PLANT AND WILDLIFE SCIENCES

January 10, 2010
Kristi Jensen
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Dear Kristi:

Attached is my final report for Assessment and Demonstration of the Sustainability of Long vs. Short Potato Rotations (SW05-142). As I mentioned previously, I am still waiting on some information from cooperators before we can pursue final publications. Several preliminary publications are already in print.

This project had several problems along the way, including serious problems with transporting and storing contaminated soils which caused significant delays and changes in the original plans. Fortunately, we were able to overcome most of these problems and completed nearly every objective we originally set out to achieve - plus a couple of extra ones. I am pleased with the results, as are most of my collaborators and farmer cooperators.

Included in this mailing is three copies of the final report including all graphs and figures and three CDs that include all written materials.

Please let me know if you need anything else.

It has been a great pleasure working with you and Phil on this project.

Sincerely,

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Project Number:	**SW05-142** (Type: Research & Education Project, Region: West)
Project Title:	**Assessment and Demonstration of the Sustainability of Long vs. Short Potato Rotations**
Report Year:	2009
Report Type:	FINAL Research and Education Project
Reporting Period:	January 1, 2009 through August 14, 2009
SARE Funds:	$135,756

SUMMARY

In response to economic pressure, growers tend to reduce years between potato crops, with higher short-term profits but reduced sustainability due to pest pressure. This effect was quantified by comparing potatoes grown in soil with long vs. short rotation history. Short rotations lead to increases in *Verticillium dahliae* and nematode infections, increase in pesticide costs, and reduction in tuber quality/yield. Therefore, amortized costs of short rotations are likely greater than when potatoes are grown less frequently. A survey of growers shows 59,203+ acres have added at least one year to their rotation length as a direct result of this project.

INTRODUCTION

The length of crop rotation plays a key role in agricultural production. In the past, short crop rotations and monoculture have lead to many cropping disasters, such as those experienced by early European settlers in America. Short crop rotations tend to result in reduced quality/yield due to reduction in soil quality and increased pest/pathogen pressure. Previous research showed an average increase of 30 to 40 cwt/A of U.S. No. 1 potatoes when switching from a two- to a three-year rotation interval between potato crops. The yield increase is similar when switching from a three- to a four-year interval.

Overall soil quality is greatly impacted by short potato rotations. Potatoes place a very high nutrient demand on the soil. More importantly, potato production tends to negatively impact soil structure and compaction due to the multiple field operations that disturb the soil and the use of heavy equipment on moist soil. This reduction in soil quality impacts subsequent crops. For example, a plant’s ability to withstand stress from nematodes and other pests that impact roots can be reduced if root growth is impeded due to compaction.

Short rotations also significantly reduce the grower’s opportunity to control weeds that are problematic in potatoes but may be easier to control in rotational crops. A longer rotational length between potatoes allows the growers to decrease the number of problematic seeds in the soil’s seed bank before the next potato crop. In addition to competition for light, water, and nutrient resources, an increase in weed pressure can exacerbate problems with nematodes and other pests as certain plants (especially those from the nightshade family) act as an alternative host.

The quality/yield difference in potatoes is partly pest/pathogen related; short rotations can increase populations of detrimental soil borne diseases, insects, and nematodes due to an abundance of host material. Certain insects and nematodes reduce yield indirectly by weakening and increasing stress on potato plants and by making them more susceptible to fungal and bacterial diseases. They can also directly damage tubers. Yield reductions attributed to nematode infection varies from slight damage to total loss in severely infested fields because of loss of marketable tubers. Diseases can also weaken and stress the plant, and/or can directly damage tubers.

Unfortunately, with market pressures in recent decades, many potato growers have felt pressured to base their cropping system decisions on short-term economic survival as they shorten the time between potato crops. These decisions to move to shorter rotations result in problems with long-term sustainability. The negative impacts of short rotations tend to increase with time, often not showing severe problems for a decade or more.

A recent study, funded by the Idaho Potato Commission and the USDA Western SARE (Sustainable Ag Research and Education) program, focused on giving growers better decision-making tools to aid in their cropping systems management. These preliminary results are part of the larger study examining the long-term effects of short vs. long crop rotations on potato production.

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OBJECTIVES

The objectives of this project were to quantify the effects and educate growers concerning the long-term impacts of short vs. long periods of time between potato crops with regard to potato yield and tuber quality parameters, all major potato pests and pathogens, as well as soil health parameters:

*nematodes
*wireworm
*bacteria:fungi ratios
*Rhizoctonia (*Rhizoctonia solani*)
*silver scurf (*Helminthosporium solani*)
*white mold (*Sclerotinia sclerotiorum*)
*pink rot (*Phytophthora erythroseptica*)
*Pythium leak (*Pythium* species)
*Verticillium wilt (*Verticillium dahliae*)
*powdery scab (*Spongospora subterranea* subsp. *subterranea*)
*weed seed bank/numbers
*herbicide-resistance development
*soil microbial activity
*soil carbon and inorganic nutrient conc.
*soil depth, density & aggregate stability
*water infiltration rate
*biomass yield
*tuber yield, size, grade, solids, and defects
*net economic return
*cost per rotational acre
*cost per potato acre and per cwt

