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Long Term Impacts of Short Rotations

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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.

OBJECTIVES

The objectives of this project are 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:

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*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 eastern Washington and Oregon. Fields in each pair were selected based on proximity and by matching as closely as possible: soil type, topography, and management history excluding rotation length. The short-rotation fields in each pair had a history of potatoes every other year with small grains typically as the rotation crop. The long-rotation fields had a history of potatoes no less than every four years with small grains, sugarbeets, and corn commonly grown in the rotation. All fields were planted in potatoes when they were sampled close to the time of harvest.

At each field location, soil and tuber samples were taken from 4 to 5 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. After collection, the soil was mixed well and subsamples distributed for various analyses.

Sample Analysis

Immediately after samples were collected in each growing season they were analyzed to determine rotational impacts. The greenhouse container study and fry quality analyses have been completed on the 2007 samples; 2008 samples are still undergoing investigation. Nematode counts have been completed on both sets of samples. Weed impact studies on both sample sets are still in progress.

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 greenhouse 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 followed as closely as possible for crop, nutrient, and water management. However, no pesticides were applied to the soil in order to allow for maximum pest/pathogen pressure to develop.

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

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.

Fry Quality Analysis

Immediately after collection, 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.

Weed Identification, Germination and Count/Herbicide Resistance Studies

Soil subsamples from all 54 fields per year were sifted and washed to facilitate weed seed separation. The seeds were then identified and counted to quantify weed pressure impacts; afterwards they were planted in the greenhouse to observe germination rates and investigate the occurrence of herbicide resistance.

RESULTS AND DISCUSSION

Although some components of the study have been completed, statistical analysis is not available yet. Once all of the project components are finished, statistical analysis will be performed. At that time enough data will be available to make the sample size large enough to accurately detect differences. All aspects of the project are on track for completion by late spring 2009.

Greenhouse Container Study

The plants grown in the short-rotation soils had lower visual ratings and began senescence an average of 15 days earlier than the plants grown in long-rotation soils (Figure 1). 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 estimated tuber size, yields, and percentage of U.S. No. 1 potatoes (Figure 2).

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. 2)
- 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. 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). 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 research confirmed, 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.

A greenhouse container study using soil collected from the 2008 paired fields has been initiated with an expected completion date of May 2009 (to allow tubers to reach a reasonable size and to accrue maximum pathogen and pest pressure).

Nematode Counts

In 2007 (Table 1), ten different nematode species were identified; however, none of the ten species was detected in *all* 27 of either long- or short-rotation fields. Root lesion nematode was the only species detected in all 27 of the long-rotation fields. Compared with the long-rotation fields, the short-rotation fields had a numerically higher average nematode count per field of the following six species: Cyst *Heterodera* viable, larvae, and eggs, Northern Root Knot, Columbia Root Knot, Stunt, Pin, and Golden Nematode.

In 2008 (Table 2), five different nematode species were identified; however, no single species was detected in *all* 27 of either long- or short-rotation fields. Compared with the long-rotation fields, the short rotation fields had a numerically higher average nematode count per field of the following four species: Cyst *Heterodera* larvae, and eggs, Columbia Root Knot, and Stunt.

For infested fields, population densities were similar when comparing long vs. short rotations for all but Columbia Root Knot which had significantly higher populations in short-rotation fields (Figure 3). 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. Figure 3 only includes data from the infected fields. These findings are particularly interesting, considering the fact that a much higher percentage of the short-rotation fields were fumigated during the year prior to sampling, 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.

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. Costs for control of pathogens, weeds, and insects are also likely higher for short vs. long rotation.

Fry Quality Analysis

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. Further interpretation will be possible when the samples are removed from storage in a few months allowing an assessment of storage quality between the rotations. Potatoes grown in long rotations tend to withstand storage conditions better than those grown in short rotations.

