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Influence of solid dairy manure and compost with and without alum on survival of indicator bacteria in soil and on potato

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Solid dairy manure and dairy compost, with and without alum, had different effects.

Abstract

We measured *Escherichia coli*, *Enterococcus* spp. and fecal coliform numbers in soil and on fresh potato skins after addition of solid dairy manure and dairy compost with and without alum ($Al_2(SO_4)_3$) treatment 1, 7, 14, 28, 179 and 297 days after application. The addition of dairy compost or solid dairy manure at rates to meet crop phosphorus uptake did not consistently increase *E. coli* and *Enterococcus* spp. and fecal coliform bacteria in the soil. We did not detect *E. coli* in any soil sample after the first sampling day. Seven, 14, 28, 179 and 297 days after solid dairy waste and compost and alum were applied to soil, alum did not consistently affect *Enterococcus* spp. and fecal coliform bacteria in the soil. We did not detect *E. coli* in any soil, fresh potato skin or potato wash-water at 214 days after dairy manure or compost application regardless of alum treatment. Dairy compost or solid dairy manure application to soil at rates to meet crop phosphorus uptake did not consistently increase *Enterococcus* spp. and fecal coliform numbers in bulk soil. Solid dairy manure application to soil at rates to meet crop phosphorus uptake, increased *Enterococcus* spp. and fecal coliform numbers in potato rhizosphere soil. However, fresh potato skins had higher *Enterococcus* spp. and fecal coliform numbers when solid dairy manure was added to soil compared to compost, N and P inorganic fertilizer and N fertilizer treatments. We did not find any *E. coli*, *Enterococcus* or total coliform bacteria on the exterior of the tuber, within the peel or within a whole baked potato after microwave cooking for 5 min.

Keywords: Dairy manure; Dairy compost; $Al(SO_4)_3$; Alum; Enteric bacteria; Fresh vegetables

1. Introduction

In the last decade, there has been a major shift in animal rearing toward large scale confined animal feeding operations (CAFOs). CAFOs are a source of agricultural pollution and pose risks to water quality and public health due to the large amount of manure generated (USEPA, 1998). US Environmental Protection Agency (EPA) estimates that animal waste production in 1992 was 13 times greater on a dry weight basis than human production. Sources of water pollution from CAFOs include direct discharges, open feedlots, treatment and storage lagoons, manure stockpiles and land application of manure. Pollution of surface flow and groundwater from animal waste applied to soils has been documented (Mallin et al., 1997; Mawdsley et al., 1995; Khaeel et al., 1980). Liquid-waste discharge onto soil initiates solute and microbe movement into the soil following groundwater

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drainage patterns and can potentially contaminate adjoining surface water. These same bodies of water are often sources of drinking water or are used for recreational activities. Human contact with recreational waters containing intestinal pathogens is an effective method of disease transmission. Thus, employing appropriate treatment strategies to maintain the quality of lakes and streams and keep them free of pathogens is important.

Runoff and groundwater from waste treated agricultural land shows that enteric bacteria: (1) increase in spring flows and decrease in the dry period; (2) increase in water after applying wastewater by irrigation or after additional manure application; and (3) rapidly decrease once manure application is halted (Entry and Sojka, 2000; Fraser et al., 1998; Howell et al., 1996). Several investigators found that enteric bacteria declined rapidly when transported through dispersed soils indicating that bacterial pollution occurs by transport via water through soil macropores (Spackman et al., 2003; Howell et al., 1996; Abu-Ashour et al., 1994; Huysman and Verstraete, 1993). In studies where animal waste has been continually applied for several years, enteric bacteria are found in soils and groundwater (Entry et al., 2000a,b;2003). Pathogen survival time in the soil varies from 4 to 160 days (Abu-Ashour et al., 1994; Sjogren, 1994), and first reflects the organism's ability to respond to non-parasitic and adverse environmental conditions. Obligate parasites usually only live a few minutes outside the host, but many pathogenic organisms can live in groundwater and soil for months (Entry et al., 2000a,b; Sorber and Moore, 1987). Several factors influence the survival of pathogens in soil after waste materials are applied. Soil moisture and temperature seem to be the most important of these factors (Sjogren, 1994; Crane and Moore, 1986). Survival of bacterial pathogens in soil increases when the soil is moist and temperatures are warm (Entry et al., 2000a,b). Although further research is necessary, when waste is continually applied to forage production systems at least a 60 day period between waste applications and crop planting is advisable to let enteric bacteria die. After land application of animal waste, the opportunity for transfer of these organisms from soils to surface and groundwater and ultimately to humans depends in part on their ability to survive in the soil environment.

