Title: Meta-Analysis of Swine Manure and Commercial Fertilizer on Environmental Endpoints and Soil Health - NPB: #17-209

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Industry Summary:
Swine manure is a valuable asset when applied to the soil; however, to others it is a waste material with little value compared to commercial fertilizer. Comparisons between commercial fertilizer and swine manure are often difficult because of the conditions that surround each study and the measurements that were made during the source of the study. Commercial fertilizer management in cropping systems has been related to reductions in soil carbon, soil aggregates stability, and in overall soil health, whereas, swine manure has been found to increase soil organic matter, soil aggregate stability, and soil health. To provide a more robust analysis of these general claims about swine manure compared to commercial fertilizer, a study was undertaken to assemble the findings from research studies and conduct a rigorous statistical analysis of the results of the studies on production, environmental quality, and soil health. This analysis extracted information on the type of soil, weather conditions, climate region, country, rate of manure and commercial fertilizer applied, manure application method, type of commercial fertilizer, crop, soil conditions, and manure handling. A large number of studies were excluded because the details of how the study was conducted was not evident in the report. The analyses conducted from the data set showed that swine manure was no different from commercial fertilizer in terms of crop yields. . There was no effect of swine manure on the emission of nitrous oxide as an environmental parameter. Water quality effects were mixed between commercial fertilizer and swine manure and more dependent upon the weather conditions after application and the rate of application. Water quality impacts of manure are reduced when the manure is applied at the recommend rate and when the conditions for runoff and leaching are reduced. It was not possible to conduct a meta-analysis because of the small sample size; however, it was possible to glean from the studies the differences between swine manure and commercial fertilizer from the published studies. The use of meta-analysis on crop yield for a range of crops produced the most observations. In general, swine manure was no different than commercial fertilizer in crop yield response; however, crop yields are affected by the number of factors other than nutrient source. From these studies, some interesting findings on crop yield emerged: lighter textured soils were more responsive to swine manure than heavier textured soils; surface application of swine manure had lower yields than commercial fertilizer potentially due to volatilization or inability of the crop to extract nutrients at the soil surface, or uneven distribution of nutrients on the soil surface; corn, wheat, and forage showed no difference in yield when swine manure was used; temperate climates were the most responsive to swine manure; and utilization of swine manure in the United States had the largest crop yield response potentially due to the fact that most of these

sites ae in temperate regions. The effect of soil type can be attributed to the lighter textured soils having a positive response to changes in organic N and soil organic matter changes in the soil caused by the addition of manures. The increased responsiveness observed in the United States is due to the combined effect with climate because most of the sites are in temperate zones where we see the largest climate impact. Overall, the conclusion from this analysis is that swine manure can be effectively used as a nutrient source for crop production without an environmental impact and with a positive effect on soil health.

Keywords: Meta-analysis of swine manure, crop yield, manure application method, soil type, commercial fertilizer

Comparison of crop production between swine manure and commercial fertilizer to agriculture soil: A global meta-analysis

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Abstract

Swine manure contains substantial amounts of nitrogen, phosphorus, and potassium capable of supplying nutrients to crops. There are published research studies that compare crop yields between swine manure and commercial fertilizer. The results vary among these studies and the results are often confusing to interpret the effect across locations. To address this problem, a meta-analysis was conducted to quantify the differences between swine manure and commercial fertilizer on crop yield, nitrous oxide emissions, phosphorus runoff, and soil organic matter changes. Meta-analysis provides a non-biased methodology to statistically compare studies that meet a given set of requirements for inclusion. It was found that over all of the studies, swine manure was not significantly different from commercial fertilizer in crop yields. There were differences in this response related to soil type (crop yields in lighter textured soil were more responsive to swine manure than heavier textured soils), application method (surface application had lower yields than commercial fertilizer potentially due to volatilization, or inability of the crop to extract nutrients at the soil surface, or uneven application of manure onto the soil surface), crops (corn, wheat, and forage showed no difference in yield when swine manure was used), climates (temperate climates were the most responsive to swine manure), and country (the United States had the largest positive response of crop yield to swine manure application because most the US are in temperate regions). Swine manure can be effectively used as a nutrient source for crop production and awareness to the areas and practices that provide the greatest response can increase the economic return compared to commercial fertilizer. Observations on nitrous oxide emissions showed no difference between swine manure and commercial fertilizer while observations on water quality, phosphorus runoff or nitrate leaching was dependent upon the weather conditions during the study and the application rate. To reduce water quality problems, application of swine manure at the recommended rate is required. Swine manure does have a positive effect on soil properties, e.g., soil organic matter, aggregate stability, bulk density, water infiltration and storage, and nutrient cycling. These changes increase the capability of effectively using swine manure or other organic sources to increase the capability of the soil withstand weather variation. A note of caution in all of these studies and their interpretation, crop yield differences in a given study may not be directly related to the

source of fertilizer and studies utilizing swine manure may not have been of sufficient duration to evaluate changes in soil properties.

Introduction

Manure is a valuable resource and misunderstood in terms of the value of the nutrient supply to agricultural crops. Brumm (1998) summarized swine manure production and utilization; however, of the studies conducted comparing swine manure to commercial fertilizer there has been no comparison among studies to quantify the differences in the response of swine manure application. Based on the 2012 Census of Agriculture, the number of swine present at any one time was over 66 million with a total of 193 million marketed in a year (USDA, 2012) and the total swine population produces over 100 million tons of manure annually with a nitrogen content of 6.4 million tons and 4.2 million tons of P_2O_5 and K_2O. This amount of manure could supply nutrients to crops in place of commercial fertilizer; however, the value of swine manure often varies among studies. In a comparison of 39 different swine operations the average application rates varied from 155 kg ha^{-1} in Oklahoma to 309 kg ha^{-1} in North Carolina with no difference between lagoon or slurry storage in the application rates (Lory et al., 2004). There have been studies conducted comparing swine manure to commercial fertilizer and to rigorously compare among these studies in a quantitative method requires a meta-analysis. Meta-analysis has been described as a quantitative method to evaluate the results from independent studies, determine the extent of heterogeneity, and provide a synthesis where possible. Card (2012) stated that the purpose of meta-analysis was not to estimate the effect of treatments but to investigate the underlying factors for differences among studies and any patterns in the estimates.

