of each grid point. To assess the potential for early-die complex, *Verticillium dahliae* and root lesion nematode levels were determined. On August 7, 2002, March 21, 2003 and Sept 6, 2003, eight samples were collected per treatment, except for the control and carbofuran where four samples were collected.

On June 18, three samples per treatment were collected. Soil biological parameters were analyzed at Western Laboratories in Parma, Idaho.

Potato Leaf Chlorophyll Levels
Potato leaf chlorophyll levels were measured using Minolta's SPAD 502 chlorophyll meter. Samples were collected weekly for five weeks from June 25 – July 23 during the growing season. The terminal leaflet of the fourth petiole from the apex was measured. Ten leaflets were randomly gathered from each sampling site and three readings were collected per leaflet. Three sampling sites per treatment area were monitored.

Aerial Photography
Four aerial photographs of the potato field were taken from early July to the day before potato vine-killing in August to assess overall plant health in the five treatment areas.

Potato Vine and Tuber Weights
Vine and tuber fresh weights were determined weekly for three weeks from July 16 – July 30 during the potato growing season. Potato vines and tubers were collected from 30 ft^2 in three sampling sites per treatment. An additional tuber fresh weight measurement was collected at potato harvest from all 32 sites.

Nutrient Monitoring
Petiole and soil samples were pulled on a weekly basis for six weeks or five weeks, respectively, during the potato-growing season. The soil and petiole NPKS status were measured and evaluated. Additional soil nutrient samples were collected following wheat harvest, before potato planting and following potato harvest on August 7, 2002, March 21 and September 6, 2003, respectively. Three samples per treatment were collected for analysis of the weekly petiole nutrient and soil nitrogen during the potato-growing season. For soil nutrient analysis on sampling dates August 7, 2002, March 21, 2003 and Sept 6, 2003, eight samples were collected per treatment, except for the control and carbofuran where four samples were collected. Petiole and soil nutrients were analyzed at Western Laboratories in Parma, Idaho.

The available soil nitrogen from each of the five treatment areas was determined by sampling 0-28 inches of soil and analyzing for ammonium-N and nitrate-N. Sampling below 28 inches was not practical due to inconsistent, undulating gravel subsurface from an ancient river bottom and or lakebed. Post-potato harvest soil nitrogen levels were compared to pre-potato planting soil nitrogen levels to determine residual nitrogen levels. Soil nitrogen was analyzed at Western Laboratories in Parma, Idaho.

Descriptive Statistics
When all 32 sampling sites were monitored, eight samples were collected from each of the mustard, radish and metam sodium areas and four samples were collected from each of the carbofuran and nontreated control areas. For some measurements, as noted above in the sampling protocols sections, three samples were collected from each of the five treatments. Means and standard deviations are reported. If the mean and standard deviations overlapped, the differences between treatments were considered insignificant.

Tuber Yields, Tuber Quality and Economic Returns

Table 2. Potato yields, quality and economic returns from September 24, 2003 sale.

Treatment	Gross Yield (cwt/acre)	Tare[1] (%)	Net Yield (cwt/acre)	US #1 (%)	7.5 oz + (%)	Gross Return ($/cwt)	Gross Return[2] ($/acre)
Control	478	19.9	383	69.0	58.3	$ 3.62	$ 1356.67
Mustard	497	10.7	444	86.4	53.8	$ 3.81	$ 1658.29
Radish	435	18.4	355	75.4	58.7	$ 3.32	$ 1151.09
Metam Sodium	520	16.7	433	80.4	51.9	$ 3.31	$ 1396.30
Carbofuran	522	12.9	455	79.2	63.2	$ 4.39	$ 1959.39

[1]Percent of gross yield that was unusable due to dirt, rot or green potatoes.
[2]Return after subtraction of USDA grading process and Idaho Potato Commission fees
Potatoes were harvested from approximately five acres in each treatment.

Table 3. Potato grades, production costs and net returns from September 24, 2003 sale.

Treatment	US #1 Small Grade	US #1 Carton Grade		Gross Return ($/acre)	Production Costs[1] ($/acre)	Net Return ($/acre)
	4-7.5 oz (%)	7.5-14.99 oz (%)	15 oz + (%)			
Control	10.7	53.3	5.0	$ 1356.67	$ 1280	$ 76.67
Mustard	32.6	48.8	5.0	$ 1658.29	$ 1397	$ 261.29
Radish	16.7	57.6	1.1	$ 1151.09	$ 1410	($ 258.91)
Metam Sodium	28.5	48.8	3.1	$ 1396.30	$ 1415	($ 18.70)
Carbofuran	16.0	53.3	9.9	$ 1959.39	$ 1340	$ 619.39

[1]The production costs for each treatment calculated from a base cost of $1280 per acre, which included potato seed, planting, harvesting, fertilizer, equipment and rent
Potatoes were harvested from approximately five acres in each treatment.

Table 4. Carton profile for US #1 potatoes.

Treatment	US #1 Carton Grade Breakdown					
	100 ct (%)	90 ct (%)	80 ct (%)	70 ct (%)	Bakers (%)	Total (%)
Control	15.0	14.0	13.0	11.3	5.0	58.3
Mustard	16.0	13.0	12.0	7.8	5.0	53.8
Radish	20.0	18.0	16.0	3.6	1.1	58.7
Metam Sodium	16.0	15.0	13.0	4.8	3.1	51.9
Carbofuran	15.0	13.0	12.0	13.3	9.9	63.2

Potatoes were harvested from approximately five acres in each treatment.

Cedar Farms harvested approximately five acres from each of the five treatments to determine potato yields and quality. Tables 2-4 report the yields, US #1s, distribution of potato size, and the resulting economic returns. Potatoes were inspected by a certified USDA inspector and sorted and graded through Wada Farms Potatoes' packing shed on September 24, 2003. The income a farmer receives for a crop is dependent largely upon the yield, tuber size distribution, overall quality, and current market price.

The breakdown of gross yield delivered is shown in Table 2. The gross yield delivered usually contains debris, rotten potatoes and green potatoes. This portion of the gross yield represents unusable potatoes and is recorded as tare weight. The tare weight is a deduction from the total yield that the packing shed cannot use or sell. The highest tare weights were found in the control, radish and metam sodium treated areas, respectively (Table 2). Field observations while hand digging potatoes at harvest suggested that tuber rot was a likely factor contributing to the increased tare weights.

The difference between gross yield and tare weight is the net yield. The net yield is the yield that the farmer receives payment on. Net yields were highest in the caroburan, mustard and metam sodium treated areas, respectively (Table 2). The carbofuran treated area produced 22 cwt per acre more than the metam sodium treated area and the mustard amended area yielded 11 cwt per acre more than the metam sodium. The mustard amended area out-yielded the radish amended area by 89 cwt per acre. The radish amended area yielded 78 cwt per acre less than the metam sodium treated area and 28 cwt per acre less than the untreated control.