MATERIALS AND METHODS

Sample Collection

Each growing season (2007 and 2008), 27 pairs of short- and long-potato rotation fields were chosen and sampled for a total of 108 fields. All fields were located across the predominant potato production areas of the Snake River Basin in southern Idaho and the Columbia Basin in Washington and Oregon. Fields in each pair were selected based on proximity and by matching, excluding rotation length, as closely as possible: soil type, topography, environmental conditions and management history. The short-rotation fields in each pair had a history of potatoes grown approximately every other year (minimum of six years of potatoes in the last 12 years) with small grains typically as the rotation crop. The long-rotation fields had a history of potatoes grown approximately every four years (maximum of three years of potatoes in the last 12 years with no less than three years between potato crops) with small grains, sugarbeets, and corn commonly grown in the rotation. All fields had potato growing in them when the soils used in the study were gathered, as well as when sampling of the canopy and soil were performed.

At each field location, soil and tuber samples were taken from five random locations within the potato growing area. Pits were hand dug to a 12-inch depth and length of 6 to 8 feet to allow researchers to collect a 5-gallon bucket of soil and approximately 100 tubers from each field. Plant tissue was also collected and evaluated for pest damage. After collection, the soil was mixed well and subsamples distributed for various analyses. Final harvest data was also collected from growers.

Sample Analysis

Immediately after samples were collected in each growing season subsamples were split and disbursed to the various cooperators for analyses to determine rotational impacts.

Nematode Counts

Each soil sample was thoroughly mixed and a 500-cm^3 subsample was processed by the wet sieve centrifugation technique and sugar flotation process. Extracted nematodes were counted by using a Hawksley counting slide and identified to genus. After counting the nematodes, specimens of each genus were fixed in a hot 5% formaldehyde solution, process to anhydrous glycerin by the modified Seinhorst method and mounted on Cobb slides with double cover slips. The nematodes were examined with a compound microscope and identified with recent taxonomic keys.

Wireworm Analysis

At the time of sampling tubers from the field, the fields and tubers were visually observed for wireworm damage by the sampling crew. The fields were scouted for poor stand due to root system damage; the tubers were observed for shallow to deep holes caused by the wireworms burrowing into the tuber during feeding.

Pathology Analysis

Soil, tubers, and, in some cases, leaf/stem/root tissue were evaluated visually and by plate counts for Rhizoctonia, silver scurf, white mold, pink rot, Pythium leak, Verticillium wilt, and powdery scab.

Weed Identification, Germination and Count/Herbicide Resistance Studies

Each sample was well mixed, then soil from a given sample was used to fill eighteen 3x3 inch greenhouse pots to a level 0.5 inch below the top. The pots were placed in a greenhouse with air temperature set at 75/65° F and a 14/10 hour period of day/night. Soil was kept moist but not saturated with daily, light watering.

Planned treatments were 1) nontreated control, or postemergence application of either 2) metribuzin or 3) rimsulfuron at field rates when emerged weeds were 2 to 3 inches tall.

The experimental design for these three treatments was a Randomized Complete Block with 6 replications, 1 pot = 1 replication.

A 2nd trial mixing the preemergence herbicide dimethenamid-p into each sample at a field-use rate, then potting as described above also was planned.

Fry Quality Analysis

Within 24-48 hours after collection from the field, tubers were transported to the Kimberly R&E Potato Storage Research Facility and divided into two sub-samples. The first sub-sample was analyzed for harvest sugar and fry color soon afterward; the other sub-sample was cured at 55°F for approximately 10 days with the storage temperature decreased by 0.5°F per day until a final holding temperature of 45°F was reached. A thermal aerosol CIPC application (22 ppm) occurred November 26, 2008 and storage sugars and fry color will be determined in May 2009.

Tubers were cut using a Keen Kut Shoe Stringer French fry cutter. One fried plank (3.0 cm x 0.8 cm) from each of the ten tubers was used for fry color determination (10 strips per replicate). Strips were fried in canola oil at 375°F for 3.5 minutes. Fry color was determined within 3 minutes using a model 577 Photovolt Reflection Meter (model 577, Photovolt Instruments Inc., Minneapolis, MN). A green filter was used and calibrated using a black-cavity standard as 0.0% reflectance and a white plaque (Cat. No. 26-570-08) as 99.9% reflectance. Measurements were taken on the bud and stem ends of each strip. A relationship between USDA fry color and photovolt reflectance as measured by our instrument and methodology was previously established. The data produced a scale of a USDA fry color rating where USDA 1 was equal to a 44.0 or greater reflectance rating, a USDA 2 rating was less than 44.0 to 35.0 reflectance rating, a USDA 3 rating was less than 35.0 to 26.0 reflectance rating, and a USDA 4 rating was less than 26.0 reflectance rating. The lower the reflectance measurement, the darker the fry color.