Wortman et al. (2017) completed a meta-analysis of several manure sources on crop yield after the first year of application. This study was restricted to organic amendments compared to a non-fertilized control and revealed that crop yield increased by 43±7% over all crops. In their study, they didn't compare manure nutrients to a similar amount for fertilized crops so the analysis doesn't represent a direct comparison of manure relative to fertilizer; however, in their study they observed that the effect of manure was dependent upon the organic matter levels in the soil. The higher organic matter levels reduced the positive impacts of the manure application. In a survey of the literature, there are many studies on the use of manure as a soil amendment and nutrient source; however, many of these studies are of short-duration that limits our ability to assess the changes in soil properties and conduct a meta-analysis. A review of the literature by Choudhary et al. (1996) on the use of swine manure found swine manure increased crop yields because of the increased concentrations of N, P, K, Ca, Mg, and Na in the soil. However, application above the recommended rates increased the leaching of NO_3-N, P, and Mg through the soil profile. Schlegel et al. (2015) evaluated the soil physiochemical properties after 10 years of cattle manure and swine manure application and found that while cattle manure application increased Mehlich-3 P, total N, total C, organic matter, and electrical conductivity compared to the control, there was no effect of the swine manure application on these soil properties. There was also no difference between swine manure and inorganic fertilizer in changing these properties. The objective of this study was to compare differences between swine manure and commercial nitrogen (N) fertilizer management across a range of research studies available in the published literature. These evaluation methods compared a number of different factors for their response using meta-analysis statistical approaches.

Objectives: The objective of this synthesis project is to: 1) conduct a meta-analysis of the available literature on manure applied to cropping system for the effects on production efficiency, environmental quality, and soil health, and 2) Utilize the meta-analysis to contrast the differences between commercial fertilizer and manure with specific emphasis on swine manure and different application methods.

Materials and methods

Data collection

A comprehensive literature search was conducted of peer-reviewed articles that reported agronomic yield following swine manure application in agriculture systems from the web of science TM (Thomason Reuters, Philadelphia, PA, USA). Keywords: ‘swine’, ‘pig’, ‘hog’, ‘manure’, ‘slurry’, ‘effluent’, ‘commercial’, ‘synthetic ‘, ‘mineral’, ‘urea’, ‘fertilizer’, ‘crop yield’, ‘fertilization’, ‘production’ were used to search for studies published prior to Jun 1 of 2018. The studies were selected to conduct comparisons on crop yield, nitrous oxide emissions, water quality, and soil properties among swine manure, synthetic N fertilizer, and/or no fertilization treatment in the same agriculture system and at the same or adjacent experimental site. In order to ensure these comparisons could be made in an unbiased manner, studies were restricted to those using the same cropping and management system and located at the same experimental site. Seasonal crop yields from the unfertilized treatment were collected to estimate the apparent nitrogen efficiency (ANE).

Crop Yield

The study included in the crop yield data pool had to meet the following criteria: a) Replicated experiment design in field, controlled environmental chamber. b) Comparable design experiment in term of similar crop rotation, identical cropping season and year, etc. c) the seasonal yield for at least one full crop season. d) Experiments that included at least one comparison of crop yields between swine manure application and synthetic n fertilizer and/ or no fertilization treatment. e) Major conditions in the experiment duration did not change dramatically, such as flooding in land condition and destructive pests in production environment. The data pool for the crop yield comparisons is shown in Table 1.

Since the mineralization factor of swine manure range from 0.3 to 0.5 for fresh to aerobic liquid manure handling, the studies were included if the difference of N application rate between swine manure and synthetic fertilizer are less than 30% (Midwest Plan Service, 1993; Klop et al., 2012). Studies considering equivalent Kjeldahl nitrogen are also included if the difference in total application rate are less 30%. Long term studies were included if the difference of average N application in comparing treatments is within the 30% difference limit. One comparison of seasonal yields on identical crop on the same or adjacent site in a successive experiment as considered as one observation in this analysis. If a study was repeated for multiple growing season, the average value of the full experiment duration was consider as one observation without violation of the above criteria.

From each study, the seasonal yield (Mg/ha) with corresponding variance and N application rate (kg/ha) were extracted for swine manure and synthetic N fertilizer application treatment, with unit conversion performed where necessary. The sample size for each observation are also collected. Conversion was perform when only standard error or standard deviation were reported in the studies. GetData Graph Digitizer software (version 2.26) was used to extract any information are represented with that figure.

To analyze the variation in crop yield among studies, four categories were used to define the data with further subcategories used to define the categories. These categories and subcategories are: site description (geographic location, Köppen climate classification, historical mean temperature and precipitation, cropping system, previous crop); soil physicochemical properties (soil texture, percentage of clay, sand silt, pH, C:N ratio, plant macronutrients); manure biochemical properties (pH, C:N, dry matter, total carbon, plant macronutrients, micronutrient, organic N, NO3-N, NH4-N); and field practice (type of crop, swine manure preparation, type of synthetic N fertilizer, study period, mean temperature, minimum and maximum temperature, participation, irrigation, split of application, amendment method). If the seasonally information for the factors were available in the original publication, the average values were used in the analyses. If the seasonally information ass not reported in the original publication, the information recorded before the experiment or at the end of the first season were assigned for all seasons in the observation. N uptake are compiled in the dataset for estimating apparent nitrogen recovery (ANR).

