ANNUAL REPORT

PROJECT NO: BJKY38

TITLE: Long-Term Impacts of Manure Applications on Production of Wheat and Other Crops

PERSONNEL: Amber Moore, Nutrient Management Specialist, Twin Falls
Juliet Marshall, Smalls Grains Specialist, Aberdeen

ADDRESS: Amber Moore, Twin Falls R & E Center, P.O. Box 1827, Twin Falls, 83303, 208-736-3629, amberm@uidaho.edu

ACCOMPLISHMENTS AND RESULTS:

Cumulative manure applications

A four-year cumulative summary of manure applications is shown in table 1. Intensive application rates of carbon, nitrogen, phosphorus, potassium, chlorides, and other nutrients (micronutrient information collected but not shown) suggest that accumulations of these materials in the soil could have a significant impact on wheat production. These effects will be discussed in greater detail throughout this report.

Manure effects on bread quality

In the spring of 2016, Katherine O'Brien from the UI Aberdeen baked 32 bread loaves with the hard red spring wheat grain (Jefferson variety) that was harvested from manure study plots on August 5th, 2015. Bread quality results from Katherine's program are listed in tables 2 and 3. Coinciding with increased grain protein in increasing manure rates that was reported in the 2016 IWC progress report for this study, flour protein and other baking factors related to protein level? increased or improved with increasing manure application rates (table 2 and 3). Ash content also increased significant with increasing manure application rate (table 2), which may improve flavor and nutritional value of the bread. Based on nutrient analysis conducted of the harvested grain, mineral nutrients that significantly increased with increasing manure application rates were nitrogen, potassium, calcium, sulfur, and zinc (tables 4 and 5). Magnesium, phosphorus, sodium, iron, manganese, copper, and boron did not consistently increase in grain concentration with increasing manure application rate.

Table 1. Cumulative amount of manure nutrients added over 4-year course of long-term manure application study in Kimberly, Idaho (2012-2016). This information may provide growers some insight on how much nutrients are really being applied from repeated dairy manure applications in Southern Idaho, as nutrient testing of field-applied manure is not a common practice in our region.

Manure treatment (wet ton/acre)	Frequency and number of applications at given rate	Manure applied (wet ton/acre)	Manure applied (dry ton/acre)	Organic C	N	P_2O_5	K_2O	Ca	Mg	S	Na	Cl
				lb/acre								
Control	—	0	0	0	0	0	0	0	0	0	0	0
Fertilizer	—	0	0	0	0	0	0	0	0	0	0	0
16.0 (x2)	Two biennial applications*	27.8	15.4	7,817	488	397	1,566	1,092	401	149	299	412
32.0 (x2)		56.0	31.0	15,735	983	799	3,153	2,199	807	301	601	829
48.0 (x2)		83.8	46.4	23,552	1,472	1,195	4,719	3,291	1,207	450	900	1,241
16.0 (x4)	Four annual applications**	64.4	30.8	17,148	1,176	882	2,686	2,067	751	344	629	1,428
32.0 (x4)		129.6	62.0	34,518	2,366	1,775	5,407	4,161	1,513	693	1,266	2,874
48.0 (x4)		193.9	92.8	51,666	3,542	2,657	8,093	6,228	2,264	1,038	1,894	4,302

*Manure applications in Fall 2012 and Fall 2014.

**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Table 2. Impact of fall dairy manure applications on wheat flour quality of Jefferson Hard Red spring wheat grown in Kimberly, Idaho in 2015.

Manure rate (wet ton/acre)	Frequency and number of applications at given rate	Flour Protein (%)	Flour Yield (%)	Flour Ash (%)	Flour Break (%)	Mixograph Peak (minutes)	Mixograph Height (cm)	Mixograph Tolerance (degrees)	Mixograph Absorption (%)
Control	—	10.1d	65.21a	0.354e	31.81a	4.55cd	5.93	74.0	56.5c
Fertilizer	—	11.7c	64.70ab	0.389d	30.86b	4.10d	6.03	74.8	59.0b
16.0 (x2)	Two biennial applications*	12.6b	63.87c	0.408bcd	30.39bcd	4.88bc	6.23	73.3	59.8ab
32.0 (x2)		12.5bc	64.37bc	0.399cd	30.79bc	4.55cd	6.25	73.0	60.3ab
48.0 (x2)		13.3ab	63.61cd	0.421ab	30.28cd	5.50ab	6.38	74.0	61.0a
16.0 (x3)	Three annual applications**	12.6b	63.98bc	0.402bcd	30.57bc	4.50cd	6.45	70.8	60.0ab
32.0 (x3)		13.1ab	63.67cd	0.415bc	30.40bcd	5.25bc	6.05	74.3	60.5a
48.0 (x3)		13.8a	62.99d	0.435a	29.87d	6.05a	6.00	75.6	61.0a
	p-value	<0.0001	0.0003	<0.0001	<0.0001	0.0006	0.0670	0.6243	<0.0001

*Manure applications in Fall 2012 and Fall 2014.

**Manure applications in Fall 2012, Fall 2013, and Fall 2014.

Table 3. Impact of fall dairy manure applications on wheat flour quality of Jefferson Hard Red spring wheat grown in Kimberly, Idaho in 2015.