When combined with polyacrylamide, $Al_2(SO_4)_3$ has been shown to reduce total and fecal coliform numbers in animal wastewater. Entry and Sojka (2000) found that PAM + $Al_2(SO_4)_3$ mixtures reduced populations of total and fecal coliform bacteria in cattle, fish, and swine wastewater leachate and surface runoff by approximately 100- to 1000-fold compared to no treatment. Entry et al. (2003) found that PAM + $Al_2(SO_4)_3$ reduced populations of total coliform and fecal coliform bacteria in swine manure leachate from columns containing four different soil types ranging from sand to clay by at least ten-fold compared to soil columns with PAM (Entry et al., 2003). In the same study, PAM + $Al_2(SO_4)_3$ reduced populations of total coliform and fecal coliform bacteria in the same leachate from 10- to 100-fold in all three manure sources compared to the control treatment. We hypothesized that alum addition may decrease the survival rate of *E. coli* and *Enterococcus* in soil.

Our objectives were to determine the influence of dairy manure and dairy compost with and without alum ($Al_2(SO_4)_3$) on the survival of *E. coli* and *Enterococcus* spp. in the top 10 cm of soil. Our second objective was to determine the influence of dairy manure and dairy compost with and without alum on the survival of *E. coli* and *Enterococcus* spp. on the surface of potato in relation to survival of these pathogens in soil.

2. Materials and methods

2.1. Site description

The site is located at USDA Agricultural Research Service's Northwest Irrigation and Soils Research Laboratory at 42°30′00″ N and 114°20′40″ W, and is at 1300 m elevation. The climate is typified by cool, moist winters and hot, dry summers with annual precipitation ranging from 175 to 305 mm, two-thirds of which occurs during October through March (Collett, 1982). Average annual temperature ranges from 9 to 10 °C. The site crops are rotated with alfalfa (*Medicago sativa* L.), wheat (*Triticum aestivum* L.), potato (*Solanum tuberosum* L.), corn (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.). Soil was classified as a coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid, with 0.1–0.21 g/g clay and 0.6–0.75 g/g silt, and organic matter of approximately 13 g kg^{-1}. The soil has a pH of 7.6–8.0. Slope on this site ranges from 1.0 to 3.0%.

2.2. Experimental design

The experimental design was a split plot design with four fertility and two alum treatments. Fertility treatments were: (1) fresh solid dairy waste; (2) solid dairy composted; (3) nitrogen and phosphorus inorganic fertilizer (11-52-0) (control); and (4) only inorganic nitrogen fertilizer (control). Each treatment was split with one half receiving alum and the other half untreated. The experiment contained four replications. At each sampling date there were four fertility treatments (two dairy waste and two inorganic fertilizer) × two alum treatments (alum applied and no alum applied) × four replications × three samples taken in each plot.

2.3. Plot design

Plots were 17×33 m and were positioned on the landscape according to contour, so that in the case of runoff, water flow down slope did not result in cross contamination. The irrigation schedule was based on evapotranspiration rates from Agrimet models.

2.4. Dairy manure, compost and alum application

Treatments were applied in designated plots at the following rates on October 10, 2003. Composted dairy manure at 15 tons acre^{-1}=(32.9 Mg ha^{-1}), solid dairy manure at 11 tons acre^{-1}=(24.4 Mg ha $^{-1}$), a N–P (11-52-0) inorganic fertilizer as mono-ammonium phosphate at 183 kg ha $^{-1}$ and a N fertilizer at 267 kg N ha $^{-1}$ (46-0-0) as urea. Plots were split with one half receiving 58.5 kg alum ha^{-1} as a liquid sprayed on to the soil. Dairy manure, compost, fertilizer and alum were disked into the top 15 cm of soil.

