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Residual Effects of Fresh and Composted Dairy Manure Applications on Potato Production

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Abstract Potato growers in Idaho and other dairy producing regions often grow potatoes on fields that have had a history of fresh and composted manure applications. Growers remain uncertain of the impacts that previous manure applications will have on tuber yield and quality, as well as diseases, physiological disorders, and contamination by human pathogenic bacteria such as E. coli. The focus of this study was to determine the long term effects of manure, compost, and chemical phosphorus (P) fertilizer applications on tuber yields, tuber quality, nutrient uptake, tuber disorders and diseases, and soil nutrient concentrations. Russet Burbank potatoes were grown in 2008 and 2009 on plots that had received dairy manure, dairy compost, P fertilizer, or no P source (control) at the same target P rate in 2003, 2004, and 2005. Compared with the P fertilizer treatment, applications of manure and/or compost significantly increased total yields, soil potassium (K), soil nitrate (NO_3-N), early season petiole P, and late season petiole K in at least one year of the two-year study. There were no significant differences between P fertilizer, manure, and compost treatments on soil test P, late season petiole P, early season petiole K, E. coli populations on tuber surfaces, common tuber diseases and disorders, and tuber quality. Based on our findings, tuber yields significantly increased three years after applications of fresh and composted dairy manure, while tuber diseases, disorders, and quality were not affected.

Resumen Los productores de papa en Idaho y de otras regiones lecheras a menudo cultivan sus papas en campos que han tenido una historia de aplicaciones de estiércol fresco y compostado. Los productores permanecen inciertos de los impactos que las aplicaciones previas de estiércol tendrán en rendimiento y calidad de tubérculo, así como de enfermedades, desórdenes fisiológicos y contaminación por bacterias patogénicas para humanos tales como E. coli. El enfoque de este estudio fue determinar los efectos a largo plazo de las aplicaciones de estiércol, la composta y el fertilizante químico de fosforo (P) en el rendimiento y calidad de tubérculo, absorción de nutrientes, desórdenes y enfermedades del tubérculo y concentración de nutrientes en el suelo. Se cultivaron papas Russet Burbank en 2008 y 2009 en lotes que habían recibido estiércol, composta, fertilizante fosforado (P) o sin fuente de P (testigo) al mismo objetivo de nivel de P en 2003, 2004 y 2005. Al comparar con los tratamientos de fertilizante de P, las aplicaciones de estiércol y/o composta aumentaron significativamente los rendimientos totales, el potasio (K) y el nitrato (NO_3-N) del suelo, el P temprano del pétalo y el K tardío del pétalo en por lo menos un año de los dos del estudio. No hubo diferencias significativas entre los tratamientos del P del fertilizante, estiércol y composta en pruebas de P del suelo, P tardío del pétalo, y K temprano del pétalo, poblaciones de E. coli en las superficies del tubérculo, enfermedades y desórdenes comunes y calidad del tubérculo. Con base en lo que encontramos, aumentaron significativamente los rendimientos de tubérculo tres años después de las aplicaciones del estiércol fresco y compostado, y no se afectaron las enfermedades, desórdenes y calidad del tubérculo.

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Introduction

With the recent expansion of the dairy industry in Idaho (170,000 dairy cattle in 1989 in 1989 to 546,000 in 2009) (USDA 2010), there has been a marked increase in the practice of applying manure or compost to fields on an annual basis. Field crops with highest nutrient removal potential (corn silage, alfalfa hay, and small grain crops) typically receive the majority of dairy waste applications in the state. However, as dairies expand into prominent potato growing regions, more potatoes are planted into fields with extensive manure application histories. It is critical for the growers to understand the potential benefits and issues associated with growing potatoes in fields with past histories of manure applications.

Research on the residual effects of manure applications on potato yields is very limited. Sharma and Grewal (1986) and Conn and Lazarovits (1999) detected no residual effects on tuber yield up to 3 years after application. These limited findings suggest that it is difficult to predict long-term effects of manure applications on potato yield.