The incidence and severity of mottling were recorded. The severity rating scale for mottling was 1= no mottling, 2 = mild mottling (light colored, non-uniform surface browning not covering the entire fried plank, 3= moderate mottling (light colored, non-uniform surface browning covering the entire fried plank, and 4= severe mottling (dark colored, non-uniform surface browning covering the entire fried plank.

The presence or absence of sugar end was recorded for each plank. A plank was considered to have a sugar end if a predominant color of number 3 or darker, when compared with the USDA Munsell Color Chart for French Fried Potatoes, was seen on any 2 sides extending ½ inch or more from the end of the fried strip.

Greenhouse Container Study

Prior to initiating any research, all soils sampled were analyzed for biological, chemical, and physical properties. The remaining soil (about 9 kg or 20 lb) was placed back in the collection buckets and potatoes were cultivated in a Brigham Young University glasshouse at Provo, Utah. Two 70 g (2.5 oz) Russet Burbank seed pieces were planted in each bucket to a depth of 15 cm (6 in) and the containers were arranged in a completely randomized experimental (CRD) design. Normal production practices were mostly followed as closely as possible for crop, nutrient, and water management. However, no pesticides were applied in order to allow for pest/pathogen pressure to develop and be evaluated.

Leaf chlorophyll values (SPAD), normalized difference vegetation index (NDVI), and visual readings were routinely recorded to monitor plant health. After the plants had completely senesced, biomass readings (leaf, vine, root, and tuber) were taken and tubers graded for quality. At that time,pathology testing completed on the leaf, root, and tuber samples; and soil-borne insect analysis concluded.

Statistical Analysis

Differences between the two treatments were determined by ANOVA using SAS Statistical Analysis software. In the case of senescence data collected over time, the data was evaluated by PROC REGRESSION.

RESULTS AND DISCUSSION

Nematode

Several different nematode species were identified in 2007 (Table 1) and 2008 (Table 2). Cyst *Heterodera,* Columbia Root Knot, and Stunt nematode species were identified in some fields in both years and Northern Root Knot, Pin, and Golden nematode species were identified in some fields in 2007 only.

Analyzing the data by year, species, and rotation length showed that there was no significant interaction for year in any comparison and, therefore, the data was combined across years for the final analysis. There was a significant species by rotation length interaction. Columbia root knot nematode was the only species having a significant increase in population in both the number of fields infected and the population in these infected fields (Figure 1).

It is important to note that only 6 out of the 54 short-rotation fields were infected with Columbia Root Knot nematode, but the populations were very high in comparison to the long-rotation fields where only 2 of the 54 fields were infected.

These findings are particularly interesting, considering the fact that a much higher percentage of the short-rotation fields (50 out of 54) were fumigated during the year prior to sampling compared to long rotation fields (19 out of 54), as well as having more fumigation events in previous years than the long-rotation fields. Although it is surprising that most of the nematode populations were not affected by rotation length, the magnitude of the differences for Columbia Root Knot nematode proved to be an exception despite the tremendous increase in fumigation incidence.

Increased nematode occurrence affects potato production in numerous ways. The increased populations not only potentially reduce yield and quality, but also likely increases grower expenses for nematicides and fumigants. Chemical control of some nematode species is expensive, often exceeding $300 per acre. It has been determined by survey that growers with fields in an every other year potato cycle nearly always need to fumigate, but growers with fields where potatoes are grown every four or more years oftentimes do not need to fumigate.

Wireworm

There were no significant differences in wireworm infection in the field stands or the harvested tubers from the greenhouse studies (data not shown) between long and short rotation soils evaluated in this study, however, it is important to note that, in both 2007 and 2008, there was very little to no wireworm damage observed by potato growers in the surrounding areas. This was confirmed by Dr. Juan Alvarez who stated that “wireworm pressure was very low across the region in 2007 and 2008”. Therefore, it is not possible to make conclusions about the impact of rotation length on wireworm infection. More study is needed under conditions of higher wireworm infection.

Pathology

In field visual analysis showed that the incidence and severity of *Verticillium dahlia* was significantly greater for short vs. long rotation fields. Nearly all short rotation fields (53 of 54) had incidence of this pathogen within the sampling area; whereas fewer of the long rotation fields (37 of 54) had incidence. On a visual rating scale of 0 (no damage) to 5 (complete necrosis), the short rotation fields had an average of 3.2 and the long had an average of 2.3.

Incidence and severity of several of the other evaluated pathogens (Rhizoctonia, white mold, pink rot, and Pythium leak) were all numerically greater for short vs. long rotation fields, but the differences were not significant. Incidence and severity of silver scurf and powdery scab were minimal and not significant.

These results were confirmed in the greenhouse study where there was minimal infection of most soil borne pathogens, except for Verticillium dahlia, which was present at high levels and dominated the rate of senescence and discussed below.