2.5. Sampling

Three 10 cm diameter cores to a 10 cm depth were collected at random points in each plot. *E. coli*, *Enterococcus* spp. and fecal coliforms in soils were determined in the 0–10 cm soil depth at −1, 1, 7, 14, 28, 63, 179 and 297 days after application of dairy and alum treatments. We took three soil cores from each treatment×alum plot on each sampling date (four fertility treatments×two alum treatments×four replications×three soil samples taken in each plot=96 samples). Each core was placed in sterile plastic bags, stored at 4 °C in coolers and transported to the Northwest Irrigation and Soils Research Laboratory. Samples were stored at 4 °C and incubation began within 2 h of collection. At harvest, 297 days after dairy waste, compost, inorganic fertilizers and alum were applied, 24–30 tubers were randomly selected from each plot. The 5.0 mm of soil surrounding the tubers (rhizosphere soil) was also sampled in the manner described below.

2.6. Escherichia coli and Enterococcus spp. and coliform procedures

A 10 g subsample of each soil was taken and gravimetric water content was determined. To enumerate desired soil bacterial populations, a 1 g subsample was placed in 99 ml of Butterfield's buffer (Greenberg et al., 1992) in a 160 ml dilution blank and shaken for 20 min on a rocking platform shaker at 100 revolutions min^{-1}. The blanks were then removed and further diluted to 10^{-2} to 10^{-5} with Butterfield's buffer. *E. coli* and *Enterococcus* spp. and fecal coliform bacteria were analyzed with the membrane filter technique (Greenberg et al., 1992). A 100 ml sample of the final dilution of each sample was vacuum-filtered through a sterile 0.45 μm filter and placed on mFC medium to enumerate fecal coliform bacteria or mTEC medium to enumerate *E. coli* or mEnterococcus medium to enumerate *Enterococcus* spp. (four fertility treatments×two alum treatments×four replications×one dilution×three soil samples taken in each plot=96 plates for each selective medium).

Tubers were stored at ambient temperatures and incubation began within 2 h of collection. The samples were tested for *E. coli*, *Enterococcus* spp. and coliform populations on the exterior of the tuber, within the peel and within a whole baked potato. To enumerate the population on the exterior of the tuber, ten unwashed tubers from each plot were selected, weighed, quartered and placed in a 500 ml wide mouth sterile bottle containing Butterfield's buffer. They were shaken for 30 s to remove the surface soil and other debris. The solution was plated at 10^{0}, 10^{-2}, and 10^{-4} onto 3M Petrifilm *E. coli*/Em *Enterococcus* plates (four fertilizer treatments (two dairy waste treatments and two inorganic fertilizer treatments)×two alum treatments×four replications×one dilution×three samples taken in each plot×three types of selective medium=288 plates). To enumerate the population within the peel, ten tubers were randomly selected, weighed, washed with tap water at 25 °C. The outer 2–3 mm of the potato was removed by peeling. Fifteen grams of the peel was added to a 90 ml dilution blank of sterile Butterfield's buffer. The mixture was blended for 2 min in a sterilized blender. The blended mixture was plated at 10^{0}, 10^{-2}, and 10^{-4} onto 3M *E. coli*/Em *Enterococcus* plates (four dairy treatments×two alum treatments×four replications×one dilution×three replications×three types of selective medium=288 plates). To enumerate the population in a cooked unpeeled potato, a medium sized tuber (200–400 g) was selected, washed, weighed, cooked in a microwave for 5 min then blended in a sterile blender with 200 ml of sterile Butterfield's buffer. The blended mixture was plated at 10^{-3} onto 3M *E. coli*/Em *Enterococcus* plates (four dairy treatments×two alum treatments×four replications×one dilution×three samples taken in each plot=96 plates).

2.7. Statistical analyses

All dependent variables were tested for normal distribution. Data were then analyzed by means of analysis of variance procedures (ANOVA) for a split plot design with Statistical Analysis Systems (SAS, 1996). *E. coli* and *Enterococcus* spp. and fecal coliform numbers were transformed using logarithms to achieve normal distributions. Statistical comparisons of *E. coli* and *Enterococcus* spp. and fecal coliform bacteria

were made for fertility treatments×alum×time since application because these interactions were significant in the GLM models (Snedechor and Cochran, 1980; Kirk, 1982). Residuals were equally distributed with constant variances. Differences reported throughout are significant at $P \leq 0.05$, as determined by the protected least squares means (LSM) test (Snedechor and Cochran,1980; Kirk, 1982). *E. coli* and *Enterococcus* spp. and fecal coliform bacteria are reported in untransformed numbers.