Several studies on recent applications (planting within 6 months after application) of cattle and farmyard (animal source not specified) manure to potatoes in northern United States and southern Canada have shown significant tuber yield increases in comparison to non-limiting chemical fertilizer applications (Dawson and Kelling 2002; Black and White 1973; Curless et al. 2005), suggesting that factors beyond nutrient content were increasing yields. Conversely, Lee and MacDonald (1977) and Hall (1905) did not detect tuber yield differences with cow and farmyard manure applications compared to fertilizer applications, and Conn and Lazarovits (1999) detected no yield differences with cow manure application of 100 t ha^{-1} in comparison to control plots not receiving fertilizers.

Nutrient cycling and accumulations in potato production systems are also important to understand, as applications of fertilizers often need to be adjusted to compliment the nutrient supply from the manure source. Grandy et al. (2002) found that fields receiving 16 t ha^{-1} cattle manure 6 years prior to potato production did not affect soil bulk density, but soil carbon content increased by 46% and medium and large soil aggregate content increased in comparison to the field that had not received manure. Curless et al. (2005) found that potatoes consumed excess phosphorus (P) from fertilizer sources, but not from manure sources. They also reported that petiole NO3-N concentrations were significantly lower for manure treatments compared to nitrogen fertilizer treatments, while yields were significantly higher with the manure treatments. These results suggest that petiole NO3-N targets for in-season N fertilizer applications may need to be adjusted for manured soils.

Reductions in tuber yield and quality may also be anticipated after long-term manure applications due to an overabundance of specific nutrients that are not typically found in potato fields. Dawson and Kelling (2002) found tuber solids decreased with liquid dairy manure applications (93,500–2,805,00 L ha^{-1}) in comparison to fertilized plots at two locations, suspecting an accumulation of salts as the cause. Black and White (1973) found that tuber starch content was not affected in the first 8 years of yearly manure applications (9 t ha^{-1} per year) to potato-oat-alfalfa rotations, but significantly decreased tuber starch in the ninth year. While the cause of decreased starch content was not identified, the author suspected K accumulations, as increasing amounts of K fertilizers reduced starch content in another treatment used in this study. Manganese toxicities have also been attributed to cow manure applications, although this was identified only under very acidic soil conditions (soil $pH<4.8$) (Lee and MacDonald 1977).

Diseases such as common scab (caused by *Streptomyces* spp.), Rhizoctonia (caused by *Rhizoctonia solani*), and Verticillium wilt (caused by *Verticillium dahlia*), can be of concern with potato production on manured fields, as manure is suspected to provide optimal conditions for these pathogens. Dawson and Kelling (2002) showed that common scab incidence increased with liquid dairy manure applications in only one of four site-years in comparison to fertilized plots. Blodgett (1940) reported that the combination of lime and manure increased common scab incidence from 0.3 to 63% on acidic soils, while manure applications alone had no significant effect. By comparison, Conn and Lazarovits (1999) found common scab incidence was actually reduced 2 and 3 years after cattle manure had been applied at a rate of 100 t ha^{-1} at one of two sites. The incidence of common scab is often related to soil pH and therefore in these studies, amending the soil with manure may be altering soil pH sufficiently to cause changes in common scab incidence (Loria 2001). In the study by Blodgett (1940), the incidence of tubers with Rhizoctonia sclerotia (black scurf) was reduced by 10% in manured plots compared to fertilized plots. Conn and Lazarovits (1999) reported the incidence of Verticillium wilt was reduced at one of two sites 1 year after application of manure, but no difference in Verticillium wilt was observed 2 and 3 years after application. The authors attributed the seasonal variation in disease incidence to a subsequent decrease in nematode populations and/or increase in soil microbial populations.

Application of fresh manure also raises concerns about contamination with bacteria responsible for food-borne illnesses in humans. Entry et al. (2005) found greater incidence of *Enterococcus spp*., *Echerichia coli (E. coli)*, and fecal coliform bacteria on potato skins and in the root rhizosphere on plots receiving applications of dairy manure solids, in comparison to plots receiving dairy compost, fertilizer, and control treatments.