In the packing shed, the potatoes were sorted by USDA grades and then marketed accordingly. Highest paying grades are the US #1s and tuber sizes greater than 7.5 ounces. The exact distribution within these categories determines the returns to the grower in dollars per cwt. The gross return per cwt is the actual dollar amount per sack (100 lb) that the farmer received after the potatoes were graded through the packing shed. Potatoes from the carbofuran treated area provided the highest return at $4.39 per cwt (Table 2). The lowest returns were received on potatoes from the radish and metam sodium treated areas at $3.32 to $3.31 per cwt, respectively. The mustard amended area returned $0.50 more per cwt than the metam sodium.

The gross return per acre was calculated from the dollars per cwt received multiplied by the total net yield and reflects the subtraction of USDA fees and Idaho Potato Commission fees. The carbofuran and mustard treated areas returned the most revenue per acre, respectively (Table 2). The radish amended area returned the least revenue per acre. The mustard amended area generated $261.99 per acre more revenue than the metam sodium.

Additional details on the percent of US #1 grade types are provided in Table 3. US #1 grades are separated into three groups: small grade (4 to 7.5 oz.); carton grade (7.5 to 14.99 oz.); bakers (15 oz +). Because of tuber size and consumer demand, small grades often return fewer dollars than the carton grades and bakers. In 2003, for example, the bakers consistently paid $10 or more per 50 lb box than the small grades. The mustard and metam sodium treated areas produced the largest percent of small grade potatoes (4-7.5 oz) (Table 3). The carbofuran treated area had 12 to 14 percent fewer small grade potatoes than the metam sodium and mustard treated areas.

The production cost for each of the five treatments is shown in Table 3. Potato production costs are highly variable. Production costs estimates range from $1100 to $1750 per acre to raise potatoes in eastern Idaho. The variation is due to multiple factors, including whether the land is owned or rented; potato seed costs; irrigation power costs on 30 to 600 feet lifts; equipment, fuel, labor, water costs, etc. Production costs for the control area on this demonstration project were estimated at $1280 per acre (Table 3). The metam sodium treatment was most expensive and the untreated control was least expensive (Table 3).

Additional information on the percent carton and baker grade potatoes is provided in Table 4. An 80-count box (80 ct) means that 80 potatoes of similar size can be sorted into a 50 lb box. Therefore, 80 cts are bigger potatoes than 100 ct and smaller than bakers and 70 ct. The highest returns generally come from a high percent of 70 ct, 80 ct and baker potatoes. In 2003, 70 ct and bakers have exceeded $24 per box, while 100 ct boxes have been less than $8 per box.

The carbofuran treated area returned the most per acre because of its higher 70 ct and baker sized potatoes (Tables 3 and 4). The mustard treated area had 3 percent more 70 ct and 1.9 percent more bakers than did the metam sodium treated area. The radish area had more small cartons and consequently returned fewer dollars.

Soil Biology

In a healthy soil environment, the soil biological community is full of beneficial organisms. These beneficial organisms include bacteria, fungi, nematodes, protozoa and others. In this project, total bacteria, total fungi, the bacteria to fungi ratio, beneficial nematodes, and the protozoan community were measured. These parameters were monitored during this demonstration project to determine whether green manure amendments stimulated the levels of beneficial groups of organisms. The soil biological parameters were determined in the five treatment areas and compared to desirable ranges provided by Harry Kreeft with Western Laboratories, Parma, Idaho.

Due to the great diversity of soil microorganisms and soil types, there are no absolute parameters governing soil biological population numbers. Soils dominant in sand will differ from soils dominant in silts or clays. The most important component of soils for the stimulation of beneficial organisms is the organic matter content. Soils should contain a minimum 2-3 percent organic matter.

Below are listed the suggested parameters of selected soil beneficial organisms and pathogens as provided by Harry Kreeft with Western Laboratories, Parma, Idaho:

Bacteria/Fungi Population	Desired Level
Total Fungi	30-60 lbs per acre
Total Bacteria	30-100 lbs per acre
Beneficial Nematodes	**Desired Level**
Bacterial Feeders	1000-2000 per 500 cc soil
Fungal Feeders	1000-2000 per 500 cc soil
Predatory	30 plus per 500 cc soil
Protozoans	**Desired Level**
Amoebae	5000 plus per g soil
Flagellates	5000 plus per g soil
Plant Pathogen Community	**Desired Level**
Root-knot Nematode	zero per 500 cc soil
Stubby-root Nematode	0-30 per 500 cc soil
Root-lesion Nematode	50-1000 per 500 cc soil
Verticillium dahliae	0-10 CFU per g dry soil

Table 5. Soil fungi and bacteria levels measured pre-green manure planting (Aug 7, 2002), post-green manure incorporation (Mar 21, 2003), during the potato-growing season (June 18, 2003), and post potato harvest (Sept 6, 2003). Mustard and radish green manures were incorporated into the soil in October 2002, metam sodium was applied in October 2002 and carbofuran was applied in April 2003. A – Total fungi; B – Total bacteria; C – Bacteria:Fungi ratio.

5A.

Treatment	Total Fungi (lbs/acre)			
	Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	5.4 ± 4.1	12.4 ± 5.8	16.8 ± 4.3	2.9 ± 0.6
Mustard	14.0 ± 25.1	19.0 ± 6.7	11.1 ± 6.5	2.7 ± 2.2
Radish	6.9 ± 5.0	9.1 ± 6.3	6.6 ± 2.3	7.1 ± 4.2
Metam Sodium	4.3 ± 3.2	10.5 ± 7.0	11.1 ± 6.1	6.7 ± 4.0
Carbofuran	18.9 ± 10.3	13.3 ± 7.4	10.0 ± 7.9	4.8 ± 2.5

mean ± standard deviation

5B.

Treatment	Total Bacteria (lbs/acre)			
	Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	6.8 ± 1.6	33.6 ± 21.2	21.3 ± 22.2	1.7 ± 1.3
Mustard	7.4 ± 6.2	78.3 ± 30.0	50.5 ± 29.8	3.0 ± 2.1
Radish	3.7 ± 2.7	30.0 ± 27.7	26.5 ± 20.6	3.3 ± 2.9
Metam Sodium	4.3 ± 3.6	1.4 ± 0.7	4.9 ± 2.62	1.7 ± 1.1
Carbofuran	12.2 ± 3.3	13.0 ± 8.0	6.5 ± 4.7	2.5 ± 2.0

mean ± standard deviation

5C.

Treatment	Bacteria:Fungi Ratio			
	Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	1.9:1 ± 1.2:1	4.4:1 ± 5.2:1	1.1:1 ± 1.0:1	0.6:1 ± 0.4:1
Mustard	1.6:1 ± 2.3:1	4.9:1 ± 3.1:1	4.7:1 ± 0.6:1	1.1:1 ± 0.7:1
Radish	0.9:1 ± 1.0:1	3.8:1 ± 3.5:1	3.7:1 ± 1.6:1	0.5:1 ± 0.5:1
Metam Sodium	1.4:1 ± 1.4:1	0.2:1 ± 0.1:1	0.4:1± 0.1:1	0.4:1 ± 0.3:1
Carbofuran	1.1:1 ± 1.3:1	1.5:1 ± 1.7:1	0.9:1 ± 0.7:1	0.5:1 ± 0.2:1

mean ± standard deviation

There were no differences in total fungi between the five treatment areas. Average total fungi levels with standard deviations in the five treatment areas overlapped at each of the four sampling dates (Table 5A.). According to the soil biological parameters provided by Harry Kreeft with Western Laboratories, none of the treatment areas in this project showed total fungi levels within the 30-60 lbs per acre desirable range. It was expected that amendment with green manures might increase the total fungal levels compared to other treatments, but this was not found. The lack of such stimulation may be the result of twenty plus years of fumigant use on this ground, so several years of green manure incorporation may be required to see such a change.