3. Results

The addition of dairy compost or solid dairy manure at rates to meet crop phosphorus uptake did not consistently increase *E. coli* and *Enterococcus* spp. and fecal coliform bacteria in this soil on any day sampled (Table 1). Alum did not consistently affect fecal coliform, *E. coli* and *Enterococcus* spp. in soils receiving the inorganic N fertilizer or inorganic N–P fertilizer treatments. Alum addition to solid dairy manure 1 day after application increased *E. coli* by three orders of magnitude. We did not detect *E. coli* in any soil sample after the first sampling day. Seven, 14, 28, 179 and 297 days after treatments were applied alum did not consistently affect fecal coliform, *E. coli* and *Enterococcus* spp. and fecal coliform bacteria.

We did not detect *E. coli* in potato rhizosphere soil, fresh potato skin or potato wash water at 214 days after application (harvest) (data not shown). Addition of dairy compost or solid dairy manure at rates to meet crop phosphorus uptake with or without alum usually, but not always, increased *Enterococcus* spp. and fecal coliform numbers in potato rhizosphere soil (Table 2). Addition of alum to compost and solid dairy manure reduced fecal coliforms in potato rhizosphere soil, but increased the numbers of these bacteria in the inorganic N–P fertilizer or inorganic N fertilizer treatment. Addition of alum to solid dairy waste did not consistently affect *Enterococcus* spp. numbers in fresh potato skins or potato wash water. We did not find any *E. coli*, *Enterococcus* or fecal coliform bacteria on the exterior of the tuber, on potato skins and within whole baked potatoes after microwave cooking for 5 min (data not shown).

4. Discussion

We found that fall application of solid dairy manure or dairy compost at rates designed to meet crop P uptake did not consistently increase *E. coli*, *Enterococcus* or fecal coliform bacteria numbers compared to soil receiving inorganic N fertilizer or inorganic N–P fertilizer treatments after 2–7 days. Reddy et al. (1981) found that fecal coliform bacteria die-off follow first order kinetics and that the two most important factors influencing survival were moisture and temperature. Soil moisture seems to be the most important of these factors (Sjogren, 1994; Crane and Moore, 1986). Entry et al. (2000b) found that decreasing soil moisture with increasing soil temperature substantially decreased survival of total and fecal coliform bacteria. Detection is based on survival but the viable numbers of pathogenic bacteria in soil that can be cultured increases when the soil is moist. We applied solid dairy manure or dairy compost to an irrigated western soil that had surface moisture concentrations of 0.07–0.14 g^{-1} water g^{-1} soil (Table 1). Soil temperature also exerts a major influence on the survival of coliform bacteria. Survival of pathogenic bacteria first reflects the organism's ability to respond to nonparasitic and adverse environmental conditions.

We did not detect *E. coli* in any soil sample after the first sampling day. Several studies have shown that $Al_2(SO_4)_3$ addition to soils reduced the survival of pathogenic bacteria (Crump et al., 2004; Entry et al., 2003; Entry and Sojka, 2000; Bulson et al., 1984; Ahmad et al., 1984). Traditional alum addition to water reduces turbidity but does not reliably reduce *E. coli* concentrations to less than 1 colony forming units (CFU) 100 ml $^{-1}$ water (Crump et al., 2004; Oo et al., 1993). *Escherichia coli*, *Enterococcus* spp. and fecal coliform numbers in soil receiving dairy manure and dairy compost with alum increased, decreased and did not differ from soils receiving dairy manure and dairy compost soil without alum. Alum addition to soils after solid dairy manure and dairy compost application most likely had a varied effect because the low *E. coli*, *Enterococcus* spp. and fecal coliform numbers compared to similar studies where soils receiving animal waste (Crump et al., 2004; Entry et al., 2000b, 2003; Entry and Sojka, 2000). Further studies with higher dairy manure and compost additions to soil with increasing amounts of alum may help explain our results.

Solid dairy manure application to soil at rates to meet crop phosphorus uptake increased *Enterococcus* spp. and fecal coliform numbers in potato rhizosphere soil. However, fresh potato skins had higher *Enterococcus* spp. and fecal coliform numbers when solid dairy manure was added to soil compared to compost, inorganic N fertilizer or inorganic N–P fertilizer treatments. The higher *Enterococcus* spp. and fecal coliform numbers in potato rhizosphere soil, compared to bulk soil, may have been affected by increased sugar and nutrient content commonly seen in rhizosphere soils (Davenport and Thomas, 1988; Mereckx et al., 1987; Barber and Martin, 1976). Rhizosphere soils favor rapidly growing microorganisms with short generation times (Klein et al., 1988; Kennedy et al., 1991) which may favor growth and survival of enteric bacteria.