The focus of this research project is to determine the effect of previous manure, compost, and chemical fertilizer applications on tuber yield, tuber quality, nutrient uptake, and soil nutrient concentrations, as well as various potato disorders and diseases.

Materials and Methods

Field Layout, Location and History

This study was conducted in 2008 and 2009 on a field site in Kimberly, Idaho that was amended 3 and 4 years prior with either fresh dairy manure solids, composted dairy manure, inorganic mono-ammonium phosphate (11-52-0) fertilizer, or no P source. The amendments were applied for 3 consecutive years (Fall 2003, Fall 2004, and Fall 2005) based on the P requirement of the succeeding crop. For more information on the 2003–2005 applications and experimental design, refer to Leytem and Bjorneberg (2009). The soil series was a Portneuf silt loam soil (coarse-silty, mixed superactive, mesic Durinodic Xeric Haplocalcids). Amendment application targets were 75 kg P ha^{-1} in Fall 2003, 109 kg P ha^{-1} in Fall 2004, and 162 kg P ha^{-1} in Fall 2005 (Table 1). Crops grown on the test site were potato in 2004, barley in 2005, dry beans in 2006, and dry beans in 2007. To insure optimal growth and yields, urea fertilizer was spring-applied as uniform pre-plant application at rates of 240 kg N ha^{-1} in 2004, 100 kg N ha^{-1} in 2005, and no application in 2006 or 2007. The experimental design was a complete randomized block design, with four replications and four treatments (compost, fertilizer, manure, and control). Plot dimensions were 30.5 m in length and 15.2 m in width.

To determine the residual effect of 2003, 2004, and 2005 treatment applications on potato production, Russet Burbank potatoes (*Solanum tuberosum*) were grown on the plots in 2008 and 2009. Cut seed pieces (40–65 g; treated with Tops-MZ Gaucho™) were planted at 31 cm plant spacing, 91 cm row spacing, and at a depth of 15.2 cm on 24 April in both years. Potatoes were planted in both 2008 and 2009 on the same site. Volunteer potatoes left over from 2008 were hand-removed in 2009 from pre-determined yield rows. Irrigation (solid set) and pest management applications were made according to University of Idaho guidelines.

Uniform fertilizer applications were continued for the 2 year duration of the study to maintain adequate tuber production. Fertilizer rates were determined using University of Idaho fertilizer guide recommendations based on soil test values averaged over the four treatments. In 2008, 90 kg ha^{-1} of mono-ammonium phosphate (MAP) (11-52-0), 151 kg ha^{-1} of urea (46-0-0) and 336 kg ha^{-1} of K sulfate (K_2SO_4) (0-0-50) were broadcasted and incorporated pre-plant in the spring. In 2009, pre-plant spring fertilizer applications were 128 kg ha^{-1} MAP, 244 kg ha^{-1} of urea and 336 kg ha^{-1} of K_2SO_4. Approximately 119 kg N ha^{-1} as urea ammonium nitrate (UAN) (32-0-0) was applied during the growing season of 2008 and 134 kg N ha^{-1} was applied in 2009.

Yield was evaluated at the end of the growing season by machine harvesting 15.2 m from a single middle row from each of the 16-row plots. Potatoes were harvested on 24 September 2008 and 15 September 2009. Yield and grade were determined for each plot for tubers with weights greater than 25 g. Individual tuber number and fresh weights were recorded.

Table 1 Application rates and nutrient concentrations of amendments to a Portneuf silt loam in Kimberly, Idaho

Year	P source	Application Rate Mg ha^{-1}	Total P kg ha^{-1}	Water Soluble P kg ha^{-1}	Total N kg ha^{-1}	C:N
2003	Manure	24.4	75	61	556	15:1
	Compost	32.9	63	10	501	12:1
	Fertilizer	0.3	59	–	29	–
2004	Manure	32.6	109	70	736	15:1
	Compost	63.4	109	11	550	12:1
	Fertilizer	0.2	47	–	23	–
2005	Manure	33	162	79	732	12:1
	Compost	42.3	162	6	436	12:1
	Fertilizer	0.7	159	–	78	–

Tuber Diseases, Disorders, Processing Quality and E. Coli

Tubers were visually assessed at harvest for grade and presence of disease and physiological disorders (USDA 1998). Specific gravity was measured on approximately 4.5 kg of tubers via the weight in air/weight in water method.