Manure rate (wet ton/acre)	Frequency and number of applications at given rate	Bake Time (minutes)	Bake Dough (1-8)	Bake Absorption (%)	Loaf Volume (cc)	Loaf Exterior (1-5)	Loaf Interior (1-5)	Dough Stickness (1-12)	Grain Hard
Control	—	4.6cd	3.75c	56.5c	1,035b	1.7	2.0a	6	72.5c
Fertilizer	—	4.2d	5.0b	59.0b	1,112a	2.1	1.6bc	6	79.0a
16.0 (x2)	Two biennial applications*	4.8cd	5.0b	59.8ab	1,150a	2.2	1.6bc	6	77.8ab
32.0 (x2)		5.2cd	4.5bc	60.3a	1,125a	2.2	1.9ab	6	76.3b
48.0 (x2)		5.7ab	5.3ab	61.0a	1,125a	2.1	1.7abc	6	77.5ab
16.0 (x3)	Three annual applications**	4.6cd	5.0b	60.0ab	1,156a	2.2	1.5c	6	80.5a
32.0 (x3)		5.6b	4.8b	60.5a	1,131a	2.0	1.6bc	6	79.0ab
48.0 (x3)		6.3a	6.0a	61.0a	1,150a	1.7	1.5c	6	77.5ab
	p-value	<0.0001	0.0040	<0.0001	0.0508	0.3201	0.0174	NA	0.0064

*Manure applications in Fall 2012 and Fall 2014.
**Manure applications in Fall 2012, Fall 2013, and Fall 2014.

Table 4. Impact of fall dairy manure applications on nutrient concentration of Jefferson hard red spring wheat, sampled on August 5, 2015.

Manure rate (wet ton/acre)	Frequency and number of applications at given rate	Total C (%)	Total N (%)	Ca (ppm)	K (ppm)	Mg (ppm)	Na (ppm)	P (ppm)	S (ppm)
Control	—	42.5	1.7d	885d	5,050c	1,575	200	5,075ab	1,475e
Fertilizer	—	41.7	1.8cd	1,061d	5,675bc	1,500	200	4,800abc	1,625d
16.0 (x2)	Two biennial applications*	42.2	2.0bcd	1,250abc	5,875abc	1,450	200	4,775bc	1,625d
32.0 (x2)		42.7	2.2ab	1,225abc	5,950abc	1,550	200	5,150a	1,700bc
48.0 (x2)		42.7	2.4a	1,450ab	6,275ab	1,525	200	5,075ab	1,700bc
16.0 (x3)	Three annual applications**	42.2	2.1bc	1,175bc	5,700bc	1,550	200	5,150a	1,725ab
32.0 (x3)		43.0	2.3ab	1,475a	6,925a	1,475	200	4,650c	1,650cd
48.0 (x3)		42.7	2.5a	1,275abc	6,575ab	1,550	200	5,075ab	1,775a
	p-value	0.3976	0.0001	0.0048	0.0473	0.4975	NA	0.0324	<0.0001

*Manure applications in Fall 2012 and Fall 2014.
**Manure applications in Fall 2012, Fall 2013, and Fall 2014.

Table 5. Impact of fall dairy manure applications on nutrient concentration of Jefferson hard red spring wheat, sampled on August 5, 2015.

Manure rate (wet ton/acre)	Frequency and number of applications at given rate	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Cd (ppm)	Nitrate-N (ppm)	B (ppm)	Cl (ppm)
Control	—	25.8	42.8	33.5b	11.2	0.80	25.0	7.5	680c
Fertilizer	—	28.0	40.3	35.5b	11.0	0.80	28.8	7.5	1,147a
16.0 (x2)	**Two biennial applications***	26.0	39.8	33.5b	11.2	0.80	25.0	7.5	900b
32.0 (x2)		25.0	41.8	36.3ab	10.9	0.80	25.0	7.5	812bc
48.0 (x2)		28.5	43.8	35.3ab	13.4	0.80	30.8	7.5	927b
16.0 (x3)	**Three annual applications****	30.8	43.3	38.3a	12.2	0.80	25.0	7.5	855bc
32.0 (x3)		25.0	38.3	34.3b	11.7	0.80	30.2	7.5	947ab
48.0 (x4)		28.5	37.0	37.5a	16.8	0.80	33.5	7.8	927b
	p-value	0.4730	0.3228	0.0410	0.7913	NA	0.4715	0.4586	0.0082

*Manure applications in Fall 2012 and Fall 2014.
**Manure applications in Fall 2012, Fall 2013, and Fall 2014.

Preplant soil parameters, 2016

Macronutrients and Micronutrients

Preplant soil test findings for the "south" potato field (following wheat) are shown in tables 6-9. In 2016, first and second foot depth nutrient soil accumulations increased significantly with increasing cumulative manure rate for organic matter, total N, and plant available forms nitrate-N, P, K, sulfate-S, Na, Mg, Cl, Zn, Mn, and B (tables 6-9). Soil Cu accumulations with increasing manure were significant at the first foot depth in 2016, but not at the second foot depth (table 7 and 9). Leaching of organic matter and soluble forms of nutrients (especially nitrate, K, Cl, and SO4-S) is likely contributing to nutrient accumulations at the second foot depth.