In total, 84 observations from 34 peer-review articles were selected with four long term studies (Table 1). Because the issue of missing values, some subcategories with less missing value were used as moderators in the analysis, such as land use (n=84), swine manure preparation (n=84), application method (n=84), times of application (n=83), Köppen Climate Classification (n=84), swine manure pH (n=52), soil pH (n=66), soil texture (n=94), and country (n=84).Environmental Quality

One of the comparisons made between swine manure and commercial fertilizer was in nitrous oxide (N_2O) emissions from different crops and management systems. From the published literature we were able to extract 46 direct comparisons for use in the meta-analysis and these are shown in Table 2. These data included the same subset values as in the crop yield data set.

The published literature was screened for water quality assessment and the most prevalent observation was found to be phosphorus from manure application. This assessment was complicated because surface runoff is not a direct result of the nutrient source applied but rather the management practices associated with cultivation of the crop. The results from these studies are discussed in a later section but lacked the capability to conduct a meta-analysis.

Soil Properties

The published literature was evaluated for studies that assessed changes in soil properties, including aggregates, bulk density, soil microbial activity, and soil quality. One of the major limitations in the current reported studies is that many of these have a short experimental period in which changes in soil properties are undetectable, were not measured, or the previous experimental conditions were not documented that would allow for a comparison of the effects of swine manure application. However, there are a limited number of studies that will be discussed in a section on soil properties.

Data analysis

The meta-analysis focused on the impact of swine manure and synthetic N fertilizer on crop yield with natural logarithm of the response ratio (ln RR) as the effect size of the comparison.

$$\theta = \ln RR = \ln\left(\frac{\overline{x_1}}{\overline{x_2}}\right) = \ln(\overline{x_1}) - \ln(\overline{x_2}) \qquad (1)$$

where $\overline{x_1}$ and $\overline{x_2}$ are the mean values of swine manure application treatment and the mean values of synthetic N fertilizer treatment, respectively.

To increase the explanatory power, the effect size was transformed to the percentage change for swine manure treatment to the synthetic N fertilizer treatment.

$$\%\, change = (\exp(\theta) - 1) \times 100\% \qquad (2)$$

The variance of ln RR for each study was estimated by the following equation.

$$V = \frac{{s_1}^2}{n_1\overline{x_1}^2} + \frac{{s_2}^2}{n_2\overline{x_2}^2} \qquad (3)$$

where s_1 and s_2 are the standard deviation of swine manure application treatment and the mean values of synthetic N fertilizer treatment, respectively; n_1 and n_2 are the sample size of swine manure application treatment and the mean values of synthetic N fertilizer treatment, respectively.

The random-effect meta-analysis model was applied with assumption of the effect size in the dataset are not intrinsically associated with study k (Schwarzer, et al., 2015). The model was also used to test relation between the effect sizes of crop yield and land use, swine manure preparation, application method, times of application, Köppen climate classification, swine manure pH, soil pH, soil texture, and country. The analysis is done by the "metafor" package with R language (Viechtbauer, 2010).

$$\hat{\theta} = \theta + u_k + \sigma_k \epsilon_k, \qquad \epsilon_k \sim N(0,1);\ u_k \sim N(0, \tau^2) \tag{4}$$

Where the $\hat{\theta}$ is the effect estimate; the u and $\sigma_k \epsilon_k$ are the random effect of observation and sample, respectively.

Table 1 Summary of each observation in the present meta-analysis

Study number (Observation)	Reference	Location	Land Use	Soil texture	Köppen Climate Classification	Yield with swine manure (Mg/ha)	Yield with Synthetic N fertilizer (Mg/ha)	N rate (kg N/ha)
1 (3)	Adeli et al., 2005	USA	Johnson Grass	silty clay	Cfa	7.3, 9.6, 9.6	7.2, 9.4, 9.1	230, 448, 665
2 (6)	Ahmed et al., 2013	USA	Corn, Soybean	medium loam	Dfa	8.9, 8.7, 9.1, 2.5, 2.6, 2.6	7.9, 7.9, 7.9, 2.6, 2.6, 2.6	168, 168, 168, 168, 168, 168
3 (1)	Akiyama and Tsuruta, 2003	Japan	Pac Choi		Cfa	2	2.3	150
4 (3)	Berenguer et al., 2008 and Martinez et al., 2017	Spain	Maize	loam	Cfb	13.1, 11.7, 10	13.8, 12.2, 13.8	200, 200, 200
5 (10)	Chantigny et al., 2007	Canada	Forage	loam	Dfb	6.1, 6.9, 6.9, 6, 7.2, 6.3, 6.8, 6.3, 7, 6.4	6.4, 7.6, 7.6, 6.4, 7.6, 6.4, 7.6, 6.4, 7.6, 6.4	145.8, 140.4, 145.8, 141.9, 141.9, 144.1, 144.1, 140.5, 140.5, 140.9
6 (10)	Chantigny et al., 2008 and 2010	Canada	Corn	clay, loam	Dfb	9.2, 9.7, 9.2, 9.5, 9, 9.6, 9.2, 9.6, 8.9, 9.9	8.8, 9.6, 8.8, 9.6, 8.8, 9.6, 8.8, 9.6, 8.8, 9.6	106, 106, 103.7, 103.7, 95.7, 95.7, 100, 100, 103, 103
7 (2)	Chantigny et al., 2012 and Gagnon et al., 2012	Canada	Corn	clay	Dfb	10.7, 9.2	14.1, 14.1	130, 149
8 (1)	Christie, 1987	United Kingdom	Perennial Ryegrass	clay loam	Cfb	12.2	11	192.7
9 (1)	Daniel et al., 2018	China	Maize	clay	Cfa	5.1	2.7	60
10 (1)	Diez et al. 2001	Spain	Maize		Bsk	13.5	12.8	162
11 (3)	Gagnon et al., 2012	Canada	Corn		Dfb	10.6, 10.4, 10	11.6, 11.6, 11.6	118.2, 122.3, 111.6
12 (2)	Gonzatto et al., 2017	Brazil	Corn	medium loam	Cfa	9.4, 10.8	9.4, 9.4	157.7, 157.7
13 (2)	Hu et al., 2015	China	Wheat, Rice		Cfa	2.2, 5.4	2.1, 4.6	52.6, 52.6
14 (3)	Huang et al., 2016	China	Rice	sandy l	Cwa	7.8, 7.7, 8.2	7.7, 7.7, 7.7	210, 210, 240