Tuber processing quality was assessed by evaluating glucose and sucrose content and fry color and quality. Sucrose and glucose concentrations for the above treatments were determined from a ten-tuber sample after harvest using the method of Sowokinos et al. (2000) with modifications. Tubers were cut using a Keen Kut Shoe Stringer French fry cutter. Two hundred grams of tuber tissue collected from the center of the ten tubers were macerated in an Acme Juicerator (Acme Equipment, Spring Hill, FL). During processing, tuber tissue was washed with 150 mL of sodium-phosphate buffer (0.05 M, pH 7.5) for a final homogenate volume of 275 mL. Glucose and sucrose concentrations were determined for the whole tuber using a YSI model 2700 Analyzer (Yellow Springs Instrument Co., Inc., Yellow Springs, OH) and expressed on a mg g^{-1} fresh weight basis. One fried plank (3.0 mm × 0.8 mm) from each of the ten tubers used in the sugar extraction procedure was used for fry color determination (10 strips per replicate). Strips were fried in canola oil at 191°C for 3.5 min. Fry color was determined within 3 min 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 (data not shown). The data produced a scale of a USDA fry color rating 1 was equal to a 43.0 or greater reflectance rating, a USDA 2 rating was between 43.0 to 35.3 reflectance reading, a USDA 3 rating was between 35.3 to 25.8 reflectance reading, and a USDA 4 rating was less than 25.8 reflectance rating. The lower the reflectance measurement, the darker the fry color.

Five tubers were selected from each plot to be tested for *E. coli* 0157:H7. Whole tubers were scrubbed with Butterfield's phosphate buffer solution to extract *E. coli* 0157:H7 from the skin and the outer flesh portion of the tuber. The Neogen Reveal Test System was used to determine presumptive positive or negative results. 3 M Petrifilm E. coli/Coliform Count Plates were used to verify or discount presumptive positive results from the Reveal test. *E. coli* testing was performed at the Washington State University Avian Health and Food Safety Laboratory in Puyallup, Washington.

Soil and Plant Analysis

Composite soil samples of 10 soil cores were taken from each plot at a 30 cm depth monthly through the growing season. Soil samples were analyzed for NO_3-N along with soil moisture content. Five g of moist soil were shaken with 25 mL of 2 M KCl solution for 30 min., and filtered through No. 42 Whatman filter paper. The concentrations of NO_3-N was measured colorimetrically via NaOH-persulfate oxidation and cadmium reduction using a Lachat Quickchem 8500 Flow Injection Analysis System (Loveland, CO). Plant available (Olsen) P and K was determined by extracting 2 g of air-dried soil with 40 mL of 0.5 M sodium bicarbonate ($NaHCO_3$) and filtered through S&S #605 filter paper. Phosphorus was measured using the ammonium molybdate method and a Milton Roy Spectronic 301 spectrophotometer (Ivyland, PA). Potassium was measured through atomic absorption using a Perkin Elmer 5100-PC Atomic Absorption Spectrometer (Waltham, MA).

In-season determinations of crop N, P, and K status were based on analysis of extractable NO_3-N, phosphate (PO_4-P), and K concentrations in petioles. Approximately thirty petioles from the fourth leaf were collected from non-yield and non-buffer rows in each plot. Petioles were sampled to be analyzed for NO_3-N concentrations on 7/14, 7/27, and 8/11 in 2008, and on 7/14, 7/27, and 8/11in 2009 to cover the periods of tuber initiation, tuber bulking, and senescence. Phosphorus and K concentrations were determined for samples collected on 7/8 and 9/2 in 2008 and 7/14 and 8/11 in 2009 to cover the periods of tuber initiation and senescence. Petioles were dried at 75°C and ground to pass through a 0.853 mm mesh screen. A 0.32 g subsample of the ground tissue sample was extracted with 25 ml of 0.33 M acetic acid solution. Nitrate-N and PO_4-P concentrations were measured through color spectroscopy using a Spectronic 20 spectrometer. Potassium concentrations were measured with atomic adsorption using a Perkin Elmer Model 2380 AA atomic absorption spectrometer (Waltham, MA).