Nutrient accumulations from manure applications are encouraging as a means of saving on fertilizer costs, but have negative implications in terms of environmental issues. Soil nitrate accumulations at the second foot depth are occurring at 4 year cumulative manure application rates of 64 ton manure/acre and greater, although it is difficult to distinguish how much of N originates from fertilizer N or manure N. In either case, it is clear that plots receiving manure and N fertilizer applications are more vulnerable to nitrate leaching than plots receiving N fertilizer alone for four-year manure rates at or above 64 ton/acre. Soil P accumulations and leaching are also of concern. According to Idaho statute code 590, manure applications are limited to P uptake on soil test (Olsen) P levels exceeding 40 ppm at the first foot depth. At cumulative rate of 32 ton/acre (392 lb P_2O_5/acre), 2016 soil test P levels only reached 23 ppm Olsen P (table 6). The 40 ppm threshold was exceeded at the 4-year cumulative manure application rate of 64 ton/acre (799 P_2O_5/acre) (2016 soil test P concentrations were 47 ppm for this treatment). These findings may help regulators and dairymen develop manure application recommendations to prevent excessive soil test P accumulations in the first foot of Southern Idaho silt loam soils. In 2016, soil test P at the second foot depth for 4 year cumulative manure rates above at or above 64 ton/acre (799 P_2O_5/acre) increased significantly over the fertilizer treatment (table 7). As soil organic matter has increased significantly over fertilizer at the second foot for the same exact treatments, it is entirely possible that P sorbed to organic matter is moving down to the second foot and becoming plant available there. This finding is significant, suggesting that P leaching may occur on our silt loam soils receiving moderate to heavy rates of dairy manure applications. USDA ARS is conducting 4-foot depth soil sampling every fall on study plots to evaluate the P leaching response further.

Soil salt accumulations

Soil EC (salinity indicator), SAR (sodicity indicator), and chloride levels in 2016 are shown in tables 6-9. Biennial applications of dairy manure cumulative rates of 32 to 96 ton manure/acre had no significant effect on soil EC at the first foot soil depth in 2016 (table 6-9). As soil EC levels did increase significantly with increasing biennial manure applications at the second foot soil depth, it appears that taking a year off between manure applications allows time for salts to leach from the first foot to the second foot depth up to manure rates of 96 ton manure/acre. In contrast, annual manure applications at cumulative rates starting at 64 ton/acre significantly increased EC at the first foot depth, further validating that annual applications of manure may not allow enough time for salts to leach from the first foot to prevent salt accumulations, in comparison to biennial applications.

Table 6. Preplant soil nutrient and chemical characteristics of a Portneuf silt loam in Kimberly, Idaho receiving various rates and frequencies of dairy manure applications. Soils were sampled on March 7th, 2016 to a depth of 0-12 inches.

Dairy manure rate (wet ton/acre)	Frequency of Applications	Total N (ppm)	% o.m.	Nitrate-N (ppm)	Ammonium-N (ppm)	Olsen P (ppm)	Olsen K (ppm)	Sulfate-S (ppm)	EC (dS/m)	B (ppm)	SAR (Sodium Adsorption Ratio)
Control	---	981.7e	1.47e	11.01d	5.11	10.25e	138.80e	4.27d	0.885c	0.575e	1.02f
Fertilizer	---	948.5e	1.49e	11.81d	5.95	14.33e	138.93e	3.97d	0.666c	0.621e	1.27ef
16.0 (x2)	Two biennial applications*	1023.4e	1.64e	14.08d	4.88	23.02e	225.79e	5.57d	0.782c	0.698de	1.56de
32.0 (x2)		1284.6d	1.96d	17.87cd	4.91	47.21d	410.53d	6.12d	0.885c	0.855c	1.76cd
48.0 (x2)		1420.8c	2.27c	19.81cd	5.51	70.66c	619.71c	6.57cd	0.964c	0.972bc	1.84cd
16.0 (x4)	Four annual applications**	1338.4cd	2.0d	27.74c	6.18	53.06d	414.44d	10.37c	1.395b	0.823cd	2.14bc
32.0 (x4)		1736.4b	2.57b	45.27b	5.12	95.28b	735.05b	16.02b	1.752b	1.076b	2.53b
48.0 (x4)		2023.7a	3.12a	68.07a	6.42	167.88a	1169.04a	24.28a	2.635a	1.268a	3.54a
	p-value	<0.0001	<0.0001	<0.0001	0.3250	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

*Manure applications in Fall 2012 and Fall 2014.

**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Table 7. Preplant soil nutrient and chemical characteristics of a Portneuf silt loam in Kimberly, Idaho receiving various rates and frequencies of dairy manure applications. Soils were sampled on March 7th, 2016 to a depth of 12-24 inches.