Table 1 (continued)

Study number (Observation)	Reference	Location	Land Use	Soil texture	Köppen Climate Classification	Yield with swine manure (Mg/ha)	Yield with Synthetic N fertilizer (Mg/ha)	N rate (kg N/ha)
15 (3)	Kaisi and Waskom, 2002	USA	Corn	sand	Bsk	6.1, 8.6, 9.5	5, 7.1, 7.4	52, 104.7, 179
16 (2)	Loria et al., 2007	USA	Corn	loam	Dfa	7.8, 9.1	8.7, 8.7	86.5, 167.8
17 (1)	Lou et al., 2011	China	Maize	silty loam	Dwa	7.4	6.3	135
18 (1)	Louro et al., 2015	Spain	Maize	silt loam	Csb	18.8	18.3	193
19 (1)	Maskina et a., 1988	India	Rice	loamy sand	Bsh	3.6	4.5	75
20 (1)	Maskina et al., 1988	India	Rice	loamy sand	Bsh	4.1	4.6	75
21 (2)	Mattila et al., 2006	Finland	Barley	clay loam	Dfc	1.9, 3.2	3.7, 5.1	112.5, 112.5
22 (1)	McGonigle et al., 2004	Canada	Corn	silt loam	Dfb	7.8	8.4	100
23 (1)	Menezes et al., 2016	Brazil	Maize	clay	Aw	8.3	7.8	158
24 (1)	Moreno-Garcia et al., 2017	Spain	Rice	silt loam	Bsk	5.1	5.1	120
25 (4)	Plaza-Bonilla et al., 2017	Spain	Barley	silty clay loam	Cfb	1.3, 2, 3.8, 3.8	0.8, 1, 2.9, 2.9	75, 150, 75, 150
26 (1)	Safley et al., 1980	USA	Corn	silt loam	Cfa	4.9	6.1	150
27 (3)	Shi et al., 2009	China	Wheat, Soybean, Hedge	medium loam	Cfa	2.3, 2, 10.8	1.8, 1.8, 10.3	158.6, 158.6, 158.6
28 (1)	Sistania et al., 2017	USA	Corn	silt loam	Cfa	7.4	8.7	202
29 (2)	Springer et al., 2005	USA	Forage	clay loam	Bsk	10.6, 17.1	11.6, 15.1	120, 240
30 (6)	Vaillancourt et al., 2018	Canada	Canola	sandy clay loam, silt clay	Dfb	2.4, 2.8, 3, 2.9, 3.2, 3.6	2.8, 3.3, 3.3, 3.3, 3.4, 3.5	50, 100, 150, 50, 100, 150
31 (1)	Wang et al., 2013	China	Rice	clay l	Cfa	8	7.4	180

Table 2. Observational studies on nitrous oxide emissions with swine manure and inorganic fertilizer application.

	Reference	Location	Land Use	Soil texture	Koppen climate classification	N_2O with swine manure	N_2O with Synthetic N fertilizer	N rate (kg N/ha)
1	Akiyama and Tsuruta, 2003	Japan	Pac Choi		Cfa	0.5	0.3	150
2	Chantigny et al., 2007	Canada	Forage	loam	Dfb	1.5	1	145.8
3	Chantigny et al., 2007	Canada	Forage	loam	Dfb	0.3	0.2	140.4
4	Chantigny et al., 2007	Canada	Forage	loam	Dfb	0.4	0.2	145.8
5	Chantigny et al., 2007	Canada	Forage	loam	Dfb	1.2	1	141.9
6	Chantigny et al., 2007	Canada	Forage	loam	Dfb	0.4	0.2	141.9
7	Chantigny et al., 2007	Canada	Forage	loam	Dfb	1.7	1	144.1
8	Chantigny et al., 2007	Canada	Forage	loam	Dfb	0.3	0.2	144.1
9	Chantigny et al., 2007	Canada	Forage	loam	Dfb	0.6	1	140.5
10	Chantigny et al., 2007	Canada	Forage	loam	Dfb	0.2	0.2	140.5
11	Chantigny et al., 2007	Canada	Forage	loam	Dfb	1.3	1	140.9
12	Chantigny et al., 2008 and 2010	Canada	Corn	clay	Dfb	7.1	11.6	106
13	Chantigny et al., 2008 and 2010	Canada	Corn	loam	Dfb	4.6	2	106
14	Chantigny et al., 2008 and 2010	Canada	Corn	clay	Dfb	7.4	11.6	103.7
15	Chantigny et al., 2008 and 2010	Canada	Corn	loam	Dfb	3.7	2	103.7
16	Chantigny et al., 2008 and 2010	Canada	Corn	clay	Dfb	9.7	11.6	95.7
17	Chantigny et al., 2008 and 2010	Canada	Corn	loam	Dfb	3.8	2	95.7
18	Chantigny et al., 2008 and 2010	Canada	Corn	clay	Dfb	7.7	11.6	100
19	Chantigny et al., 2008 and 2010	Canada	Corn	loam	Dfb	3.6	2	100
20	Chantigny et al., 2008 and 2010	Canada	Corn	clay	Dfb	8.9	11.6	103
21	Chantigny et al., 2008 and 2010	Canada	Corn	loam	Dfb	3.1	2	103
22	Chantigny et al., 2012	Canada	Corn	clay	Dfb	6.1	8.3	161
23	Chantigny et al., 2012	Canada	Corn	clay	Dfb	4.3	8.3	147
24	Chantigny et al., 2012	Canada	Corn	clay	Dfb	5	8.3	133
25	Chantigny et al., 2012 and Gagnon et al., 2012	Canada	Corn	clay	Dfb	2.3	8.3	130
26	Chantigny et al., 2012 and Gagnon et al., 2012	Canada	Corn	clay	Dfb	2.1	8.3	149
27	Dambreville et al , 2008	France	Maize	silt loam	Cfb	1	2.2	180
28	Dambreville et al , 2008	France	Maize	silt loam	Cfb	0.9	0.9	132
29	Daniel et al., 2018	China	Maize	clay	Cfa	1	0.6	60
30	Grave et al , 2018	Brazil	None	medium loam	Cfa	2.5	1.9	140