Total bacteria levels were elevated in the March and June sampling dates in the green manure amended areas and the control (Table 5B). The average levels of total bacteria in the mustard and radish amended and control areas on the March sampling date were within the desired range of 30-100 lbs per acre. Only the mustard amended area showed an average level within the desired range at the June sampling date.

The ratio of bacteria to fungi is around 1:1 in highly productive agricultural soils, but is often bacteria-dominated in many agricultural soils (Ingham, 2002). Bacteria to fungi ratios were greater than 1:1 in all five treatment areas on at least one sampling day (Table 5C). The greatest deviation from the 1:1 ratio was found in the green manure amended and nontreated control areas in March, indicating that the bacterial biomass was greater than the fungal biomass (Table 5C). The lowest ratios, indicating a more fungal dominated soil, were found in the metam sodium treated area.

Table 6. Actinomycetes in soil collected from each of the five treatment areas on June 18, 2003.

Treatment	Actinomycetes (lbs/acre)
Control	7.5 ± 2.2
Mustard	9.2 ± 5.5
Radish	3.2 ± 1.8
Metam Sodium	7.4 ± 6.0
Carbofuran	7.4 ± 3.7

mean ± standard deviation

Another important component of the soil microbial community are actinomycetes. Actinomycetes are a group of microorganisms that decompose organic matter, fix atmospheric nitrogen and provide numerous useful soil antibiotics. These soil antibiotics are of interest because of their ability to suppress plant pathogens.

Actinomycete population levels were determined on June 18 during early potato root growth. Considering the variation among samples within each treatment, actinomycete levels during early potato root growth did not differ across the five treatment areas.

Table 7. Protozoan community measured prior to potato planting (Mar 21), during the potato-growing season (June 18) and post potato harvest (Sept 6). Mustard and radish green manures were incorporated into the soil in October 2002, metam sodium was applied in October 2002 and carbofuran was applied in April 2003. A – amoebae; B – flagellates.

7A.

Treatment	Amoebae (no./ g soil)		
	Mar 21 (Pre-plant)	**June 18 (Mid-season)**	**Sept 6 (Post-harvest)**
Control	27,900 ± 39,258	12,333 ± 7,371	29,950 ± 33,527
Mustard	5,085 ± 7,145	2,500 ± 1,323	6,400 ± 5,760
Radish	488 ± 638	933 ± 929	93,845 ± 112,030
Metam Sodium	3,706 ± 3,179	4,200 ± 1,058	50,400 ± 23,724
Carbofuran	6,775 ± 9,986	4,767 ± 2,155	3,540 ± 2,607

mean ± standard deviation

7B.

Treatment	Flagellates (no./ g soil)		
	Mar 21 (Pre-plant)	**June 18 (Mid-season)**	**Sept 6 (Post-harvest)**
Control	12,950 ± 15,438	15,133 ± 17,224	61,200 ± 49,361
Mustard	20,713 ± 20,514	12,667 ± 6,807	60,300 ± 74,422
Radish	7,964 ± 8,670	7,900 ± 7,108	24,025 ± 23,316
Metam Sodium	20,700 ± 9,744	14,667 ± 3,512	61,650 ± 59,230
Carbofuran	16,075 ± 3,622	24,400 ± 21,140	97,400 ± 166,692

mean ± standard deviation

Protozoa, which are single-celled animals, play an important role in soil nutrient cycling by consuming other microorganisms, such as bacteria, and releasing nutrients. Population levels of two groups of protozoa, amoebae and flagellates, were highly variable among samples within each treatment (Table 7A and B). Some sampling sites showed no protozoa while other sites contained thousands. Consequently, the five treatment areas showed no overall difference in population levels of the protozoan community. Average flagellate levels were above the desired level of 5000 per g soil in all treatment areas on all sampling dates. Average amoebae levels were above the desired level of 5000 per g soil in all treatment areas on at least one of the sampling dates.

Beneficial Nematode Community

Table 8. Beneficial nematodes sampled prior to potato planting, at mid-season and following potato harvest. Mustard and radish green manures were incorporated into the soil in October 2002, metam sodium was applied in October 2002 and carbofuran was applied in April 2003. A – Bacterial feeder nematodes; B – Fungal feeder nematodes; C – Predatory nematodes.

8A.

Treatment	Bacterial Feeders (no./500 cc soil) Mar 21 (Pre-plant)	June 18 (Mid-season)	Sept 6 (Post-harvest)
Control	1078 ± 1002	2377 ± 2107	963 ± 320
Mustard	535 ± 351	3163 ± 2542	414 ± 375
Radish	504 ± 304	700 ± 447	763 ± 749
Metam Sodium	532 ± 601	1257 ± 716	1268 ± 555
Carbofuran	2518 ± 2255	3753 ± 1688	575 ± 485

mean ± standard deviation

8B.

Treatment	Fungal Feeders (no./500 cc soil) Mar 21 (Pre-plant)	June 18 (Mid-season)	Sept 6 (Post-harvest)
Control	268 ± 261	1363 ± 959	235 ± 125
Mustard	181 ± 120	1130 ± 871	113 ± 85
Radish	121 ± 110	467 ± 501	266 ± 273
Metam Sodium	44 ± 54	1430 ± 1351	425 ± 663
Carbofuran	503 ± 566	1860 ± 750	375 ± 110

mean ± standard deviation

8C.

Treatment	Predatory Nematodes (no./500 cc soil) Mar 21 (Pre-plant)	June 18 (Mid-season)	Sept 6 (Post-harvest)
Control	0 ± 0	0 ± 0	0 ± 0
Mustard	5 ± 14	0 ± 0	0 ± 0
Radish	4 ± 11	0 ± 0	0 ± 0
Metam Sodium	0 ± 0	0 ± 0	0 ± 0
Carbofuran	0 ± 0	0 ± 0	0 ± 0

mean ± standard deviation

Nematodes are a diverse group of roundworms widely distributed in soils. Soil dwelling nematodes are divided into groups based up their diet, whether it is composed of plants, algae, bacteria, fungi or other nematodes (Ingham, 2002). Nematodes that feed on bacteria, fungi and other nematodes are considered beneficial nematodes, while root feeders are plant parasitic nematodes. The beneficial nematode community provides several important functions within a healthy soil ecosystem, including nutrient cycling and control of plant parasitic nematode populations. Bacterial feeding nematodes release nitrogen and other nutrients to the soil environment when they consume bacteria. Fungal feeding nematodes release nutrients to the soil environment when they consume fungi. Fungal feeders also consume plant parasitic fungi. The predatory nematode community enhances the soil by keeping other nematode populations in check.