Weed Identification, Germination and Count/Herbicide Resistance Studies

After 2 weeks, only a very few scattered yellow foxtail (*Seteria viridis*) and pigweed sp (*Amaranthus sp*) plants germinated throughout the 18 pots, which was not a critical mass, so the potting was repeated with more soil from the sample bags. After a 3 week period under the same growing conditions as described above, only a few scattered weeds germinated, which was again, not enough to test. As minimal weeds germinated in these repeated attempts, the preemergence herbicide trial was not conducted.

There was a question as to whether or not herbicides the growers had applied to the test fields might still be present in the soil samples and therefore affecting weed seed germination.

- A bioassay was conducted by planting 4 tame oat seeds into the already potted soil samples.
- By 2 weeks after planting, 95% or greater oats had emerged with no sign of herbicide symptoms.

Although the soil-sampling and weed-seed planting projects reportedly kept the soil samples cool, dry, and dark, the samples may have been exposed to a short period(s) of high temperatures, which in turn, may have killed the weed seed in the samples. Since sample handling was well monitored, the possibility of this event occurring is quite remote. If the soil was somewhat moist inside the sample bags, weed seeds possibly germinated and died before the samples were processed at the Aberdeen R&E greenhouse. However, when the soil was mixed for greenhouse planting, no weed seedling “skeletons” were noticed. It could be that weed seeds did germinate and die in the sample bags but became too desiccated by greenhouse planting time to be recognizable. In our experience, germinated weed seeds in soil samples are recognizable for a long enough period of time to have been seen during this trial. Even if this did occur, one would expect enough weed seeds in the samples to have emerged once the soil was potted.

Otherwise, no reasonable explanation for the unsuccessful weed seed germination seems plausible to this project and further study in needed in order to draw conclusions regarding the impact of short vs. long rotation length on weeds in potato.

Soils

There were no impacts of rotation length on soil carbon, mineral nutrients, bulk density, aggregate stability, or water infiltration (data not shown).

Greenhouse Container Study

The plants grown in the short-rotation soils had lower visual ratings (evaluations performed blindly – without knowledge of which plants were grown in short vs. long rotation soils) and began senescence an average of 15 days earlier than the plants grown in long-rotation soils (Figure 2). Total senescence was achieved 5 days later for potatoes grown with the long-rotation soils. The potatoes grown in long-rotation soils also had numerically higher tuber size, yields, and percentage of U.S. No. 1 potatoes (Figure 3). It should be noted that tuber size was small due to constraints of growing tubers in buckets in a greenhouse environment.

In comparison to plants grown in the long-rotation soil, plants grown in short-rotation soils:

- began senescence an average of 15 days earlier
- produced 19.6% less tuber yield
- yielded no effect on root growth (Fig. 3)
- generated no differences for tuber numbers (data not shown)

As compared to long rotations, short-rotation practices lead to earlier senescence and lower tuber yields. Based on previous research that shows an average yield loss of 7 cwt per acre per day, the five-day difference in total senescence could lead to a potential yield loss of 35 cwt per acre for the short-rotation fields. Since senescence began 15 days earlier, this could result in even greater yield losses--up to 105 cwt per acre based on the 7 cwt per acre loss for 15 days. Although larger in magnitude, this finding is similar to the yield loss of approximately 60 cwt per acre that was shown in previous field studies on short- vs. long-rotation fields (Dr. Jeff Stark, University of Idaho at Idaho Falls, personal communication). The difference in magnitude could be due to the longer time frame in which the soils used in our study were subjected to short- or long-rotation practices.

The likely reason for this response is due to increased pest/pathogen pressure (Stark and Love, 2003). In our study, the early senescence was caused by verticillium wilt (early die complex); although this conclusion was based solely on visual observation (lab results are pending). Nematode damage was also likely (Tables 1 and 2), although direct damage to tubers was not observed. Damage instead could have been to roots.

These results confirm the hypothesis that potato plants grown in short-rotation soils would likely require more pesticides relative to potato plants grown in long-rotation soils. With this confirmation, researchers can now proceed to the next steps: quantification of single factors (nematodes, pathogens, insects, etc.) to determine exactly why long crop rotations are more productive and to study their economic impacts.

Fry Quality Analysis

Post-harvest fry color rating (bud end, stem end and USDA rating), mottling (severity and percent incidence), percent sugar ends and sugar content are summarized in Table 3. In general, the long-rotation fields had numerically higher values/scores on the fry quality parameters compared with the short-rotation fields. Overall, values for both rotation lengths were within the standard range.

Post-storage fry color rating, mottling, percent sugar ends and sugar content are summarized in Table 4. Once again, the long-rotation fields, in general, had higher numerical higher value/score on the fry quality parameters compared with the short-rotation fields. The percent incidence of mottling was significantly higher in both short and long-rotation fields post-storage compared with post-harvest values; the severity scores were higher as well. The changes in values exhibited after storage are consistent with typical storage behavior.