31	Grave et al , 2018	Brazil	None	medium loam	Cfa	2.1	1.9	140
32	Grave et al , 2018	Brazil	None	medium loam	Cfa	1.6	1.9	140
33	Grave et al , 2018	Brazil	None	medium loam	Cfa	5.6	3.5	140
34	Grave et al , 2018	Brazil	None	medium loam	Cfa	2.9	3.5	140
35	Grave et al , 2018	Brazil	None	medium loam	Cfa	4.7	3.5	140
36	Jarecki et al., 2008	USA	None and Not In Field	sandy loam	Dfa	6.3	7.5	200
37	Jarecki et al., 2008	USA	None and Not In Field	clay	Dfa	4	0.8	200
38	Lopez-Fernandez et al., 2007	Spain	Maize	sandy loam	Bsk	5.1	5.9	170
39	Lopez-Fernandez et al., 2007	Spain	None In Field	sandy loam	Bsk	4.3	3.7	170
40	Louro et al., 2015	Spain	Maize	silty loam	Csb	15.3	15.8	193
41	Wang et al., 2013	China	Rice	clay loam	Cfa	0.2	0.2	180
42	Whalen, 2000	USA	Wheat	sandy loam	Cfa	0.1	0.1	165
43	Zhou et al., 2016	China	Wheat		Cwa	1.7	0.7	130
44	Zhou et al., 2016	China	Maize		Cwa	0.9	1	150

Results:

Effect of swine manure application on crop yields compared to synthetic N fertilizer

On average swine manure application reduced the crop yields by -2.8% (95% CI: -5.9% to 0.4%) compared to synthetic N fertilizer (Fig. 1). The random-effect model for the entire dataset showed that effect size is not different from zero based to the p-value of 0.0822. The random-effect model for the subcategories showed that the effect size is associated with times of application, manure pH, soil texture, and country, but associated not with land use, manure preparation, application method, Köppen climate classification, or soil pH. The results might not be representative except for subcategories of corn, forage, maize and rice because of the small sample size. For corn and forage, there was no difference between manure application and commercial fertilizer on crop yield.

Land use does not significantly affects swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig.1, P = 0.1439). Swine manure application significantly reduced yields of barley and canola by 25.4% (95% CI: -39.7% to -7.8%) and 9.9% (95% CI: -16.7% to -2.5%) relative to synthetic N fertilizer. The swine manure application increased yields of hedge, johnson grass, perennial ryegrass, rice and soybean. In hedge (5.1%, 95% CI: -37.2% to 76%), johnson grass (3.5%, 95% CI: -19.1% to 32.5%), perennial ryegrass 10.7% (95% CI: -13.7% to 42.1%), 1% (95% CI: -7.1% to 9.8%), 2.2% (95% CI: -11.6% to 18%), respectively, relative to synthetic N fertilizer.

Manure treatment does not significantly affect crop yields relative to synthetic N fertilizer yields (Fig. 2, P = 0.5029). Both raw (-2.6%, 95% CI: -18.7% to 16.7%) and treated (-1.5%, 95% CI: -6.8% to 4.1%) swine manure did not significantly change yields relative to synthetic N fertilizer. Vetsch et al. (2017) found that fall application of swine manure when combined with nitrapyrin increased corn yields and delaying fall application to late November in combination with nitrapyrn increased corn yields and N uptake in years with greater than normal spring precipitation.

Application method does not significantly affect swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig. 2, P = 0.0558). When the application methods were subdivided, surface application significantly reduced crop yields by 6.7% (95% CI: -12.2% to -1%); however, subsurface application or incorporation did not significantly reduce crop yields by 2.4% (95% CI: -6.2% to 1.6%). The reason for the negative impact of the surface application of manure is not obvious in the reports; however, part of this effect may be due to application distribution, timing of precipitation events after application, or other conditions during the growing season that affected crop yield other than nutrient management.

Times of application significantly affects swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig. 3, P = 0.0416). On average, swine manure application significantly reduced crop yields by 4.3% (95% CI: -7.7% to -0.7%) when the swine manure was applied once during a cropping season. The swine manure application reduced yield relative to synthetic N fertilizer by 0.6% (95% CI: -7% to 6.3%) when the applied swine manure was applied twice during the growing season. The swine manure application increased yield relative to synthetic N fertilizer by 25.4% (95% CI: -4% to 63.7%) when the applied swine manure was applied three times, but might not be representative because of small sample size.

The Köppen climate classification does not significantly affect swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig. 4, P = 0.1994). When the climate zones are evaluated separately, swine manure application significantly reduced crop yields by 6.3%, (95% CI: -10.3% to -2.1%) in snow climate zone with humid summers. Swine manure application increased crop yields relative compared to synthetic N fertilizer in tropical wet climate zone (5.8%, 95% CI: -21.6% to 42.8%), arid steppe climate zone (3%, 95% CI: -6.4% to 13.3%), warm temperate climate zone with humid summers (-0.1%, 95% CI: -6.9% to 7.2%), warm temperate climate zone with dry summer (2.5%, 95% CI: -28.7% to 47.2%), warm temperate climate zone with dry winter (1.1%, 95% CI: -8.2% to 11.3%), snow climate zone with dry winter (13.6%, 95% CI: -16.7% to 54.9%). The results might not be representative for subcategories of tropical wet climate zone, warm temperate climate zone with dry summer, snow climate zone with dry winter because of the small sample size.