The beneficial nematode groups monitored in this demonstration project included bacterial feeders, fungal feeders and predatory nematodes (Table 8A-C). Bacterial and fungal feeders were found in all treatments (Table 8A and B). The levels varied between samples in each treatment resulting in no clear trend of levels being higher or lower in specific treatments. Amendment with the mustard or radish green manures did not appear to stimulate the bacterial and fungal feeders as compared to the control, metam sodium or carbofuran treatments. Average levels of bacterial feeders in all treatments except radish amendment were within the desired range of 1000-2000 bacterial feeders per 500 cc of soil on at least one sampling day (Table 8A). Only on the June sampling day were average levels of fungal feeders within the desired range of 1000-2000 fungal feeders in all treatments except radish amendment (Table 8B).

Predatory nematodes were only found at potato pre-plant in the mustard and radish amended fields (Table 8C). While the average number of predatory nematodes in the mustard and radish amended fields were below the recommended level of 30 predatory nematodes per 500 cc of soil, one sample in the mustard amended field and one sample in the radish amended field exceeded this level. Predatory nematode populations are easily decimated by conventional agricultural practices. Once populations become very low or undetectable, they seem to require long periods of time under favorable environmental conditions to recover. At Western Laboratories, 260 soil samples assessed mainly from Idaho, Oregon and California fields showed that only 30 of the samples had predatory nematodes. Most of the samples with predatory nematode were from fields on diverse rotations or from fields receiving some sort of composting program.

Predatory nematodes are likely in low abundance in this demonstration field due to over twenty years of wheat-potato rotations and the regular use of fumigants on this ground. Thus, it may require the incorporation of several green manure crops to fully stimulate predatory nematodes.

Plant Parasitic Nematode Community

Table 9. Plant parasitic nematode levels measured pre-green manure planting (Aug 7, 2002), post-green manure incorporation (Mar 21, 2003), during the potato growing season (June 18, 2003), and post potato harvest (Sept 6, 2003). Mustard and radish green manures were incorporated into the soil in October 2002, metam sodium was applied in October 2002 and carbofuran was applied in April 2003. A – Columbia root-knot nematode; B – Stubby-root nematode; C – Root-lesion nematode.

9A.

Treatment	Columbia Root-knot Nematode (no./ 500 cc soil) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Mustard	0 ± 0	0 ± 0	0 ± 0	1 ± 4
Radish	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Metam Sodium	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Carbofuran	0 ± 0	0 ± 0	0 ± 0	0 ± 0

mean ± standard deviation

9B.

Treatment	Stubby-root Nematode (no./ 500 cc soil) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	0 ± 0	2.5 ± 5.0	0 ± 0	0 ± 0
Mustard	0 ± 0	33 ± 88	0 ± 0	0 ± 0
Radish	1 ± 4	4 ± 7	0 ± 0	0 ± 0
Metam Sodium	6 ± 18	0 ± 0	0 ± 0	0 ± 0
Carbofuran	0 ± 0	0 ± 0	0 ± 0	13 ± 25

mean ± standard deviation

9C.

Treatment	Root-lesion Nematode (no./ 500 cc soil) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	40 ± 67	145 ± 251	167 ± 81	765 ± 466
Mustard	118 ± 179	836 ± 1434	93 ± 137	889 ± 1006
Radish	123 ± 174	775 ± 1147	77 ± 133	416 ± 532
Metam Sodium	319 ± 515	19 ± 32	0 ± 0	125 ± 176
Carbofuran	98 ± 62	1298 ± 851	313 ± 390	1090 ± 143

mean ± standard deviation

The plant parasitic nematodes causing the most yield damage and quality problems in Idaho potatoes are the root-knot nematodes (*Meloidogyne* spp.), the root-lesion nematodes (*Pratylenchus* spp.) and the stubby-root nematodes (*Trichodorus* spp.) (Hafez and Sundararaj, 2001). Plant parasitic nematodes, if left uncontrolled, usually cause economic losses from both yields and quality. As a result, potato growers spend between $80-200 per acre in nematicides or fungicides to control plant parasitic nematodes.

The effects of the five treatments on the population levels of plant-parasitic nematodes were examined. The root-knot and stubby-root nematodes were negligible or not detected in all five treatment areas (Table 9A and B). Root-lesion nematodes were found in all treatments on all dates, except on June 18 when no root-lesion nematodes were detected in the metam sodium treated areas (Table 9C). The metam-sodium treated area showed the lowest root-lesion nematode counts (Table 9C). Levels dropped to 19 nematodes per 500 cc of soil after treatment with metam sodium and remained low through the potato-growing season.

Western Laboratories recommends maintaining levels of zero root-knot nematodes, 0-30 stubby-root nematodes and 50-1000 root-lesion nematodes per 500 cc to prevent considerable yield and economic losses. Detected root-knot nematode levels in all five treatments and stubby-root nematodes in all five treatments, except mustard, were within recommended levels on all sampling days (Table 9A and B). Average root-lesion nematode levels were within the accepted range on all sampling dates in all treatments, except carbofuran (Table 9C). Average root-lesion nematode levels exceeded the range in the carbofuran treated area on the March sampling date, which was prior to carbofuran treatment, and on the September sampling date, which was one day after completion of the potato harvest.

The population levels of plant-parasitic nematodes may be low due to the regular use of fumigants prior to potato planting on this field over the past twenty years. Additional years of the control, mustard amended and radish amended fields are needed to determine how plant parasitic nematode levels might change in these treatment areas compared to chemically-treated areas.

Potato Early-Die Complex

Table 10. *Verticillium* levels measured pre-green manure planting (Aug 7, 2002), post-green manure incorporation (Mar 21, 2003), and post potato harvest (Sept 6, 2003). Mustard and radish green manures were incorporated into the soil in October 2002, metam sodium was applied in October 2002 and carbofuran was applied in April 2003.

Treatment	*Verticillium* (CFU/ g dry soil) Aug 7 2002	Mar 21 2003	Sept 6 2003
Control	0.8 ± 0.5	1.5 ± 1.7	1.3 ± 2.5
Mustard	2.1 ± 2.2	1.5 ± 1.8	7.5 ± 8.9
Radish	0.4 ± 0.7	0.4 ± 0.5	2.5 ± 3.8
Metam Sodium	3.5 ± 5.7	1.3 ± 2.8	1.3 ± 2.3
Carbofuran	6.0 ± 8.5	6.0 ± 7.3	1.3 ± 2.5

mean ± standard deviation

Table 11. Root lesion nematode levels measured pre-green manure planting (Aug 7, 2002), post-green manure incorporation (Mar 21, 2003), during the potato growing season (June 18, 2003), and post potato harvest (Sept 6, 2003). Mustard and radish green manures were incorporated into the soil in October 2002, metam sodium was applied in October 2002 and carbofuran was applied in April 2003.