IMPACT OF RESULTS

The impacts of this study, combined with previous projects, have been significant. In addition to the contribution to the body of scientific evidence, the impact on actual farms has been substantial. Surveys completed in 2006 and 2009 (prior to and after the study) show that 59,203 acres have increased the length of rotation by at least one year and 9,870 acres by two by years. Growers completing these surveys attended workshops and roundtables and were surveyed immediately after the end of the following growing season. These growers indicated that the results of this project were at least 50% of the reason why they chose to make the change, although almost all of them also indicated that they had begun to notice problems with short rotation practices. Additional undocumented acres were also likely impacted as well.

Nearly all of these growers also indicate that they plan to spend less money on fumigants (92%) and fungicides (58%), although they currently are not spending less (likely takes several for the benefits of the long rotation to be expressed). Fewer growers suggested that they may expect to spend less money on herbicides (33%) and insecticides (14%), although it is likely that they will have an easier time controlling problematic weeds in their potatoes if they have more than one rotational year to do so. Very few growers expected to reduce fertilizer rates (2%) or tillage (8%) operations.

ECONOMIC ANALYSIS

The economic analysis of this project is continuing as some grower information is still being collected (common for the 2008 crop not to be sold until almost one year of storage; also, some growers had storage failures and were in process of determining cause and economic impact).

A cursory evaluation of the economics shows average total yield was significantly higher for growers with long rotation fields (48 cwt/acre increase), with an even greater impact on tuber quality (67 cwt/acre increase for US No. 1 tubers). There was no impact on other grades or size categories. Nor was there a significant impact on specific gravity or internal defects. The effects of damage from nematodes and tuber pathogens is not complete enough for even an initial analysis, however, it is apparent that a larger percentage of growers were having issues with these problems in short rotation fields.

To date, the net impact on gross return was an average of approximately $469 per acre, although this figure needs further adjustment for pathogen and nematode damage. Growers with short rotation fields spent an average of $187.31, $32.01, $3.07, $1.20, and $0.11 per acre less on fumigation, fungicide, herbicide, insecticide, and fertilizer, respectively. Only the fungicide reduction was statistically significant. The total reduction in costs for these inputs was $223.70. The net difference when accounting for these costs and the increase in gross returns was $692.70, which was also statistically significant.

Although these results are dramatic, it should be noted that, in general, the net return for rotational crops is often significantly less than potato. A grower with a four year rotation will only be able to sell one crop compared to two crops for a short rotation. It is not likely that the $692.70 benefit for the long rotation will be enough to cover the lost revenue completely. However, many growers are beginning to realize that the long term costs of short rotations may not make up for the immediate returns. Also, rotation acreage costs are still being analyzed (again, waiting for growers to finalize sales and litigation) and these results may be more favorable. Furthermore, the impacts of fry color could impact economics as well and this factor needs to be inserted into the final analysis.

PUBLICATIONS/OUTREACH

Workshops have been conducted over the project's duration every year at the Idaho Potato Conference and once at similar conferences in Washington and Oregon. Presentation was made at the Sustainable Agriculture Research and Education (SARE) Conference in Kansas City, MO in 2008. In addition, 12 grower roundtables have been done with as many as 35 and as few as 3 growers in attendance at each (combined total of 67 different growers – several attended more than one roundtable) where growers have learned about the importance of rotation frequency and participation in this project. These growers were also very helpful in guiding this project, publications, and ideas for future research.

Publications include:

Hopkins, B.G., 2005. Production Efficiency - Cropping Sequence and Rotation: Impact on Potato Production and Soil Condition. p. 47-56 *In* Craven et. al. (*eds*.) Trade Adjustment Assistance for Idaho Fresh Potatoes – Technical Assistance Curriculum. UI. Moscow, ID.

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Miller, J.S. and B.G. Hopkins. 2007. Checklist for a holistic potato health management plan. chp. 2. p. 7-10. *In* D.A. Johnson (*ed.*) *Potato Health Management*. American Phytopathological Society. Minneapolis, MN.

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Also, are nearly ready to submit this data to the *American Journal of Potato Research* and a review article on potato rotations in *Agronomy Journal* or *Journal of Sustainable Agriculture*.

FARMER ADOPTION

Idaho's agricultural statistics are showing a substantial trend on more acres towards longer and more sustainable rotations.

The impacts of this study, combined with previous projects, have been significant. In addition to the contribution to the body of scientific evidence, the impact on actual farms has been substantial. Surveys completed in 2006 and 2009 (prior to and after the study) show that 59,203 acres have increased the length of rotation by at least one year and 9,870 acres by two by years. Growers completing these surveys attended workshops and roundtables and were surveyed immediately after the end of the following growing season. These growers indicated that the results of this project were at least 50% of the reason why they chose to make the change, although almost all of them also indicated that they had begun to notice problems with short rotation practices. Additional undocumented acres were also likely impacted as well.

AREAS NEEDING ADDITIONAL STUDY

These results clearly confirm the overall benefit to soil and a potato crop of longer potato rotations when these rotations have been established in actual fields over long periods of time. Further study is needed to evaluate the impact of weeds, wireworms, and possibly other diseases that did not show significant pressure in this study.