Manure pH significantly affects swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig. 5, P = 0.0113). On average, swine manure application significantly reduced crop yields by 8.4 (95% CI: -14.2% to -2.4%) relative to synthetic N fertilizer when manure pH is neutral. The swine manure application reduced crop yields relative to synthetic N fertilizer when manure is basic by 2.9% (95% CI: -7.1% to 1.5%). No data in dataset for acidic manure.

Soil pH does not significantly affect swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig. 5, P = 0.1439). On average, swine manure application significantly reduced crop yields by 6.8%, (95% CI: -12.4% to -0.8%) relative to synthetic N fertilizer when soil pH is neutral. The swine manure application did not significantly reduce crop yields relative to synthetic N fertilizer with values of 1.6% (95% CI: -7.9% to 5.2%) and 1.8% (95% CI: -8.7% to 5.6%) when soil is acidic and basic, respectively.

Soil texture significantly affects swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig. 6, P = 0.0025). On average, relative to synthetic N fertilizer, swine manure application significantly reduced crop yields by 12.4% (95% CI: -21.5% to -2.2%) and 13.3% (95% CI: -21.3% to -4.4%) in clay soil and sandy clay loam soil, respectively. The swine manure application reduced crop yields relative to synthetic N fertilizer by 7.9% (95%, CI: -0.6% to 17.3%), 24.1% (95%, CI: -0.2% to 54.3%) and 44.3% (95%, CI: -8.3% to 127%) in medium loam soil, sand soil, silty clay loam soil, respectively. These responses due to soil type are related to the mineralizable N pools in the soil, which was more significant in the coarser textured soils (Thomas et al., 2015).

Country significantly affects swine manure application-induced crop yields relative to synthetic N fertilizer-induced crop yields (Fig. 7, P < 0.0001). On average, relative to synthetic N fertilizer, swine manure application significantly reduced crop yields by 9.1% (95% CI: -12.7% to -5.4%) and 37.7% (95% CI: -28.0% to-22.8%) in Canada and Finland, respectively, but not in Brazil, China, India, Japan, Spain (-4.3%, 95% CI: -11.6% to 3.6%), United Kingdom, and USA. The swine manure application significantly increased crop yields relative to synthetic N fertilizer in Brazil (5.8%, 95% CI: -9.4% to 23.4%)), China (4, 95% CI: -2% to 10.4%), United Kingdom (10.7%, 95% CI: -10.9% to 37.7%), and USA (5.8%, 95% CI: -0.2% to 12.2%), whereas negative in India (-14.6%, 95% CI: -28% to 1.2%), Japan (-10.9%, 95% CI: -22.8% to 2.7%), Spain (-4.3%, 95% CI: -11.6% to 3.6%). The results might not be representative for Brazil, Finland, India, Japan, and United Kingdom because of the small sample size.

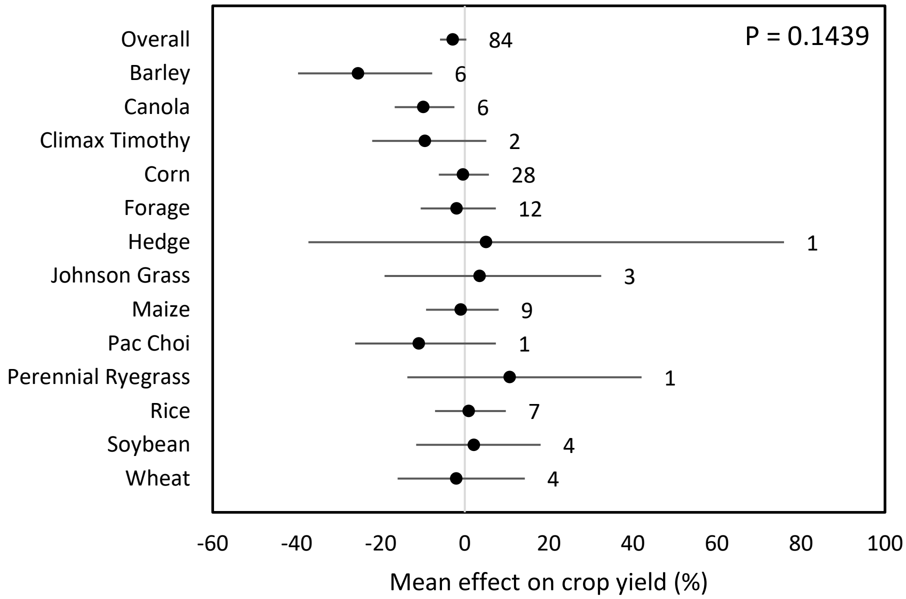

Figure1. Comparison of crop yield in swine manure vs. synthetic N fertilizer applications for the entire dataset (overall) and for different agronomic crops: barley, canola, climax timothy, corn, forage, hedge, johnson grass, maize, pac choi, perennial ryegrass, rice, soybean, and wheat. The number of observations included in each category is shown next to the error bar. The error bar represent the 95% confidence intervals. One observation with unknow time of application is not shown.