Dairy manure rate (wet ton/acre)	Frequency of Applications	Total N (ppm)	% o.m.	Nitrate-N (ppm)	Ammonium-N (ppm)	Olsen P (ppm)	Olsen K (ppm)	Sulfate-S (ppm)	EC (dS/m)	B (ppm)	SAR (Sodium Adsorption Ratio)
Control	—	512.7c	0.783c	12.65ef	3.00	2.80d	70.38d	16.01cd	0.821ef	0.385d	1.26e
Fertilizer	—	501.0c	0.766c	7.66f	3.50	2.62d	78.20cd	12.81d	0.753f	0.393d	1.38e
16.0 (x2)	Two biennial applications*	513.3c	0.763c	16.03def	3.56	3.32d	73.31cd	16.99cd	1.08ef	0.402d	1.96d
32.0 (x2)		554.3bc	0.822bc	22.71cde	3.55	6.02cd	111.43cd	21.73bc	1.29de	0.456cd	2.55c
48.0 (x2)		634.7ab	0.919a	31.08c	3.39	10.08c	133.91bc	21.39bc	1.58cd	0.556ab	3.17b
16.0 (x4)	Four annual applications**	605.7ab	0.883ab	27.05cd	2.87	8.67c	109.47cd	23.59b	1.78c	0.496bc	2.53c
32.0 (x4)		658.5a	0.938a	47.06b	2.52	15.03b	181.81ab	26.71b	2.38b	0.607a	3.09b
48.0 (x4)		685.0a	0.974a	68.94a	3.01	19.94a	242.41a	35.56a	3.50a	0.604a	4.09a
	p-value	0.0011	0.0003	<0.0001	0.2112	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

*Manure applications in Fall 2012 and Fall 2014.

**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Table 8. Preplant soil nutrient and chemical characteristics of a Portneuf silt loam in Kimberly, Idaho receiving various rates and frequencies of dairy manure applications. Soils were sampled on March 7th, 2016 to a depth of 0-12 inches.

Dairy manure rate (wet ton/acre)	Frequency of Applications	Lime%	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Ext Ca (meq/100g)	Ext Mg (meq/100g)	Ext Na (meq/100g)	Ext Cl (ppm)
Control	—	5.26	1.30f	13.07	8.68cd	3.23d	36.59a	4.94d	0.325e	6.29c
Fertilizer	—	5.98	1.19f	11.21	8.03d	3.05d	36.72a	5.00d	0.386de	13.43c
16.0 (x2)	Two biennial applications*	4.82	1.37ef	12.29	8.46cd	3.66d	35.77ab	5.09d	0.422de	9.44c
32.0 (x2)		6.29	1.57de	12.08	10.15bcd	4.69c	34.86bc	5.60c	0.470de	8.12c
48.0 (x2)		5.82	1.85bc	13.19	10.76bc	5.65b	33.62d	5.51c	0.528cd	8.31c
16.0 (x4)	Four annual applications**	6.04	1.72cd	13.46	10.57bcd	4.88c	35.43b	5.56c	0.678bc	34.57c
32.0 (x4)		6.02	2.00b	13.17	12.67ab	6.06b	34.11cd	6.03b	0.834b	73.52b
48.0 (x4)		5.66	2.67a	12.76	14.56a	8.01a	32.48e	6.59a	1.159a	123.12a
	p-value	0.4075	<0.0001	0.2213	0.0005	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

*Manure applications in Fall 2012 and Fall 2014.
**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Table 9. Preplant soil nutrient and chemical characteristics of a Portneuf silt loam in Kimberly, Idaho receiving various rates and frequencies of dairy manure applications. Soils were sampled on March 7th, 2016 to a depth of 12-24 inches.

Dairy manure rate (wet ton/acre)	Frequency of Applications	Lime%	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Ext Ca (meq/100g)	Ext Mg (meq/100g)	Ext Na (meq/100g)	Ext Cl (ppm)
Control	---	18.18	0.87	6.44	3.30c	0.45d	35.61	4.10d	0.350e	19.01d
Fertilizer	---	15.42	1.03	7.65	3.55bc	0.49d	36.51	4.67abc	0.341e	19.56d
16.0 (x2)	Two biennial applications*	11.77	0.99	7.80	3.76bc	0.49d	34.18	4.54bc	0.560d	52.10bcd
32.0 (x2)		13.58	1.04	7.38	3.51bc	0.69cd	36.64	4.80ab	0.689c	31.72d
48.0 (x2)		11.89	1.25	9.51	4.55ab	1.03abc	33.47	4.37cd	0.767c	37.68cd
16.0 (x4)	Four annual applications**	19.85	1.10	8.16	3.83bc	0.81bcd	35.97	4.71abc	0.707c	87.53bc
32.0 (x4)		12.61	1.10	8.90	4.43abc	1.17ab	35.61	4.94ab	0.918b	102.76b
48.0 (x4)		11.56	1.26	8.68	5.40a	1.25a	35.95	4.96a	1.257a	194.20a
	p-value	0.2877	0.1160	0.1177	0.0326	0.0008	0.7585	0.0050	<0.0001	<0.0001

*Manure applications in Fall 2012 and Fall 2014.

**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Soil health

Soil organic matter is a major contributor to soil health, with benefits including improved soil moisture retention, improved infiltration, increased microbial and biological activity, and improved soil structure. In 2016, soil organic matter in the first foot increased significantly from 1.5% (fertilizer-only treatment) to 2.0-3.1% for cumulative manure applications ranging from 64 to 196 ton manure/acre (table 6). For Southern Idaho growers, our study suggests that dairy manure or compost applications are likely the most effective affordable method for significantly increasing soil organic matter in our region, as other methods such as no-till, minimum till, and inclusion of cover crops for improving soil health typically have little to no benefit on soil organic matter levels.