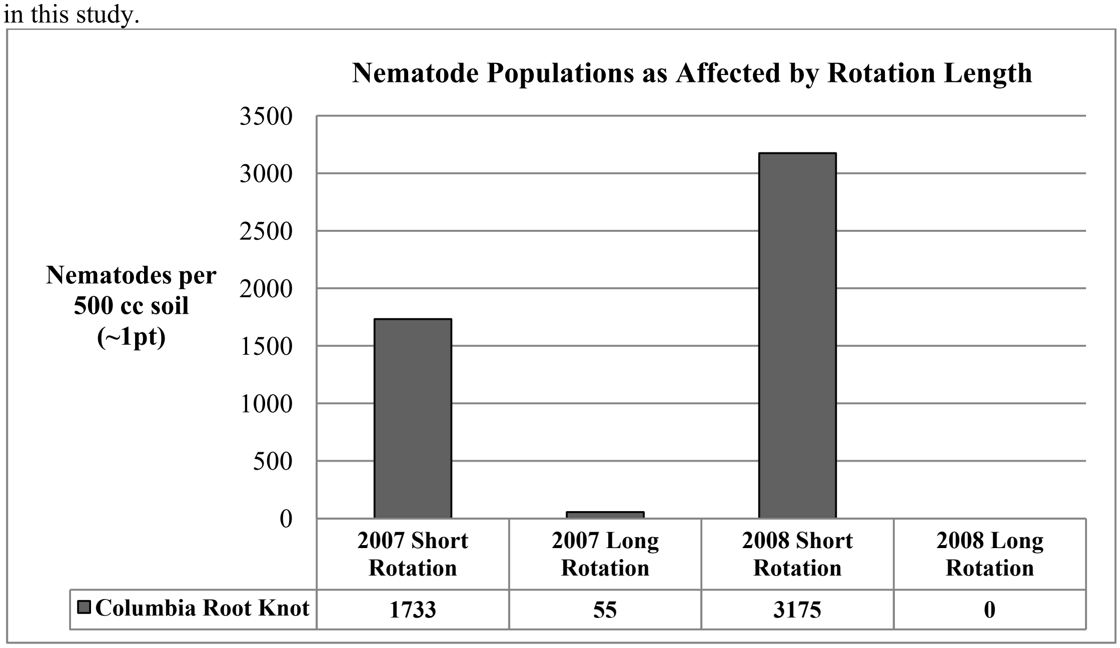


Figure 1. Average populations of Columbia Root Knot nematode fields in soils with detection of this pest. In 2007, 4 fields for short rotation and 2 fields for long rotation were affected; in 2008, 0 fields for short rotation and 2 fields for long rotation were affected. Short rotation = potatoes grown at least 6 times in 12 years. Long rotation = potatoes no more than 3 times in 12 years.