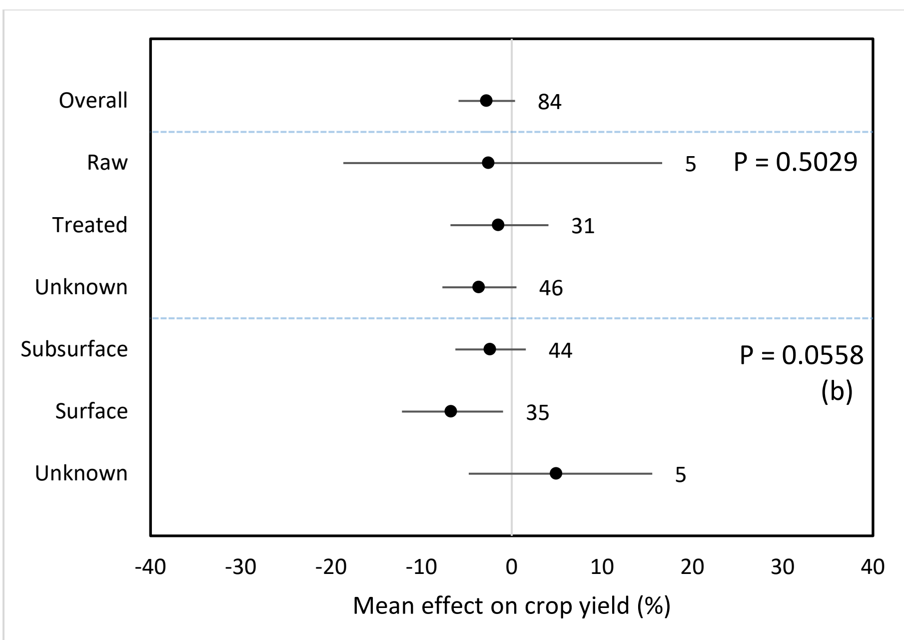

Figure2. Comparison of crop yield in swine manure vs. synthetic N fertilizer applications for the entire dataset (overall), swine manure preparation subcategories (a) and application method (b) of acid (<6.5), alkaline (>7.3) and neutral (6.5-7.3). The number of observations included in each category is shown next to the error bar. The error bar represent the 95% confidence intervals. One observation is not shown since the manure were raw and treated in different year.

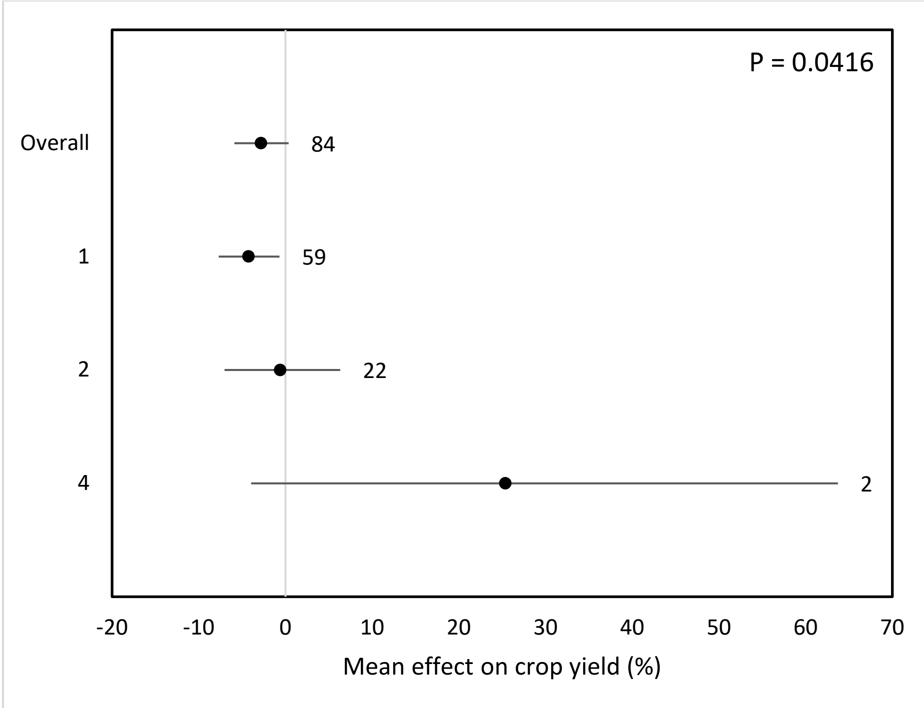

Figure 3. Comparison of crop yield in swine manure vs. synthetic N fertilizer applications for the entire dataset (overall) and for times of application subcategories of single time (1), two time (2) and four time (4). The number of observations included in each category is shown next to the error bar. The error bar represent the 95% confidence intervals. One observation with unknow time of application is not shown.

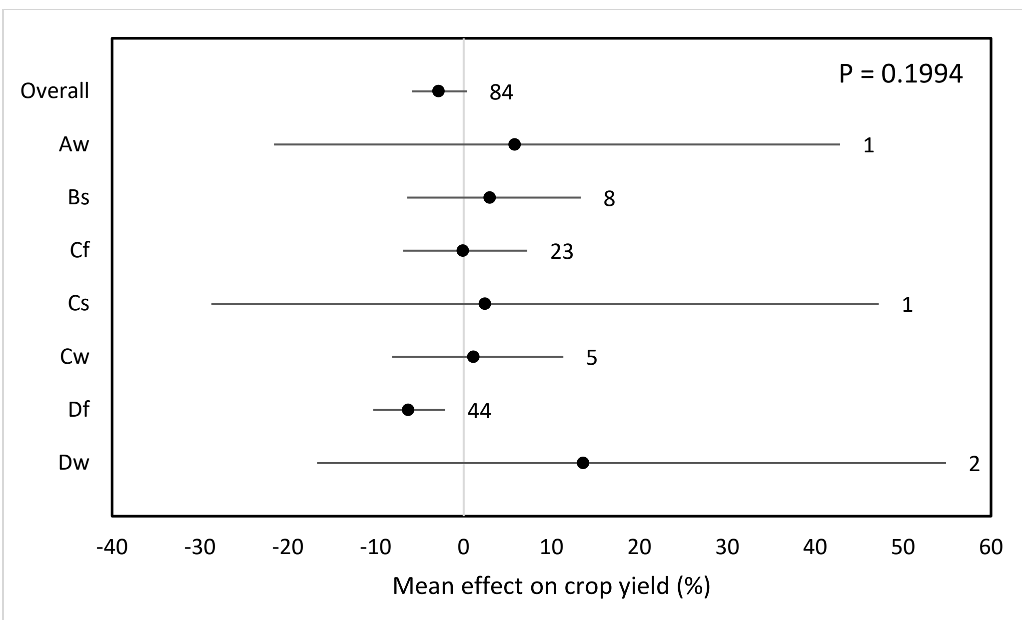

Figure 4. Comparison of crop yield in swine manure vs. synthetic N fertilizer applications for the entire dataset (overall), Köppen Climate Classification subcategories of tropical wet climate (Aw), arid steppe climate (Bs), warm temperate climate, fully humid (Cf), warm temperate climate with dry summer (Cs), warm temperate climate with dry winter (Cw), snow climate, fully humid (Df), snow climate with dry winter (Dw). The number of observations included in each category is shown next to the error bar. The error bar represent the 95% confidence intervals.