Treatment	Root Lesion (no./ 500 cc soil) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	40 ± 67	145 ± 251	167 ± 81	765 ± 466
Mustard	118 ± 179	836 ± 1434	93 ± 137	889 ± 1006
Radish	123 ± 174	775 ± 1147	77 ± 133	416 ± 532
Metam Sodium	319 ± 515	19 ± 32	0 ± 0	125 ± 176
Carbofuran	98 ± 62	1298 ± 851	313 ± 390	1090 ± 143

mean ± standard deviation

The potato early-die complex (PED) involves the interaction of the fungus *Verticillium dahliae* and the root-lesion nematode *Pratylenchus neglectus*. When both organisms exist at high populations, severe yield losses can occur. Yield losses of 50 to 100 cwt per acre are not uncommon with *Verticillium dahliae* alone (Davis, 1993). To control PED, farmers usually fumigate with Vapam®, K-PAM® or Telone®.

The PED complex organisms on this demonstration field were not elevated (Tables 10 and 11). Yield losses of 25 percent or more usually require root lesion counts in excess of 2000 per 500 cc soil and or *Verticillium* counts exceeding 20 CFU per gram dry soil. Average *Verticillium* levels were within the desired level of 0-10 colony forming units per gram dry soil in all treatment areas.

Potato Plants

Table 12. Potato leaf chlorophyll levels measured weekly over five weeks during the growing season.

Treatment	Potato Leaf Chlorophyll Levels (SPAD units) June 25 (70 DAP)	July 2 (77 DAP)	July 9 (84 DAP)	July 16 (91 DAP)	July 23 (98 DAP)
Control	48.0 ± 1.9	50.3 ± 1.7	47.6 ± 0.5	42.9 ± 0.8	42.9 ± 2.5
Mustard	47.8 ± 1.2	50.1 ± 3.2	45.7 ± 0.8	45.0 ± 2.3	43.6 ± 0.5
Radish	51.5 ± 0.9	49.0 ± 2.1	47.3 ± 1.7	47.4 ± 4.4	45.0 ± 2.9
Metam Sodium	47.0 ± 0.9	48.0 ± 1.6	45.5 ± 1.1	45.2 ± 1.5	43.0 ± 0.9
Carbofuran	47.6 ± 0.9	49.4 ± 0.9	45.8 ± 1.1	45.9 ± 1.4	41.4 ± 0.9

mean ± standard deviation

Chlorophylls are the primary pigments involved in capturing energy from sunlight for photosynthesis. Chlorophyll levels can be used as an indicator of plant health.

Average chlorophyll levels in potato plants from the five treatments were quite similar on sampling dates June 25 through July 23. Chlorophyll levels were highest in June and early July and decreased in mid to late July. Chlorophyll levels of 42 SPAD units or higher in potato leaflets have been found to be adequate (Bowmer and Taberna, unpublished data).

Aerial photography was utilized mid-season on July 16 and late-season shortly before vine-killing on August 6 (Figure 2A and B). The aerial photographs allowed for an overall view of the five treatment areas on the entire demonstration field. Plant health was determined by visual inspection of field color in the five treatment areas.

A. B.

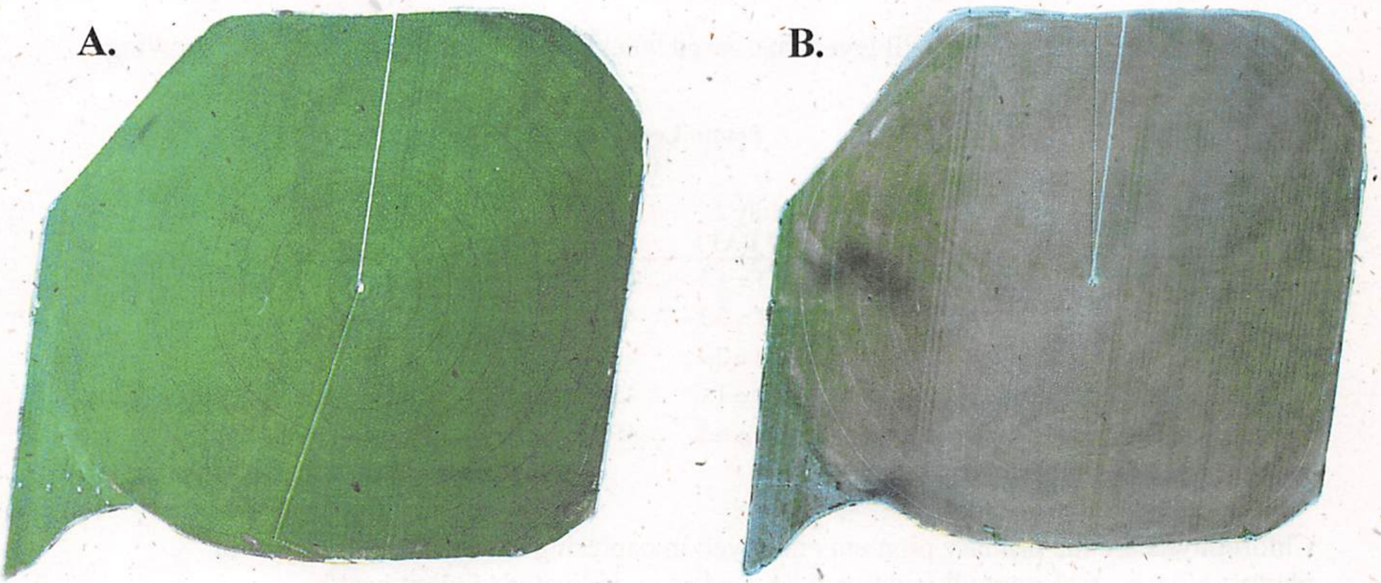


Figure 2. Aerial photographs of the 160-acre field taken on July 16, 2003 (A.) and August 6, 2003 (B.).

There were no visible differences between the five treatment areas in the July 16 photograph (Figure 2A), indicating plant health was fairly uniform across the five treatment areas. There were visible differences in the photograph taken on August 6 (Figure 2B), two days before vine kill. The treatments from left to right are metam sodium, radish, mustard, control and carbofuran (See Figure 1). A sharp demarcation was seen between the metam sodium treated area and the radish and mustard amended portions of the field (Figure 2B). The radish and mustard amended areas showed less green, indicating the plants were dying down more quickly than the metam sodium and carbofuran treated areas.

Table 13. Potato vine and tuber weights collected over three weeks near the end of the potato-growing season. A – Vine weight; B – Tuber weight.

13A.

Treatment	Vine Weight (lbs fresh weight/30ft^2) July 16 (91 DAP)	July 23 (98 DAP)	July 30 (105 DAP)
Control	27 ± 8.9	25 ± 2.6	21 ± 2.1
Mustard	32 ± 2.1	25 ± 2.6	21 ± 2.9
Radish	27 ± 2.1	23 ± 0.6	19 ± 2.3
Metam Sodium	31 ± 3.1	26 ± 3.1	20 ± 1.8
Carbofuran	28 ± 1.0	26 ± 1.0	22 ± 0.6

mean ± standard deviation

13B.