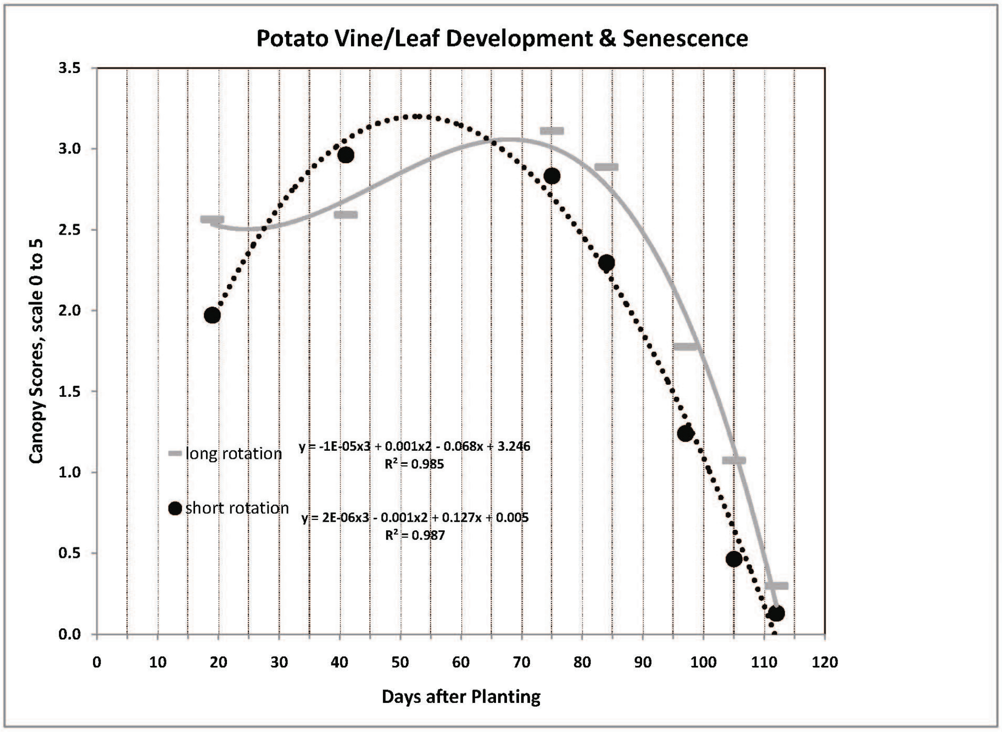
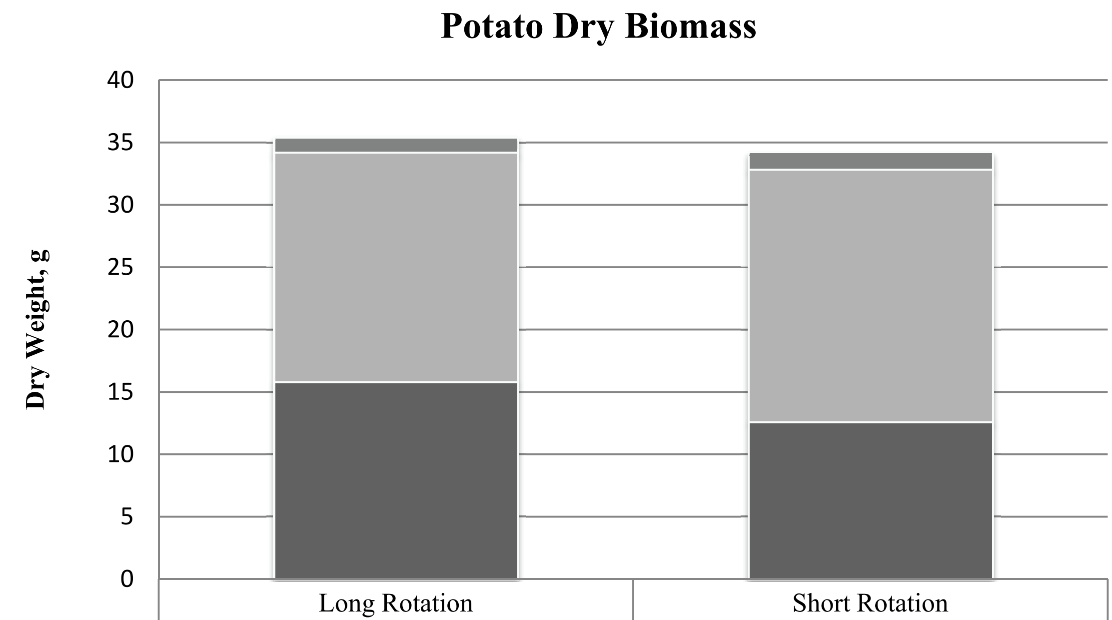


Figure 2. Visual canopy scores indicating *Russet Burbank* potato canopy development and senescence for greenhouse trials in 2007 and 2008 (combined) grown in soils with a history of either long or short rotation. Long rotation = potatoes no more than 3 times in 12 years. Short rotation = potatoes grown at least 6 times in 12 years.



	Long Rotation	Short Rotation
root	1.3	1.4
vine/leaf *	18.4	20.3
tuber **	15.8	12.6

Figure 3. Root, vine/leaf and tuber dry weight values indicating *Russet Burbank* growth for greenhouse trials in 2007 and 2008 (combined) grown in soils with a history of either long or short rotation. Long rotation = potatoes no more than 3 times in 12 years. Short rotation = potatoes grown at least 6 times in 12 years. *Significant at p=0.05. **Significant at p=0.01.

Table 1. Nematode species, counts, and averages[1] of 2007 short and long rotations soil samples.

	Northern Root Knot	**Columbia Root Knot**	**Root-Lesion**	**Stubby Root**	**Stunt**	**Spiral**	**Pin**	**Ring Nematode**	**Golden Nematode**	**Cyst *Heterodera* (Viable)**	**Cyst *Heterodera* (Larvae)**	**Cyst *Heterodera* (Eggs)**	**Others**
						Short Potato Rotation Fields							
Number of infected fields	1	4	24	7	14	4	1	0	1	1	1	1	0
Minimum count[2]	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum count	180	4210	4620	40	1130	110	70	0	56	79	460	160	0
Mean of infected fields	**180**	**1733**	**953**	**21**	**257**	**45**	**70**	**0**	**56**	**79**	**460**	**160**	**0**
						Long Potato Rotation Fields							
Number of infected fields	0	2	27	1	24	11	3	2	0	2	1	2	0
Minimum count[3]	0	0	30	0	0	0	0	0	0	0	0	0	0
Maximum count	0	60	5620	80	210	2610	60	110	0	31	230	70	0
Mean of infected fields	**0**	**55**	**1407**	**80**	**109**	**385**	**40**	**70**	**0**	**16**	**230**	**45**	**0**

[1] Twenty-seven pairs of short- and long-potato rotation fields (54 fields total) are included in the study and were sampled in 2007. Short rotation fields have a history of potatoes every other year and long rotation fields have a history of potatoes planted a minimum of every three years. Small grains are the typical rotation crop in both rotation types.

[2] Of the 10 species identified, there were no nematode species which were detected in all 27 of the short-rotation fields

[3] Of the 10 species identified, Root lesion nematode was the only species detected in all 27 of the long-rotation fields.