In 2016, postdoctoral research associate Mriganka De measured bulk density and gravimetric soil moisture content in neighboring manure study plots the north field at the 0-6 and 6-12 inch soil depths, which has the same history of manure application as the south field (table 10). (The north field was planted to sugar beets in 2016). Significant decreases in soil bulk density and significant increases in porosity with increasing cumulative manure application rate suggests that manure additions soil are significantly improving soil structure. We suspect that this decrease in density may be causing the significant increase in extra-large size class potato tubers and increase in beet yield that we have seen in this study in 2014 and 2016. Soil moisture content also improves with more manure. Organic matter additions are likely the primary cause of improved soil structure (organic matter "glues" mineral soil particles together, disrupting the brick-like structure that can occur in mineral silt loam soils) and increased moisture content (organic matter has more cation exchange sites than mineral soils, which improves the soils ability to hold on to water as well as plant nutrients).

Table 10. Soil physical parameters, 0-12 inch soil depth, July 27, 2016, "north field".

Manure rate (wet ton/acre)	Frequency and number of applications at given rate	Bulk density, g/cm3	Soil Porosity (%)	Soil gravimetric moisture content (%)
Control	----	1.39a	47.4d	21.8d
Fertilizer	----	1.38a	48.1d	22.1cd
16.0 (x2)	Two biennial applications*	1.37a	48.5d	21.8d
32.0 (x2)		1.33b	49.9c	22.2cd
48.0 (x2)		1.33b	49.9c	22.9bc
16.0 (x4)	Four annual applications**	1.31bc	50.5bc	22.6cd
32.0 (x4)		1.27d	52.2a	23.6ab
48.0 (x4)		1.29cd	51.4ab	24.1a
	p-value	<0.0001	<0.0001	<0.0001

*Manure applications in Fall 2012 and Fall 2014.

**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Nematode pressure

In 2016, spiral nematode population decreased significantly with increase manure application rate and manure application frequency in preplant soil samples collected at the first foot depth in the south field (figure 1). This was the first time in the 4-year study that a significant effect of manure application on nematode population was observed. For reference, the crop rotation was barley (2013) – sugar beet (2014) – wheat (2015). Our next step is to compare nematode counts to soil organic matter content and other soil parameters, to see if we can determine why increasing manure applications increase spiral nematode counts.