Treatment	Tuber Weight (lbs fresh weight/30ft^2) July 16 (91 DAP)	July 23 (98 DAP)	July 30 (105 DAP)	Sept 6 (harvest)
Control	18 ± 1.5	24 ± 0.6	27 ± 2.5	37 ± 3.7
Mustard	21 ± 1.5	26 ± 0.6	32 ± 1.8	36 ± 4.4
Radish	20 ± 3.0	24 ± 2.0	30 ± 4.3	33 ± 5.7
Metam Sodium	20 ± 6.1	28 ± 1.5	31 ± 1.1	35 ± 3.0
Carbofuran	17 ± 1.0	27 ± 1.7	31 ± 2.6	37 ± 3.2

mean ± standard deviation

Vine weights were measured to assess plant biomass in the five treatment areas. No measurable differences in vine weights between the five treatment areas sampled on July 16, July 23 and July 30 were found (Table 13A).

Tubers were hand dug three times during the growing season and also at harvest time. All tubers, regardless of size and quality, were weighed. Tuber weights were similar for all five treatment areas throughout the growing season and at harvest time (Table 13B).

Results from analysis of chlorophyll levels (Table 12), aerial photographs (Figure 2A and B) and vine (Table 13A) and tuber weights (Table 13B) indicate that overall plant health was similar across the five treatment areas.

Cost Benefit Analysis

Alternative 1: Will it pay to use a **mustard** green manure crop for disease and nematode control in potato production, **instead of metam sodium?**

Added Costs:	Added Income:
$34 per acre for mustard seed $12 per acre for mustard planting $31 per acre for fertilizer $12 per acre for herbicide treatment $18 per acre for irrigation water and power $10 per acre for chopping $117 per acre	$262 per acre for higher yields
Reduced Income: None	Reduced Costs: $135 per acre for no metam sodium application
Total added costs & reduced income: $117 per acre	Total added income & reduced cost: $397 per acre
	Net change: **$280 per acre**

Alternative 2: Will it pay to use a **radish** green manure crop for disease and nematode control in potato production, **instead of metam sodium?**

Added Costs:	Added Income:
$47 per acre for radish seed $12 per acre for radish planting $31 per acre for fertilizer $12 per acre for herbicide treatment $18 per acre for irrigation water and power $10 per acre for chopping $130 per acre	None
Reduced Income: $245 per acre for reduced yields	Reduced Costs: $135 per acre for no metam sodium application
Total added costs & reduced income: $375 per acre	Total added income & reduced cost: $135 per acre
	Net change: **($240) per acre**

Figure 3. Cost benefit analysis for mustard and radish green manure use versus metam sodium treatment during August 2002 to September 2003 on the demonstration project field.

Cost benefit analyses were conducted to compare the expenses and revenue of using a mustard or radish green manure crop instead of metam sodium. Expenses and revenue were tracked from wheat harvest in August 2002 to potato harvest in September 2003. The added expenses from producing the mustard, $117, or radish, $130, green manure crop were offset by the savings from not treating with metam sodium, $150 (Figure 3). While these cost benefit analyses reflect only one year's data from the demonstration trial and conditions specific to Cedar Farms, higher gross returns (Table 2) were earned from the mustard amended field as compared to the metam sodium treated field resulting in a positive net change of $295 per acre (Figure 3). In this one-year demonstration trial on Cedar Farms, the radish amended field showed lower gross returns (Table 2) as compared to the metam sodium treated fields, resulting in a negative net change of $225 per acre (Figure 3).

Conclusions

This demonstration project indicates that there are viable alternatives to the continuous use of fumigants. The mustard green manure amended area produced yields higher than the metam sodium treated area. The mustard area returned more US #1 potatoes than all other treatments. On an economic return basis, the mustard, control, and carbofuran areas returned more net dollars per acre than metam sodium. In comparison, the radish treated area performed poorly on yields and economic returns. The reason for this weak performance in this demonstration project is not known. Additional monitoring of the effects of the green manure crops on potato yields in future years is needed to determine if these patterns represent a real difference.

The various treatments may have performed well because the populations of plant parasitic nematodes and *Verticillium* were low in this demonstration field. This was the first time in over twenty years that the carbofuran, control, radish, and mustard treated areas of the field were not fumigated in the fall prior to potato crop planting.

Treating with fumigants prior to potato crop production is a standard practice for many fields on the Fort Hall Indian Reservation. These fields are often treated with fumigants without an assessment of nematode population levels and *Verticillium* inoculum levels. Soil testing for nematodes and *Verticillium* will likely provide farmers valuable information on whether or not fumigant use is necessary in a given year.

The expected stimulation of soil microorganisms by green manure amendment was not realized following the incorporation of a single fall planting of the green manure crops. The expected flush of soil microorganisms may not have been captured with the selected sampling dates or it may not have occurred. More than a single fall planting of the green manure crops may be necessary to stimulate soil microorganisms in a field that has been regularly fumigated for twenty years.

Future Work

Green manures are not an immediate remedy to the problems that have been created through short rotations and continuous fumigant use. Future work is necessary to monitor the soil biological community on this demonstration project field and determine whether additional green manure crop amendments stimulate populations of beneficial organisms. Other soil quality measures also need to be monitored to assess the impact of the green manures.

Additional work needs to be conducted to optimize green manure production methods and use in potato cropping systems on the Fort Hall Indian Reservation. Raising a green manure crop with adequate biomass does not come without added costs and management. Questions remain regarding input levels that are required to produce satisfactory green manure biomass. Inputs include water, which is often in short supply during the fall, nitrogen and sulfur fertilizers and herbicides for the control of volunteer wheat. Areas of particular interest for this demonstration project on the Fort Hall Indian Reservation include 1) determining the adequate green manure fertilizer input levels, and 2) determining or removing the need for volunteer wheat control.

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Glossary of Terms and Acronym List

CFU = colony forming units
DAP = days after planting
Ec = Electrical conductivity of soil water solution. Total dissolved salts within the soil solution.
GDD = growing degree days
GPS = Global Positioning System
meq = milli-equivalent per 100 g of soil

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Soil and Plant Nutrient Levels

Table A-1. Soil nutrient levels sampled on August 7, 2002 prior to any field treatments or fertilization.