Statistics

Year and treatment effects were determined using a one-way ANOVA using SAS PROC GLM. For all analyses excluding petiole P and K, the impact of specific treatments was determined using the least square differences (LSD) multiple comparison analysis. Due to unbalanced data, the

Duncan multiple comparison analysis was used for petiole P and K data.

Results and Discussion

Tuber Yield and Quality

The residual effects of fresh dairy manure solids, composted dairy manure, triple superphosphate fertilizer, or no phosphorus source applied (control)) on tuber number, yield, size, and specific gravity are shown in Table 2. Data collected in 2008 and 2009 represent yield effects for 3 and 4 years after the amendment applications, respectively.

In 2008, the previous addition of fresh dairy manure solids and dairy compost in 2003, 2004, and 2005 (last P treatment application 3 years prior) significantly increased total tuber yield by 20% over the phosphorus fertilizer treatment and 42% over the control treatment (no P source added in 03, 04, or 05), respectively. U.S. #1 tuber yields were also significantly greater for manure and composted treatments in comparison to the control treatment. While there were no evident treatment effects on the smaller tuber size categories, yields of 0.17 to 0.34 kg tubers were significantly greater for compost, manure and fertilizer treatments in comparison to the control. There were no significant treatment effects on specific gravity of harvested tubers.

Other studies have shown tuber yield increases with manure applications (Dawson and Kelling 2002; Black and White 1973; Curless et al. 2005). Because fertilizer treatments in all of these studies were applied at non-limiting rates, the authors suggested that external factors, such as carbon content, soil structure, and microbial activity may be increasing yields on manured soils. As the fertilizer-only treatment in our study was limited for optimal tuber production, it is possible that the addition of N, K, and micronutrients from previous manure and compost applications had the greatest effect on yield increases.

Residual effects of manure and compost applications from 2003, 2004, and 2005 on tuber yield and size distribution did not continue into 2009 (last P treatment application 4 years prior). There was a trend ($p=0.06$) toward higher total tuber yields with manure treatments in comparison to control treatment. In addition, there were no significant effects on U.S. #1 yields or any tuber size category. As was seen in 2008, there was also no significant effect on specific gravity of harvested tubers in 2009.

The increased production of large tubers for compost treatments compared to P fertilizer treatment in 2008 and the trend for increased yields with manure treatments compared to P fertilizer treatment in 2009 suggests greater potential for tuber bulking on fields with manure and compost application histories over fields only receiving chemical fertilizer applications. In addition, manure additions increased total tuber counts in 2008 over P

Table 2 The effect of manure, compost, or phosphorus fertilizer applications as the primary phosphorus source in 2003, 2004, and 2005 on tuber number, yield, size distribution and specific gravity of Russet Burbank potatoes, grown in 2008 and 2009 at Kimberly, Idaho on a Portneuf silt loam soil

Year	Treatment	Total tuber number #/ha	Total yield Mg ha^{-1}	US #1 yield	< 0.11 kg	0.11–0.17 kg	0.17–0.34 kg	>0.34 kg	Specific gravity
2008	Manure	912a	55.3a	37.3a	4.5	7.8	26.7a	16.2	1.0692
	Compost	860ab	54.5a	35.9a	4.5	6.6	24.0a	19.5	1.0705
	Fertilizer	848b	46.2b	30.5ab	4.8	7.5	25.1a	8.7	1.0705
	Control	704c	39.0b	22.2b	4.4	6.0	18.7b	9.9	1.0680
	LSD=0.05	62	7.9	10.3	ns	ns	3.6	ns	ns
	Pr>F	0.0002	0.0036	0.0244	0.8108	0.1475	0.0041	0.0628	0.4766
	Manure	1166	48.5	28.6	11.4	10.2	19.9	7.0	1.0787
	Compost	919	40.9	26.9	7.9	8.9	18.4	5.7	1.0830
2009	Fertilizer	939	38.0	24.8	8.8	10.3	15.0	3.8	1.0777
	Control	835	36.8	23.3	7.1	8.7	16.0	5.0	1.0835
	LSD=0.05	ns	ns	ns	ns	ns	ns	ns	ns
	Pr>F	0.1029	0.0635	0.2783	0.1881	0.4731	0.1472	0.1831	0.9049