Table 1
Fecal coliform, *E. coli*, and *Enterococcus* spp. mean numbers in the 0–10 cm of soil after application of inorganic fertilizer, dairy compost, and solid dairy manure

Day since application	Dairy waste	Alum	Moisture (g H_2O^{-1} g $soil^{-1}$)	Fecal coliform (cfu/g^{-1} soil)	*Escherichia coli* (cfu/g^{-1} soil)	*Enterococcus* (cfu/g^{-1} soil)
1	N fertilizer	No alum	0.11	515 c	0 c	346 b
	N fertilizer	Alum	0.09	338 c	0 c	320 b
	N–P fertilizer	No alum	0.08	1783 b	0 c	16 c
	N–P fertilizer	Alum	0.09	300 c	0 c	26 c
	Compost	No alum	0.09	2837 a	0 c	319 b
	Compost	Alum	0.09	436 c	0 c	725 a
	Manure	No alum	0.09	15 d	5 b	266 bc
	Manure	Alum	0.08	73 d	4868 a	656 a
7	N fertilizer	No alum	0.07	125 a	0 a	71 b
	N fertilizer	Alum	0.10	5 d	0 a	42 bc
	N–P fertilizer	No alum	0.08	0 d	0 a	128 ab
	N–P fertilizer	Alum	0.08	2 d	0 a	10 c
	Compost	No alum	0.08	47 c	0 a	142 a
	Compost	Alum	0.08	143 a	0 a	86 b
	Manure	No alum	0.08	67 b	0 a	13 c
	Manure	Alum	0.08	74 b	0 a	23 c
14	N fertilizer	No alum	0.05	2 b	0 a	9 b
	N fertilizer	Alum	0.07	3 b	0 a	9 b
	N–P fertilizer	No alum	0.06	3 b	0 a	6 b
	N–P fertilizer	Alum	0.08	8 b	0 a	94 a
	Compost	No alum	0.07	27 ab	0 a	106 a
	Compost	Alum	0.08	10 b	0 a	120 a
	Manure	No alum	0.08	21 ab	0 a	23 b
	Manure	Alum	0.08	57 a	0 a	28 b
28	N fertilizer	No alum	NS	ND	ND	NS
	N fertilizer	Alum	NS	ND	ND	NS
	N–P fertilizer	No alum	0.07	2 b	0 a	8 c
	N–P fertilizer	Alum	0.07	3 b	0 a	4 c
	Compost	No alum	0.06	32 a	0 a	93 ab
	Compost	Alum	0.07	24 a	0 a	142 a
	Manure	No alum	0.07	53 a	0 a	64 b
	Manure	Alum	0.07	12 a	0 a	103 a
179	N fertilizer	No alum	0.14	177 d	0 a	3 b
	N fertilizer	Alum	0.14	541 c	0 a	4 b
	N–P fertilizer	No alum	0.14	131 d	0 a	304 a
	N–P fertilizer	Alum	0.12	821 bc	0 a	49 b
	Compost	No alum	0.13	1223 b	0 a	4 b
	Compost	Alum	0.07	1171 b	0 a	3 b
	Manure	No alum	0.13	200 d	0 a	1 b
	Manure	Alum	0.15	2575 a	0 a	3 b
297	N fertilizer	No alum	0.11	0 c	0 a	0 d
	N fertilizer	Alum	0.10	8 c	0 a	88 c
	N–P fertilizer	No alum	0.09	1412 a	0 a	287 b
	N–P fertilizer	Alum	0.09	190 a	0 a	258 b
	Compost	No alum	0.11	0 c	0 a	728 a
	Compost	Alum	0.14	0 c	0 a	177 b
	Manure	No alum	0.13	0 c	0 a	697 a
	Manure	Alum	0.13	1000 a	0 a	21 c

For each day, in each column, values followed by the same letter are not significantly different as determined by the least square means test. ($P \leq 0.05$, $n = 16$). ND = no data.