CONCLUSION

Deciding on a cropping rotation system is complex and dependent on many factors (potato and rotational crop values, risks, and ownership and operating costs per acre), but growers need to understand the costs of growing potatoes in short rotation, which is increased cost of pest/pathogen control and/or reductions in yield and crop quality. Increasing the frequency of potatoes in a rotation might seem to increase profitability, but this may not be reality when long-term negative consequences are considered. When developing budgets for increasing the time between potato crops (from 2 to 4 years), we recommend that growers consider the following possible results:

*Increase of 60 cwt/acre (this is likely a conservative value – could be as high as 105 cwt/acre),

*Increase in percentage of U.S. No. 1 tubers (we have not yet quantified this, but stay tuned),

*Decrease in fumigation costs (likely that fields with 4-year rotation will not need fumigation),

*Decrease in the number of fungicide applications (we estimate at least one less application),

*Possibly less herbicide needed and/or fewer weed escapes.

REFERENCES

Stark, J.C. 2003. Field Selection, Crop Rotations, and Soil Management. p. 71-79. *In* J.C. Stark and S.L. Love (*eds.*), Potato Production Systems, Univ. Idaho Ag Comm., Moscow, ID.

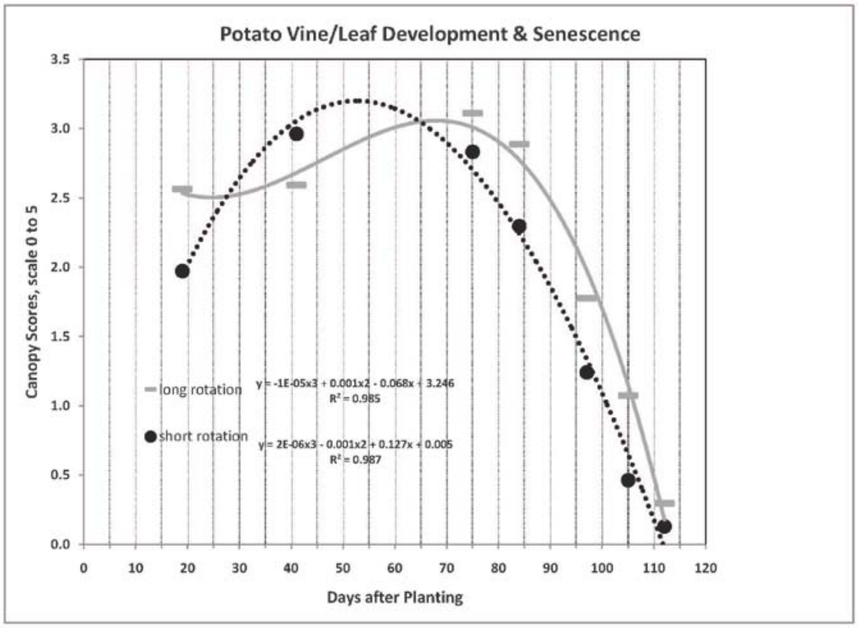
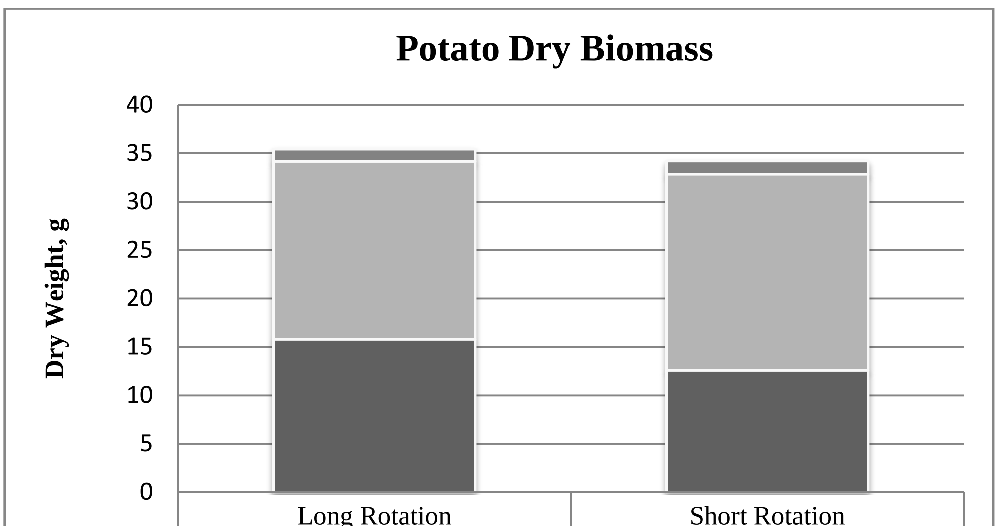
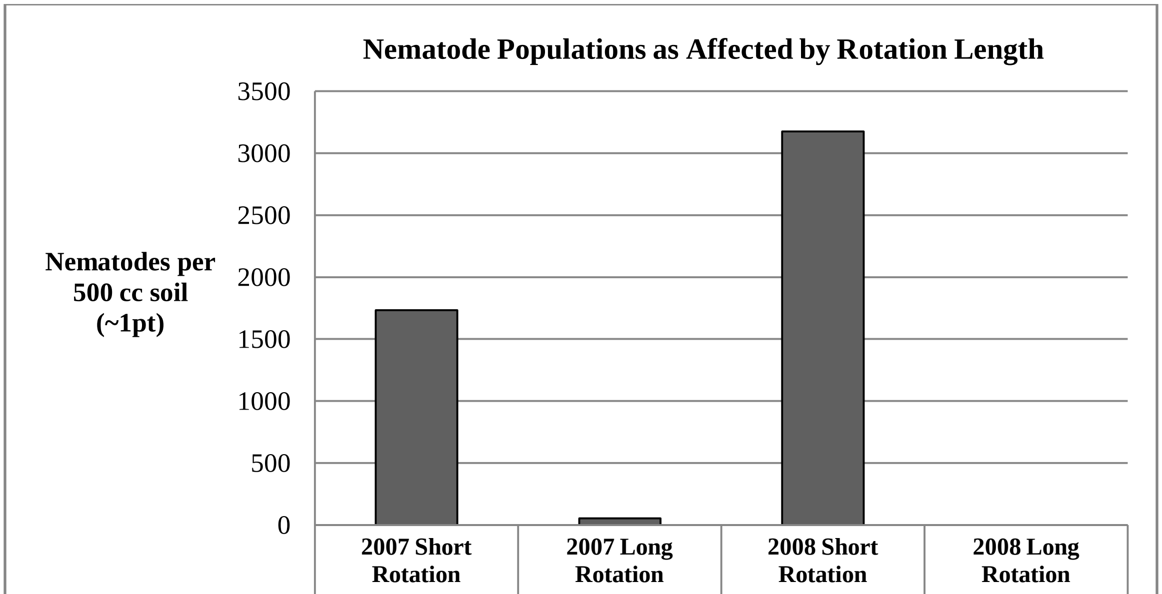


Figure 1. Visual canopy scores indicating *Russet Burbank* potato canopy development and senescence for greenhouse trial with 2007 soil samples with a history of either long or short rotation. Long rotation = potatoes no more than 3 times in 12 years. Short rotation = potatoes grown at least 6 times in 12 years.



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

Figure 2. Root, vine/leaf and tuber dry weight values indicating *Russet Burbank* growth for greenhouse trial with 2007 soil samples 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.



	2007 Short Rotation	2007 Long Rotation	2008 Short Rotation	2008 Long Rotation
Columbia Root Knot	**1733**	**55**	**3175**	**0**

Figure 3. 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.

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.

	Fry color rating[1]			Mottling[2]		% Sugar Ends	Sugars (% fwt)	
Cultivar	**Bud end**	**Stem end**	**USDA score**	**Severity**	**% incidence**		**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