Means followed by the same letter or no letters within each year are not significantly different at the 0.05 probability level as determined by the LSD multiple comparison test.

fertilizer treatments, a potential indication of greater tuber initiation.

Soil and Petiole Nutrients

The residual effects of previous manure and compost applications appears to be directly related to soil properties, particularly with regard to NO_3-N and K concentrations in the 0–30 cm soil depth (Tables 3 and 4). In 2008, soil NO_3-N concentrations were significantly higher for manure treated soils sampled in April and May in comparison to compost, fertilizer, and control soils. As nitrogen has more impact on tuber initiation and bulking than any other soil nutrient, it is likely that the increased NO_3-N concentrations on the manured soils at least partially caused the yield differences that were found between manured and fertilized soils in 2008. No differences in soil NO_3-N concentrations were seen in 2009, suggesting that the mineralizeable organic fraction of N was negligible after 4 years.

On all sampling dates except July 27th in 2009, differences in NO_3-N concentrations in the fourth petiole were not significant (Table 3). Because petioles were sampled for NO_3-N shortly after in-season applications of UAN fertilizer had started, treatment effects on petiole NO_3-N concentrations may have been masked by the recent N additions. However, because most potato growers also add in-season N fertilizers, they also may not see the effects of previous manure applications on petiole NO_3-N concentrations. Soil NO_3-N and K concentrations from soils sampled in April were more closely related to yield differences among treatments than petiole NO_3-N concentrations. Based on this finding, we recommend that growers rely more on preplant soil test NO_3-N and K concentrations to guide fertilizer applications compared to using petiole NO_3-N and K concentrations when working on soils with a manure or compost application history.

The level of P and K in the soil 2 weeks prior to planting, as well as P and K concentrations in the fourth petiole, are listed in Table 4. As there was no year-treatment interaction for P or K in soil and petiole data, the results from years 2008 and 2009 were combined. Olsen P concentrations in the control soil were significantly lower than in plots receiving manure, compost, or P fertilizer, but there was no difference in Olsen P concentrations among the treated plots. As P was applied at the same rate using the different sources from 2003–2005, Olsen P did not differ significantly 3 and 4 years after applications had ceased, regardless of source.

When sampled at the early tuber bulking stage (7/8/2008 and 7/14/2009), concentrations of P in the fourth petiole were significantly higher for manure treatments than compost, fertilizer, and control treatments (Table 4). Higher P concentrations in petioles from manured soils may be related to soil N concentrations, as increased concentrations of N in the soil is often attributed to greater uptake of P (Havlin et al. 2005). However, petioles sampled at the time of mid to late-season tuber bulking (9/2/2008 and 8/11/2009) from manured and composted plots had significantly lower P concentrations than

Table 3 Soil NO_3-N and petiole NO_3-N concentrations sampled at various dates in 2008 and 2009 on a Portneuf silt loam in Kimberly, Idaho, receiving manure, compost, or phosphorus fertilizer applications as the primary phosphorus source in 2003, 2004, and 2005