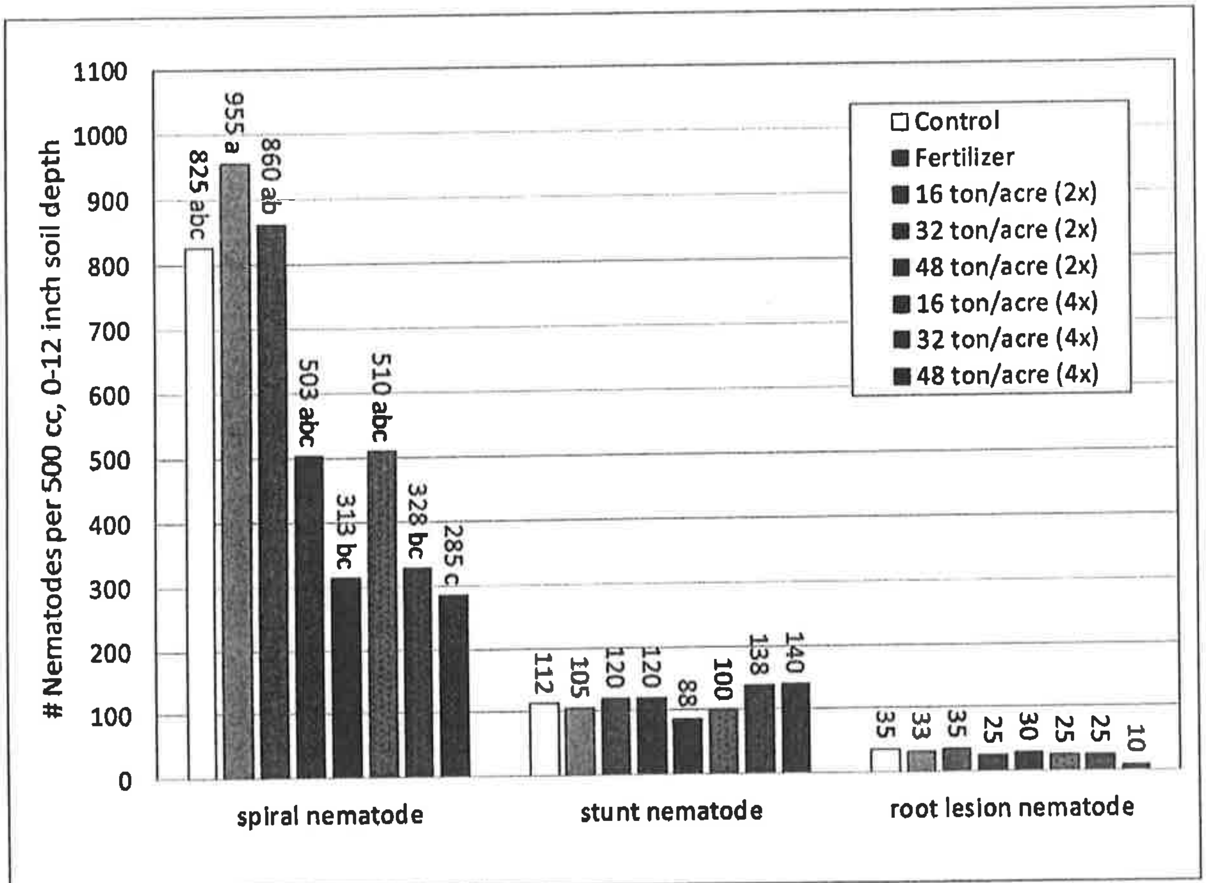

Figure 1. Impact of manure application history on nematode presence in preplant soil samples (Portneuf silt loam) taken from a 0-12 soil depth on March 7th, 2016 in Kimberly, Idaho. This field was planted to hard red spring wheat in 2015, with potatoes planted on May 2nd 2016. Dairy manure applied either 2 or 4 times at listed rate since 2012 (wet basis), as designated by 2x and 4x in the treatment label. Our findings illustrate that repeated dairy manure applications have a suppressive effect on spiral nematode populations in a silt loam soil.

Nitrogen mineralization

Potentially mineralizeable N (2013-2016 lab incubation study of preplant soil samples)

Net N mineralization potential (measured via the aerobic incubation method) that were collected as preplant soils in 2013-2016 are shown in table 11 below. Soils incubated in sealable plastic bags, with bags left partially opened and water added weekly to maintain aerated field moist conditions. The term "net" means that N mineralization over the growing season is described, which means that the values are in addition to the soil nitrate and ammonium that were already in the soil at the start of the incubation. These values are currently being compared to soil test parameters to determine if a general N mineralization potential prediction equation can be developed for Southern Idaho silt loam soils with dairy manure application histories.

Table 11. Net N mineralization potential of preplant soil samples (lb/acre), 0-12 inch soil depth. Net N mineralization determined via 100 day aerobic lab incubation at room temperature (72 degrees F), by subtracting soil nitrate concentration at day 100 from day 0 of the incubation. These values represent how much plant available N is potentially available to the crop for the growing season, and does not include the additional soil nitrate already in the soil at preplant.

Manure rate (wet ton/acre)	Frequency	2013* *Barley*	2014** *Sugar Beet*	2015*** *Wheat*	2016**** *Potato*
		---------------Net mineralizeable N, lb N/acre--------------			
Control	----	54e	43c	96e	116ef
Fertilizer	----	62de	49c	102e	114f
16.0	Biennial	95c	101bc	128de	140def
32.0		121bc	104bc	166cd	171cde
48.0		175a	110abc	270ab	207bc
16.0	Annual	90cd	81bc	183c	177cd
32.0		131b	140ab	249b	242b
48.0		143b	186a	298a	346a
	p-value	<0.0001	0.0259	<0.0001	<0.0001

*Annual and Biennial treatments received one manure application (Fall 2012).

** Annual treatments received two manure applications (Fall 2012 and 2013); Biennial treatments received one manure applications (Fall 2012).

*** Annual treatments received three manure applications (Fall 2012, 2013, and 2014); Biennial treatments received two manure applications (Fall 2012 and 2014).

**** Annual treatments received four manure applications (Fall 2012, 2013, 2014, and 2015); Biennial treatments received two manure applications (Fall 2012 and 2014).

To estimate N mineralization originating from manure applications specifically, control soil net N mineralization was subtracted from manure treated soil net N mineralization values (table 12). While N fertilizer recommendations generally account for 50-100 lb N/acre to be mineralized from the soil, they do not usually account for additional N release from dairy manure applications. Our findings suggest that as much as an additional 230 lb N/acre could be plant available over the growing season on fields with 196 lb N/acre applied over a four-year period (table 12). The release of additional N can be helpful for crop growth if accounted for, but could cause crop quality and nitrate leaching issues if it's not accounted for. Unfortunately, these values reflect only N mineralization potential, and can be greatly decreased if soil temperature, soil moisture, and other factors are not optimum for microbial processes that cause N mineralization to occur. Therefore, we do not recommend using these values alone to estimate N mineralization from a field receiving manure applications.

Table 12. Net N mineralization potential of preplant soil samples originating from amendment additions, with control soil values subtracted from each of the other amended treatments (0-12 inch soil depth). These values represent how much plant available N is potentially available to the crop for the growing season from the added amendment (manure or fertilizer).

Manure rate (wet ton/acre)	Frequency	2013	2014	2015	2016
		--------------Net mineralizeable N, lb N/acre--------------			
Control	----	0e	0c	0e	0ef
Fertilizer	----	8de	6c	6e	-2f
16.0	Biennial	41c	58bc	32de	24def
32.0		67bc	61bc	70cd	55cde
48.0		121a	67abc	174ab	91bc
16.0	Annual	36cd	38bc	87c	61cd
32.0		77b	97ab	153b	126b
48.0		89b	143a	202a	230a
	p-value	<0.0001	0.0259	<0.0001	<0.0001

*Annual and Biennial treatments received one manure application (Fall 2012).
** Annual treatments received two manure applications (Fall 2012 and 2013); Biennial treatments received one manure applications (Fall 2012).
*** Annual treatments received three manure applications (Fall 2012, 2013, and 2014); Biennial treatments received two manure applications (Fall 2012 and 2014).
**** Annual treatments received four manure applications (Fall 2012, 2013, 2014, and 2015); Biennial treatments received two manure applications (Fall 2012 and 2014).