Table 2
Fecal and total coliform and *Enterococcus* spp. numbers in soils on potato skins and in potato wash water at harvest 214 days after fall application of inorganic fertilizer, dairy compost, and solid dairy manure

Dairy waste	Alum	Soil		Potato skins[a]		Potato wash water[a]	
		Fecal coliforms (cfu/g^{-1} soil)	*Enterococcus* (cfu/g^{-1} soil)	Total coliforms (cfu/g^{-1} peel)	*Enterococcus* (cfu/g^{-1} peel)	Total coliforms (cfu/ml^{-1} wash water)	*Enterococcus* (cfu/ml^{-1} wash water)
N fertilizer	No alum	726 e	6 c	21265 c	91 c	8 c	23 c
N fertilizer	Alum	20853 c	87 d	308086 b	4013 d	8 c	87 c
N–P fertilizer	No alum	5552 e	111 b	593086 d	882 c	1444 a	287 b
N–P fertilizer	Alum	14899 c	31 c	274899 d	1697 d	174 b	5 8
Compost	No alum	9705 d	1952 a	320268 b	14672 c	8 c	728 a
Compost	Alum	1762 e	6 c	738517 b	1004 d	0 c	176 b
Manure	No alum	233113 b	341 b	12714774 a	43032 b	0 c	24 c
Manure	Alum	171823 a	1151 a	2745468 b	249478 a	0 c	863 a

In each column, values followed by the same letter are not significantly different as determined by the least square means test ($P \leq 0.05$, $n = 16$).
[a] Potato soils, skins and wash water were tested for *Escherichia coli* presence. *Escherichia coli* was not found on any sample.

Several studies have found high fecal coliform and *Enterococcus* spp. on fruits and vegetables. Gagliardi et al. (2003) found high fecal coliform and *Enterococcus* spp. numbers in irrigated soils and on cantaloupe that were irrigated with Rio Grande River water. *E. coli* O157:H7 has been found on a variety of salad vegetables (Islam et al., 2004; Taorminina et al., 1999; Taorminina and Beuchat, 1999; Diaz and Hotchkiss, 1996; Abdul-Raouf et al., 1993). *E. coli* O157:H7 has been found inside raddish (Hara-Kudo et al., 1997), lettuce leaves (Seto and Frank, 1999) and cantaloupe that were grown in soils amended with animal waste or irrigated with waste water (Gagliardi et al., 2003). We did not find *E. coli*, *Enterococcus* or fecal coliform bacteria on the exterior of the tuber, on potato skins and within baked potatoes after microwave cooking for 5 min. We found relatively low *E. coli*, *Enterococcus* and fecal coliform numbers in bulk soil 179 days after treatment application, but elevated *Enterococcus* and fecal coliform numbers in potato rhizosphere soil, on potato skins and in potato wash-water at harvest regardless of treatment. Potable water and food requires only one fecal coliform or *E. coli* in 100 mg samples to be deemed unsafe for human consumption (Greenberg et al., 1992). *Salmonella* spp., *Listera* spp. and *E. coli* O157:H7 on ready-to-eat salad vegetables and fruits caused several disease outbreaks (Sagoo et al., 2003; Del Rosario and Beuchat, 1995). Farm managers and consumers need to be aware that bacterial pathogens have been found on and inside and on potato even when manure has not been applied to soils and that these pathogens can potentially cause disease.

5. Conclusions

Dairy compost or solid dairy manure application to soil at rates to meet crop phosphorus uptake did not consistently increase *Enterococcus* spp. and fecal coliform numbers in bulk soil. Solid dairy manure application to soil at rates to meet crop phosphorus uptake increased *Enterococcus* spp. and fecal coliform numbers in potato rhizosphere soil. However, fresh potato skins had higher *Enterococcus* spp. and fecal coliform numbers when solid dairy manure was added to soil compared to compost, inorganic N fertilizer or inorganic N–P fertilizer treatments. There is a lack of data on the survival of pathogenic bacteria on vegetables planted in soils that have been amended with animal waste. If we are to address food safety issues further research in the area of vegetables planted in soils amended with animal waste and compost is necessary.

Farm managers and consumers need to be aware that bacterial pathogens have been found on and inside and on potato even when manure has not been applied to soils.

Uncited references

The following references were uncited: SAS Institute Inc, 1996; Snedecor and Cochran, 1980; Buckhouse and Gifford, 1976; Taorminia and Beuchat, 1999; Taorminia et al., 1999.

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