Year	Treatment	Soil NO_3-N conc. (0–30 cm)				NO_3-N conc. in the fourth petiole		
		mg kg^{-1}				mg kg^{-1}		
2008		4/8	5/30	6/20	7/11	7/14	7/27	8/11
	Manure	43.2a	35.2a	21.0	1.3	5925	9375	4650
	Compost	31.0b	26.5b	18.3	1.4	6900	7500	5550
	Fertilizer	26.2b	23.4b	16.2	0.7	7200	9225	4950
	Control	22.5b	22.9b	15.7	1.6	5025	8850	5550
	LSD 0.05	8.7	4.4	ns	ns	ns	ns	ns
	Pr>F	0.0023	0.0005	0.1259	0.3221	0.5150	0.6234	0.5714
2009		3/17	5/13	6/1	6/22	7/14	7/27	8/11
	Manure	19.0	6.1	1.3	0.2	6075	4275b	4350
	Compost	13.7	8.0	3.7	0.6	7575	5550b	4237
	Fertilizer	12.6	9.5	2.1	0.3	5925	5025b	5062
	Control	11.1	12.4	3.4	0.2	7575	7950a	6450
	LSD 0.05	ns	ns	ns	ns	ns	1525	ns
	Pr>F	0.0749	0.3044	0.3396	0.3550	0.5782	0.0022	0.0884

Means followed by the same letter or no letters within each year are not significantly different at the 0.05 probability level as determined by the LSD multiple comparison test.

Table 4 Residual soil and petiole phosphorus and K concentrations averaged over 2008 and 2009 for Russet Burbank potatoes grown on a Portneuf silt loam in Kimberly, Idaho. Treatments included manure, compost, or phosphorus fertilizer applications as the primary phosphorus source in 2003, 2004, and 2005. Soil P and soil K measured two weeks prior to planting

P source	Soil conc. (0–30 cm)		Nutrient conc. in the fourth petiole			
	P	K	Petiole PO_4-P		Petiole total K	
Month	mg kg^{-1}		mg kg^{-1}			
			July[a]	Aug/Sept	July	Aug/Sept
Manure	21.5a	193a	1770a	460b	81,100	58,400a
Compost	19.0a	166b	1435b	470b	78,500	51,700a
Fertilizer	19.5a	117c	1510b	520a	73,700	39,400b
Control	4.9b	120c	1320b	500ab	77,800	41,600b
Pr>F	<0.0001	<0.0001	0.0091	0.0414	0.0757	0.0014

Means followed by the same letter or no letters within each column are not significantly different at the 0.05 probability level as determined by the Duncan multiple comparison test.

[a] Month denotes time of petiole sampling.

petioles from fertilized plots. Curless et al. (2005) also found significant increases in tuber P concentrations and P uptake in potatoes receiving fertilizer P in comparison to manure P, without a related yield response. These findings suggest that recommended petiole P concentrations for potatoes may need to be adjusted to account for P source. Soil test P seemed to work as well or better than petiole P, particularly in 2008. This finding suggests that early petiole P concentrations may be more indicative of yield response than soil test P concentrations or late season petiole P concentrations.

Olsen soil K concentrations were significantly greater for manure than compost treatments, while fertilized and control treatment soils had significantly lower Olsen K concentrations than both manured and composted soils. While K concentrations of the manure and compost treated plots from 2003–2005 were not measured, we can assume that the higher residual K concentrations are directly related to the K in the manure and compost. As the recommended soil test K in southern Idaho is 175–200 ppm for most realistic yield goals for Russet Burbank potatoes (Stark et al. 2004), lower yields for the fertilizer and control plots may also be related to limiting K concentrations in the soils. Blanket applications of K fertilizer were applied in 2008 and 2009, but may not have been enough to eliminate a possible K deficiency effect for the P fertilizer and control treatments. In general, K from manure and compost applications helped to alleviate K limiting conditions.