N mineralization under field conditions (2016 buried bag field study)

In addition to lab incubations, in situ field incubations were also conducted to evaluate N mineralization. In contrast to N mineralization potential, these values illustrate in-season fluctuations in N mineralization under field temperatures, not room temperature. While a detailed analysis will occur in the spring of 2017, we speculate that cooler soil temperatures in May, June, and July of 2016 delayed N mineralization, and prevented N mineralization from approaching estimated N mineralization potential (field and lab incubation N mineralization amounts at the end of the season were similar to each other in 2013, 2014, and 2015). We also speculate that cooler soil temperature and reduced N mineralization throughout Southern Idaho may have attributed to the overall decrease in grain protein levels that were seen in 2016 in barley and wheat crops.

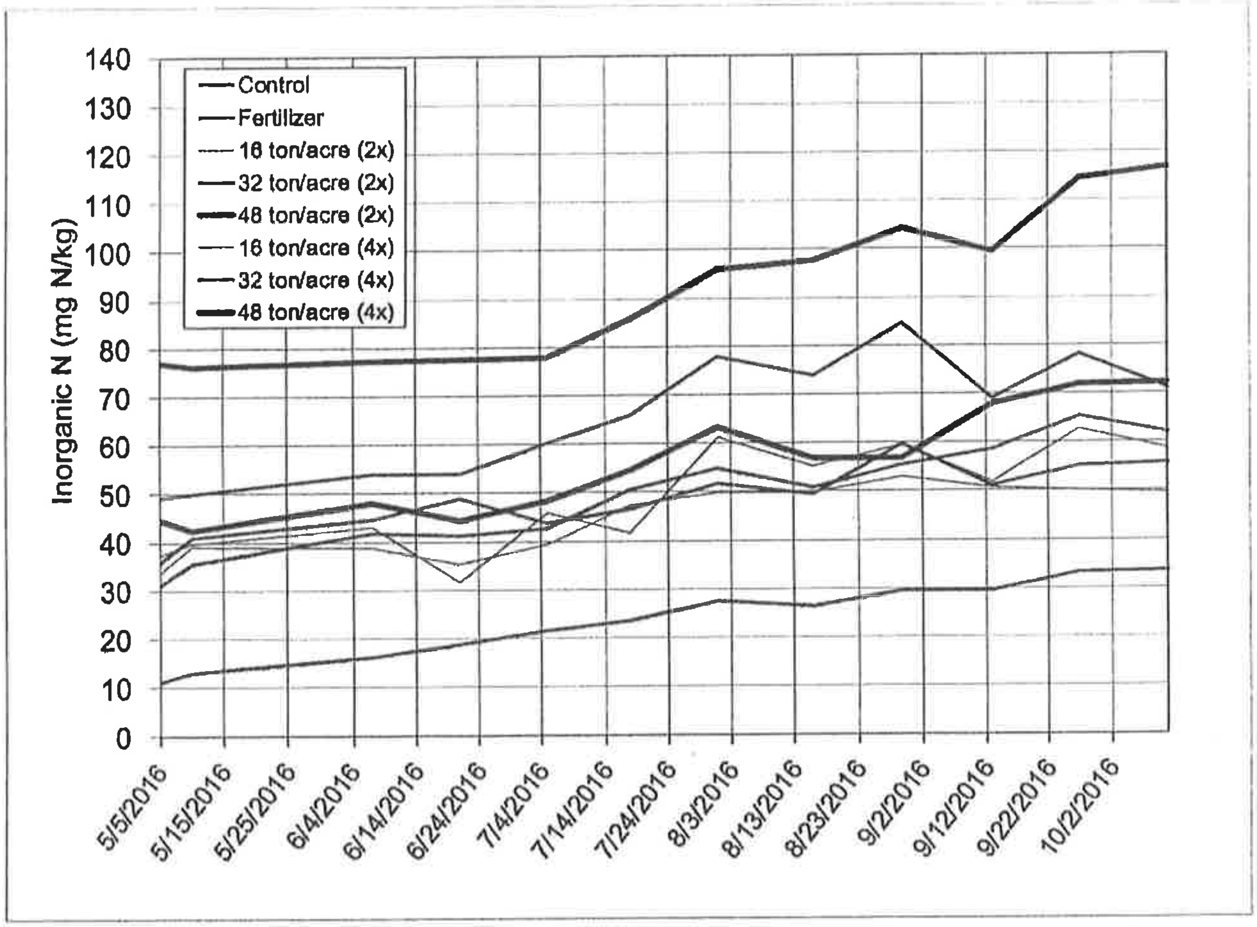

Figure 2. In situ N mineralization in the south field in 2016 (potatoes), measured using the buried bag method. Patterns reflect manure application histories and preplant application of urea and MAP fertilizers, but do not incorporate the effect of ESN urea (ESN urea was applied at germination, which was after the buried bag study was started).