Table 2. Nematode species, counts, and averages[1] of 2008 short and long rotations soil samples.

	Columbia Root Knot	Root-Lesion	Stunt	Spiral	Cyst *Heterodera* (Viable)	Cyst *Heterodera* (Larvae)	Cyst *Heterodera* (Eggs)	Others
				Short Potato Rotation Fields Rotations				
Number of Fields Infected	2	24	19	0	4	3	4	0
Minimum Count[2]	0	0	0	0	0	0	0	0
Maximum Count	3280	2610	360	0	44	210	40	0
Mean of Infected Fields	**3175**	**587**	**106**	**0**	**21**	**120**	**33**	**0**
				Long Field Rotations				
Number of Fields Infected	0	24	23	3	2	2	0	0
Minimum Count[3]	0	0	0	0	0	0	0	0
Maximum Count	0	3720	360	220	27	40	0	0
Mean of Infected Fields	**0**	**1074**	**105**	**160**	**24**	**35**	**0**	**0**

[1] Twenty-seven pairs of short- and long-potato rotation fields (54 fields total) are included in the study and were sampled in 2008. Short rotation fields have a history of potatoes every other year and long rotation fields have a history of potatoes planted a minimum of every three years. Small grains are the typical rotation crop in both rotation types.

[2] Of the 5 species identified, there were no nematode species which were detected in all 27 of the short-rotation fields

[3] Of the 5 species identified, there were no nematode species which were detected in all 27 of the long-rotation fields.

Table 3. Tuber processing quality parameters at harvest of *Russet Burbank*, *Ranger Russet* and *Russet Norkotah* potatoes grown in 2008 fields with a history of either short or long potato rotation. Long rotation = potatoes no more than 3 times in 12 years. Short rotation = potatoes grown at least 6 times in 12 years.

Cultivar	Fry color rating[1] Bud end	Stem end	USDA score	Mottling[2] Severity	% incidence	% Sugar Ends	Sugars (% fwt) Glucose	Sucrose
				Short Potato Rotation Fields				
Russet Burbank	51.4	53.7	1,1	1.0	4.5	3.6	0.0224	0.1370
Ranger Russet	54.6	56.9	1,1	1.5	40.0	0.0	0.0157	0.1511
Russet Norkotah	49.7	46.9	1,1	1.2	23.3	13.3	0.0286	0.1137
Mean	**51.9**	**52.5**	**1,1**	**1.2**	**22.6**	**5.6**	**0.0222**	**0.1339**
				Long Potato Rotation Fields				
Russet Burbank	54.0	54.1	1,1	1.1	10.9	9.1	0.0236	0.1289
Ranger Russet	50.1	51.1	1,1	2.3	76.7	3.3	0.0277	0.2485
Russet Norkotah	49.7	48.7	1,1	1.9	65.0	1.7	0.0430	0.1265
Mean	**51.3**	**51.3**	**1,1**	**1.8**	**50.9**	**4.7**	**0.0314**	**0.1680**

[1]USDA fry color rating #1≥ 44, #2 < 44 but ≥ 35, #3 < 35 but ≥26, #4 < 26 reflectance

[2]Mottling severity 1=no mottling 2=mild 3=moderate 4=severe

Table 4. Tuber processing quality parameters after storage of *Russet Burbank*, *Ranger Russet* and *Russet Norkotah* potatoes grown in 2008 fields with a history of either short or long potato rotation. Long rotation = potatoes no more than 3 times in 12 years. Short rotation = potatoes grown at least 6 times in 12 years.

	Fry color rating[1]			Mottling[2]		%	Sugars (% fwt)	
Cultivar	**Bud end**	**Stem end**	**USDA score**	**Severity**	**% incidence**	**Sugar Ends**	**Glucose**	**Sucrose**
				Short Potato Rotation Fields				
Russet Burbank	46.6	39.3	1,2	1.5	33.7	4.2	0.0645	0.1137
Ranger Russet	47.7	41.9	1,2	3.1	100	0.0	0.0833	0.0938
Russet Norkotah	43.1	37.5	2,2	2.6	90.0	20.0	0.0585	0.0996
Mean	**46.2**	**39.2**	**1,2**	**1.7**	**46.5**	**6.2**	**0.0650**	**0.1102**
				Long Potato Rotation Fields				
Russet Burbank	47.8	37.5	1,2	1.8	56.7	8.6	0.0865	0.1081
Ranger Russet	40.5	35.3	2,2	3.3	96.7	0.0	0.1818	0.0796
Russet Norkotah	50.0	44.9	1,1	1.8	53.4	1.7	0.0483	0.1129
Mean	**47.6**	**38.4**	**1,2**	**1.9**	**59.1**	**7.0**	**0.0878**	**0.1068**

[1]USDA fry color rating #1≥ 44, #2 < 44 but ≥ 35, #3 < 35 but ≥26, #4 < 26 reflectance

[2]Mottling severity 1=no mottling 2=mild 3=moderate 4=severe

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