	Treatment				
Nutrient	**Control**	**Mustard**	**Radish**	**Metam Sodium**	**Carbofuran**
nitrate 0-12 in. (ppm)	11 ± 6	10 ± 5	9 ± 5	13 ± 4	15 ± 3
P (ppm)	23 ± 2	26 ± 5	28 ± 4	24 ± 4	29 ± 4
K (ppm)	141 ± 35	136 ± 22	159 ± 15	186 ± 18	119 ± 22
Zn (ppm)	1.0 ± 0.4	1.1 ± 0.5	0.7 ± 0.2	1.1 ± 0.2	0.9 ± 0.5
Mn (ppm)	4 ± 1	4 ± 2	3 ± 1	6 ± 2	3 ± 1
Ca (ppm)	1770 ± 137	1636 ± 145	1885 ± 342	2536 ± 288	1759 ± 146
Mg (ppm)	170 ± 29	154 ± 22	144 ± 8	182 ± 20	184 ± 9
S (ppm)	4 ± 1	4 ± 1	4 ± 1	41 ± 7	5 ± 1
Fe (ppm)	7 ± 1	7 ± 1	7 ± 1	16 ± 3	8 ± 1
Cu (ppm)	0.5 ± 0.1	0.6 ± 0.2	0.5 ± 0.3	0.5 ± 0.2	0.5 ± 0.1
B (ppm)	0.3 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.4 ± 0.1	0.2 ± 0.1
Soluble salts (Ec)	0.3 ± 0.07	0.27 ± 0.05	0.24 ± 0.04	0.29 ± 0.06	0.35 ± 0.06
Na (ppm)	35 ± 2	46 ± 8	52 ± 20	33 ± 5	52 ± 12
Cation exchange capacity (meq)	7 ± 2	6 ± 2	7 ± 2	7 ± 0	8 ± 1
pH	6.9 ± 0.2	7.0 ± 0.2	7.3 ± 0.2	7.5 ± 0.1	6.7 ± 0.1
Lime (%)	0 ± 0	0 ± 0	0.03 ± 0.07	0.3 ± 0.4	0 ± 0
Organic Matter (%)	2.1 ± 0.2	2.0 ± 0.1	1.9 ± 0.1	2.0 ± 0.2	2.0 ± 0.1

mean ± standard deviation

Table A-2. Soil nutrient levels sampled on March 21, 2003 following fall 2002 incorporation of the mustard and radish green manures, fall 2002 application of metam sodium and fall 2002 fertilizer application. The fields were treated with 135-104-60-70-7 (N, P_2O_5, K_2O, S, Zn), which included the standard fall potato fertilizer and fertilizer for the mustard and radish green manure crops.

	Treatment				
Nutrient	Control	Mustard	Radish	Metam Sodium	Carbofuran
nitrate 0-12 in. (ppm)	15 ± 2	13± 2	14 ± 2	17 ± 7	15 ± 1
ammonium 0-12 in. (ppm)	9 ± 1	8 ± 1	8 ± 1	10 ± 4	9 ± 1
P (ppm)	36 ± 6	32 ± 4	30 ± 3	37 ± 11	40 ± 9
K (ppm)	188 ± 30	182 ± 36	157 ± 23	151 ± 15	201 ± 13
Zn (ppm)	2.0 ± 0.1	2.1 ± 0.3	1.9 ± 0.2	2.3 ± 0.3	2.0 ± 0.3
Mn (ppm)	3 ± 1	2 ± 0	2 ± 0	4 ± 1	4 ± 1
Ca (ppm)	2458 ± 231	2232 ± 447	2101 ± 331	2114 ± 126	2527 ± 453
Mg (ppm)	175 ± 26	158 ± 14	164 ± 18	169 ± 13	189 ± 17
S (ppm)	9 ± 3	11 ± 3	9 ± 3	12 ± 3	8 ± 3
Fe (ppm)	11 ± 3	10 ± 2	10 ± 2	12 ± 1	13 ± 1
Cu (ppm)	0.8 ± 0.5	0.6 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	0.8 ± 0.2
B (ppm)	0.5 ± 0.1	0.5 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.5 ± 0.1
Soluble salts (Ec)	0.18 ± 0.05	0.15 ± 0.04	0.19 ± 0.05	0.35 ± 0.14	0.21 ± 0.03
Na (ppm)	39 ± 3	29 ± 4	33 ± 11	39 ± 13	41 ± 9
Cation exchange capacity (meq)	5 ± 1	4 ± 1	4 ± 0	5 ± 0	5 ± 1
pH	7.6 ± 0.3	7.5 ± 0.1	7.4 ± 0.2	7.0 ± 0.4	7.7 ± 0.3
Lime (%)	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Organic Matter (%)	1.3 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.3 ± 0.1	1.3 ± 0.1

mean ± standard deviation

Table A-3. Soil residual N contribution.

	Total Nitrogen 0-28 inches ($ppm\ NO_3 + ppm\ NH_4$)		
Treatment	**Spring 2003**	**Fall 2003**	**Change in N (Fall minus spring)**
Control	19.6 ± 1.5	16.1 ± 3.8	no difference considering variation
Mustard	13.4 ± 0.8	14.3 ± 4.2	no difference considering variation
Radish	15.8 ± 1.4	11.5 ± 2.2	slightly less
Metam Sodium	18.7 ± 12.3	13.0 ± 3.6	no difference considering variation
Carbofuran	17.8 ± 4.1	16.2 ± 3.1	no difference considering variation

mean ± standard deviation

Table A-4. Soil N status during the potato-growing season.

Treatment	Mar 21 (pre-plant)	Jun 18 (63 DAP)	June 25 (70 DAP)	July 2 (77 DAP)	July 9 (84 DAP)	July 16 (91 DAP)	Sept 6 (post-harvest)
	Total Nitrogen in 0-12 inch depth ($ppm\ NO_3 + ppm\ NH_4$)						
Control	24 ± 4	12 ± 8	24 ± 7	21 ± 4	12 ± 6	23 ± 12	27 ± 7
Mustard	19 ± 1	4 ± 2	6 ± 3	20 ± 9	7 ± 2	16 ± 2	23 ± 8
Radish	20 ± 3	11± 9	15 ± 8	22 ± 6	13 ± 10	20 ± 4	16 ± 5
Metam Sodium	26 ± 18	11 ± 5	36 ± 14	25 ± 2	19 ± 1	7 ± 6	20 ± 8
Carbofuran	24 ± 3	15 ± 13	15 ± 5	21 ± 3	10 ± 2	30 ± 20	26 ± 5

mean ± standard deviation

Table A-5. Soil nutrient levels and soil characteristics following wheat harvest, pre-potato planting, mid-potato growing season, and following potato harvest.

A.

Treatment	Phosphorous (ppm) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	23 ± 2	36 ± 6	57 ± 8	29 ± 6
Mustard	26 ± 5	32 ± 4	43 ± 8	27 ± 8
Radish	28 ± 4	30 ± 3	45 ± 4	29 ± 7
Metam Sodium	24 ± 4	37 ± 11	50 ± 8	29 ± 6
Carbofuran	29 ± 4	40 ± 9	45 ± 14	37 ± 8

mean ± standard deviation

B.

Treatment	Potassium (ppm) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	141 ± 35	188 ± 30	124 ± 25	154 ± 48
Mustard	136 ± 22	182 ± 36	141 ± 30	137 ± 38
Radish	159 ± 15	157 ± 23	132 ± 24	110 ± 32
Metam Sodium	186 ± 18	151 ± 15	150 ± 26	117 ± 25
Carbofuran	119 ± 22	201 ± 13	142 ± 11	165 ± 21

mean ± standard deviation

C.