2016 Potato tuber yield and quality (following wheat)

Potato tuber yield and quality at the 2016 harvest are shown in table 13. In comparison to fertilizer treatment, manure application history did not affect total tuber yield, USDA No. 1 yield, or 6-12 ounce size class yield in 2016 (table 13). However, increasing manure applications did significantly increase the <4 ounce, 4-6 ounce, and >12 ounce size class yields in comparison to fertilizer treatments. As mentioned earlier, the increase in extra large size class potatoes on manured plots may be attributed to greater soil porosity and lower soil bulk density associated with our heavily manured plots (table 10). The increase of cull and small size class potatoes may be attributed to delayed maturity and late-season release of N from the manure additions.

2016 Sugar Beet Yield and Quality (following barley)

Sugar beet yields and quality findings closely mirrored findings from 2014 (table 14). Total beet yield increased from 35.9 (fertilizer treatment) to range of 37.9 to 40.4 ton/acre for all 6 manure application treatments, with 4 of the 6 beet yield increases qualifying as statistically significant increases (table 14). We believe that the increased soil porosity and lower soil bulk density that we measured this year with increasing manure application rates in the same field is likely contributed to increased root yields, as the soil is "softer" and less restrictive for beet root growth than non-amended mineral silt loam soils.

However, also similar to 2014 findings, sugar content declined significantly with increasing manure applications, with the lowest sugar content recorded at 15.6% for the heaviest manure treatment (fertilizer only treatment had a 18.6% sugar content) (table 14). Plant available nitrogen is likely the greatest contributor to sugar content decreases, as indicated by increasing sugar beet Brei nitrate levels with increasing manure rate and frequency. Again, there appears to still be a place for manure applications in a sugar beet rotation, with the highest ERS (estimated recoverable sugar) yield occurring at the cumulative manure application rate of 32 ton/acre over the four year study (table 14).

Table 13. Impact of fall dairy manure applications on Russet Burbank potatoes grown in Kimberly, Idaho in 2016, following a spring hard red wheat crop (Jefferson).

Dairy manure rate (wet ton/acre)	Frequency of Applications	Total Yield (cwt/acre)	US No. 1 (cwt/acre)	US No. 2 (cwt/acre)	Specific Gravity
Control	----	345.72b	302.51c	43.21	1.082a
Fertilizer	----	559.55a	521.64ab	37.91	1.079ab
16.0 (x2)	Two biennial applications*	596.19a	547.70ab	48.49	1.082a
32.0 (x2)		566.63a	519.41ab	47.22	1.082a
48.0 (x2)		557.80a	496.69b	61.12	1.080a
16.0 (x4)	Four annual applications**	622.48a	560.21a	62.27	1.082a
32.0 (x4)		595.26a	531.23ab	64.03	1.079b
48.0 (x4)		620.23a	561.03a	59.20	1.075b
	p-value	<0.0001	<0.0001	0.4934	0.0163

*Manure applications in Fall 2012 and Fall 2014.
**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Table 14. Impact of fall dairy manure applications on sugar beets (BTS-21RR25) grown in Kimberly, Idaho in 2016, following a spring malt barley crop (Moravian 69).

Dairy manure rate (wet ton/acre)	Frequency of Applications	Root Yield (beet ton/acre)	Sugar %	Estimated Recoverable Sugar (lb/acre)	Brei Nitrate (ppm)
Control	----	27.44c	18.94a	8867d	71d
Fertilizer	----	35.86b	18.61a	11485a	97d
16.0 (x2)	Two biennial applications*	39.19a	17.74b	11596 a	174cd
32.0 (x2)		39.20a	17.30b	11229ab	263c
48.0 (x2)		37.91ab	16.64c	10301bc	423b
16.0 (x4)	Four annual applications**	38.56ab	17.46b	11126ab	221c
32.0 (x4)		40.11a	16.5 c	10769abc	436b
48.0 (x4)		40.39a	15.63d	9863cd	653a
	p-value	<0.0001	<0.0001	0.0003	<0.0001

*Manure applications in Fall 2012 and Fall 2014.
**Manure applications in Fall 2012, Fall 2013, Fall 2014, and Fall 2015.

Other findings

In addition to the findings reported above, manure applications were found to have no significant effect on presence of pathogenic E. coli (none was detected) or weed population in 2016. While these issues could still occur in other manure application environments, they are not evident in this specific study.

PROJECTIONS: Results from these studies will allow us to develop clear recommendations for Idaho barley growers on how to get the most out of their manure application without compromising crop production or soil quality.

PUBLICATIONS:

Weyers, E., D. Strawn, D. Peak, A. Moore, L. Baker, and B. Cade-Menun. 2016. Phosphorus speciation in calcareous soils following annual dairy manure amendments. Soil Science Society of America Journal. 80:1531-1542.

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Graybill, D., A. Moore, and R. Lentz. 2016. Nitrogen mineralization of dairy manure in a calcareous soil under field conditions. SSSA conference, November 6-9, 2016, Phoenix, Arizona. Abstract ID 100426.

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