The addition of K from manure and compost did not affect tuber specific gravity, as has been seen in other studies (Dawson and Kelling 2002; Black and White 1973). Potassium in Idaho soils has been estimated to be depleted through agricultural practices by at least 50% over the last

Table 5 Incidence of common scab and processing quality attributes of Russet Burbank potatoes harvested in 2008 and 2009 affected by prior fertilization treatment

Year	Treatment source	Incidence of common scab (%)	Glucose (mg g^{-1} fresh weight)	Sucrose (mg g^{-1} fresh weight)	Stem end fry color[a]
2008	Manure	0	0.5a	1.2	43
	Compost	3	0.6a	1.3	43
	Fertilizer	5	0.5a	1.2	42
	Control	0	1.0b	1.0	35
	LSD 0.05	ns	0.3	ns	4
	Pr>F	0.3272	0.0129	0.7256	0.0012
2009	Manure	1	0.4	1.2	43
	Compost	0	0.4	1.0	44
	Fertilizer	0	0.4	1.0	39
	Control	0	0.8	1.0	39
	LSD 0.05	ns	ns	ns	ns
	Pr>F	0.9219	0.0755	0.6519	0.3015

[a] USDA fry color rating #1 ≥ 43, #2 < 43 but ≥ 35, #3 < 35 but ≥ 26, #4 < 26 reflectance

50 years (Westermann and Tindall 1997), it would appear that manure and compost applications at reasonable rates will be beneficial for refilling K reserves with few negative effects on tuber quality.

Tuber Disorders, Diseases, Processing Quality and E. Coli

Previous research indicated a potential association between field applications of manure and disease development (Dawson and Kelling 2002; Blodgett 1940; Conn and Lazarovits 1999). Results from the 2008 and 2009 field studies indicated no significant differences among fertilizer, manure or compost treatments on common scab (Table 5), as well as the following common potato diseases and disorders: common scab, black scurf, silver scurf, pink eye, pink rot, dry rot, vascular discoloration, brown center or tuber malformation (data not shown). Incidence of these diseases and disorders was relatively low in these experimental plots.

Fertilizer applications can impact the processing quality of harvested tubers (Iritani and Weller 1978). These studies indicate tubers harvested from the control treatment showed a significantly higher glucose concentration at harvest compared to the other treatments in 2008 (Table 5). The higher glucose concentration translated to a darker fry color as indicated by the lower stem end reflectance values for the control treatment tubers. A similar trend ($p<0.10$) was observed the following year in 2009 of higher glucose concentration in the control tubers compared to the manure, fertilizer and compost treatments. Higher glucose levels can often be seen at harvest with overly mature potatoes (Iritani and Weller 1978). Higher glucose levels may indicate a difference in maturity between treatments and lower processing quality with inadequately fertilized control treatment. Processing quality was not impacted by historical applications of manure or compost to the plots.

Tubers collected in 2008 and 2009 from all treatments were negative for the presence of E. coli 0157:H7. These results are encouraging for growers who are concerned about the transference of pathogenic bacteria from previous manure applications to potatoes and other root crops. However, as the initial concentrations of *E. coli* 0157:H7 in the manure and compost sources used in this study were not known, we cannot use these results as conclusive evidence that *E. coli* 0157:H7 is not an issue on manured soils. Further research is needed to specifically monitor the survival of *E. coli* 0157: H7 in manured soils and the potential for transferance of the bacteria from manure to the potato.

Conclusion

Based on our findings, it appears that the impact of fresh and composted dairy manure application after 3 or more years on potato crop yields is greater than has been reported by other authors in production regions outside of Idaho. The most obvious causes for improved yields appear to be the concentrations of K and NO_3-N in the soil from the manure and compost sources, although there may be other factors that were not measured that may also be improving the yield potential. In contrast, our findings also suggest that the impact of fresh and composted dairy manure after 3 or more years of application on potato tuber quality, diseases, and disorders is less than previously reported. Comparing manure and compost treatments to fertilizer only treatments, there was no significant effect on any of the parameters measured, including E. coli populations, specific gravity, common scab, black scurf, silver scurf, pink eye, pink rot, dry rot, vascular discoloration, brown center, tuber malformation, glucose, sucrose, and fry color. When working with soils that have a manure or compost history, our findings suggest that it may be more reliable to use preplant soil test NO3-N and K concentrations instead of petiole values for predicting tuber yield. Conversely, petiole P values during tuber set may be better than soil test P values or late season petiole P values for predicting yield.

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