Treatment	Organic Matter (%) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	2.1 ± 0.2	1.3 ± 0.1	1.4 ± 0.1	1.4 ± 0.1
Mustard	2.0 ± 0.1	1.2 ± 0.1	1.4 ± 0.1	1.4 ± 0.1
Radish	1.9 ± 0.1	1.2 ± 0.1	1.4 ± 0.1	1.4 ± 0.1
Metam Sodium	2.0 ± 0.2	1.3 ± 0.1	1.4 ± 0	1.4 ± 0.1
Carbofuran	2.0 ± 0.1	1.3 ± 0.1	1.5 ± 0.1	1.3 ± 0

mean ± standard deviation

D.

Treatment	pH (%) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	6.9 ± 0.2	7.6 ± 0.3	5.9 ± 0.4	6.7 ± 0.3
Mustard	7.0 ± 0.2	7.5 ± 0.1	6.1 ± 0.2	6.9 ± 0.4
Radish	7.3 ± 0.2	7.4 ± 0.2	6.5 ± 0.1	6.8 ± 0.2
Metam Sodium	7.5 ± 0.1	7.0 ± 0.4	5.9 ± 0.1	6.7 ± 0.2
Carbofuran	6.7 ± 0.1	7.7 ± 0.3	6.5 ± 0.4	6.3 ± 0.2

mean ± standard deviation

E.

Treatment	Cation exchange capacity (meq) Aug 7 2002	Mar 21 2003	June 18 2003	Sept 6 2003
Control	7 ± 2	5 ± 1	7 ± 3	9 ± 0
Mustard	6 ± 2	4 ± 1	7 ± 3	8 ± 1
Radish	7 ± 2	4 ± 0	6 ± 1	8 ± 1
Metam Sodium	7 ± 0	5 ± 0	9 ± 2	8 ± 1
Carbofuran	8 ± 1	5 ± 1	7 ± 0	10 ± 1

mean ± standard deviation

Table A-6. Potato petiole nutrient levels measured over six weeks during the growing season.

A. nitrate (ppm)

Treatment	June 18 (63 DAP)	June 25 (70 DAP)	July 2 (77 DAP)	July 9 (84 DAP)	July 16 (91 DAP)	July 23 (98 DAP)
Control	28,130 ± 1620	23,970 ± 900	24,900 ± 350	24,260 ± 2160	20,910 ± 2710	14,540 ± 1520
Mustard	27,430 ± 300	23,250 ± 2510	22,970 ± 1090	23,770 ± 1030	19,510 ± 2730	15,200 ± 250
Radish	25,580 ± 1310	24,550 ± 2420	23,480 ± 900	21,320 ± 140	17,820 ± 820	15,100 ± 650
Metam Sodium	27,450 ± 880	23,460 ± 2360	24,950 ± 930	23,450 ± 1260	19,820 ± 2950	13,330 ± 1640
Carbofuran	29,020 ± 1520	29,730 ± 6240	24,140 ± 2150	24,010 ± 1820	18,210 ± 2410	16,480 ± 2500

mean ± standard deviation

B. phosphorous (%)

Treatment	June 18 (63 DAP)	June 25 (70 DAP)	July 2 (77 DAP)	July 9 (84 DAP)	July 16 (91 DAP)	July 23 (98 DAP)
Control	0.51 ± 0.04	0.54 ± 0.09	0.58 ± 0.11	0.52 ± 0.08	0.39 ± 0.08	0.26 ± 0.10
Mustard	0.50 ± 0.02	0.50 ± 0.01	0.49 ± 0.06	0.46 ± 0.04	0.37 ± 0.01	0.18 ± 0.04
Radish	0.50 ± 0.02	0.51 ± 0.07	0.50 ± 0.07	0.40 ± 0.06	0.36 ± 0.07	0.27 ± 0.12
Metam Sodium	0.54 ± 0.03	0.54 ± 0.02	0.59 ± 0.04	0.57 ± 0.04	0.46 ± 0.03	0.48 ± 0.07
Carbofuran	0.49 ± 0	0.56 ± 0.01	0.58 ± 0.05	0.53 ± 0.06	0.47 ± 0.06	0.36 ± 0.07

mean ± standard deviation

C. potassium (%)

Treatment	June 18 (63 DAP)	June 25 (70 DAP)	July 2 (77 DAP)	July 9 (84 DAP)	July 16 (91 DAP)	July 23 (98 DAP)
Control	13.2 ± 0.5	15.8 ± 1.0	10.6 ± 1.2	11.3 ± 1.5	11.1 ± 1.5	7.3 ± 1.7
Mustard	13.0 ± 0.6	15.8 ± 0.6	10.2 ± 0.9	11.3 ± 1.7	10.3 ± 1.2	6.7 ± 0.8
Radish	12.2 ± 0.6	15.9 ± 1.4	10.0 ± 0.3	8.9 ± 0.4	9.7 ± 0.4	8.1 ± 1.7
Metam Sodium	13.3 ± 0.2	16.3 ± 0.4	10.1 ± 0.7	9.5 ± 0.6	10.2 ± 0.5	10.7 ± 1.6
Carbofuran	13.0 ± 0.3	17.0 ± 0.5	10.4 ± 1.0	11.6 ± 1.5	10.2 ± 0.7	7.1 ± 0.9

mean ± standard deviation

D. sulfur (%)

Treatment	June 18 (63 DAP)	June 25 (70 DAP)	July 2 (77 DAP)	July 9 (84 DAP)	July 16 (91 DAP)	July 23 (98 DAP)
Control	0.32 ± 0.01	0.23 ± 0.02	0.16 ± 0.02	0.24 ± 0.03	0.28 ± 0.08	0.09 ± 0.04
Mustard	0.32 ± 0.02	0.22 ± 0.03	0.14 ± 0.02	0.25 ± 0.02	0.30 ± 0.03	0.11 ± 0.03
Radish	0.33 ± 0.02	0.24 ± 0.01	0.16 ± 0.02	0.26 ± 0.01	0.34 ± 0.04	0.17 ± 0.01
Metam Sodium	0.34 ± 0.03	0.23 ± 0.01	0.15 ± 0.01	0.25 ± 0.01	0.31 ± 0.02	0.18 ± 0.03
Carbofuran	0.32 ± 0.01	0.23 ± 0.01	0.15 ± 0.01	0.24 ± 0.01	0.33 ± 0.03	0.13 ± 0.01

mean ± standard deviation

Table A-7. NPK levels in potato leaflets collected on July 9, 2003 (84 DAP).

Treatment	N (%)	P (%)	K (%)
Control	6.25 ± 0.17	0.46 ± 0.06	7.96 ± 1.37
Mustard	5.63 ± 0.12	0.42 ± 0.04	8.28 ± 0.04
Radish	5.55 ± 0.41	0.41 ± 0.07	6.24 ± 0.55
Metam Sodium	6.13 ± 0.19	0.53 ± 0.05	6.74 ± 0.27
Carbofuran	5.64 ± 0.22	0.55 ± 0.07	8.68 ± 0.96

mean ± standard deviation