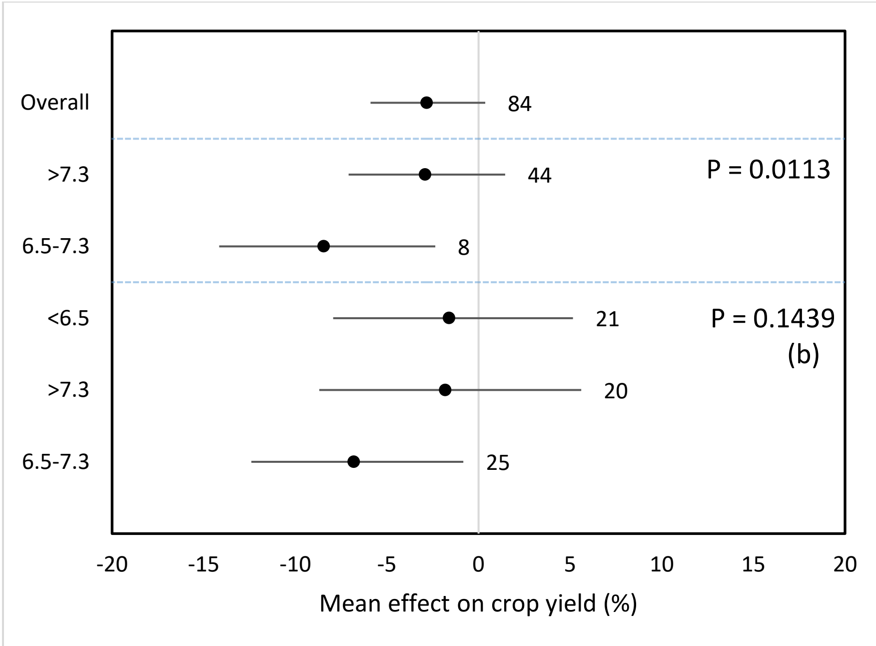

Figure 5. Comparison of crop yield in swine manure vs. synthetic N fertilizer applications for the entire dataset (overall), swine manure pH subcategories (a) and soil pH subcategories (b) of acid (<6.5), alkaline (>7.3) and neutral (6.5-7.3). The number of observations included in each category is shown next to the error bar. The error bar represent the 95% confidence intervals.

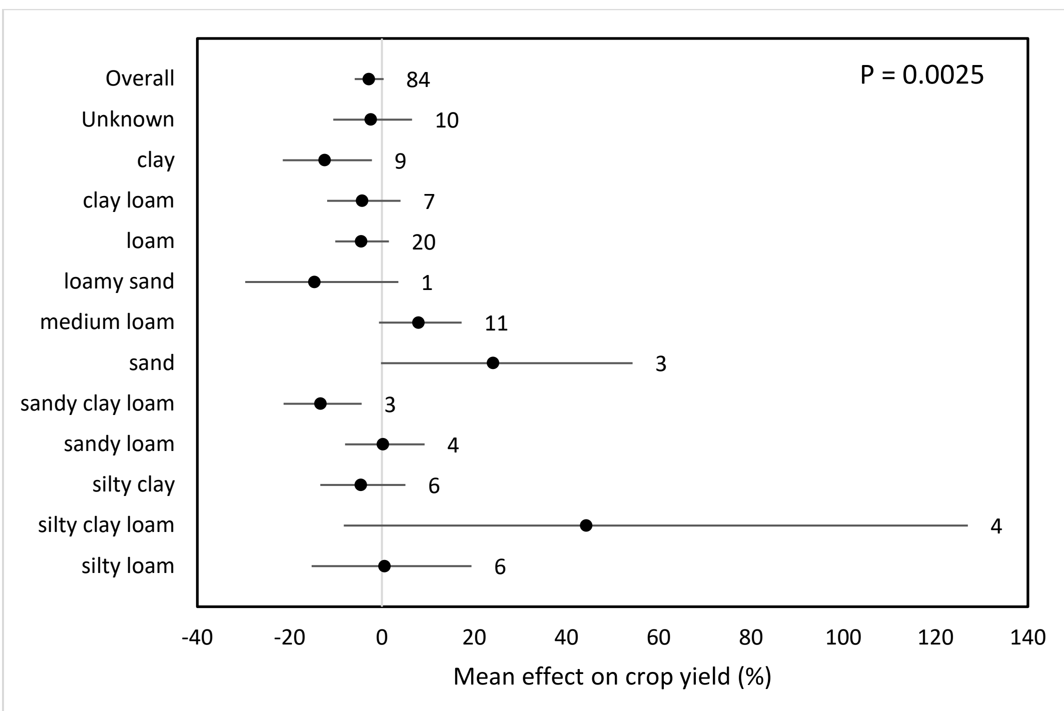

Figure 6. Comparison of crop yield in swine manure vs. synthetic N fertilizer applications for the entire dataset (overall), soil texture subcategories of unknown, clay, clay loam, loam, loamy sand, medium loam, sand ,sandy clay loam, sandy loam, silty clay, silty clay loam, silty loam. The number of observations included in each category is shown next to the error bar. The error bar represent the 95% confidence intervals.

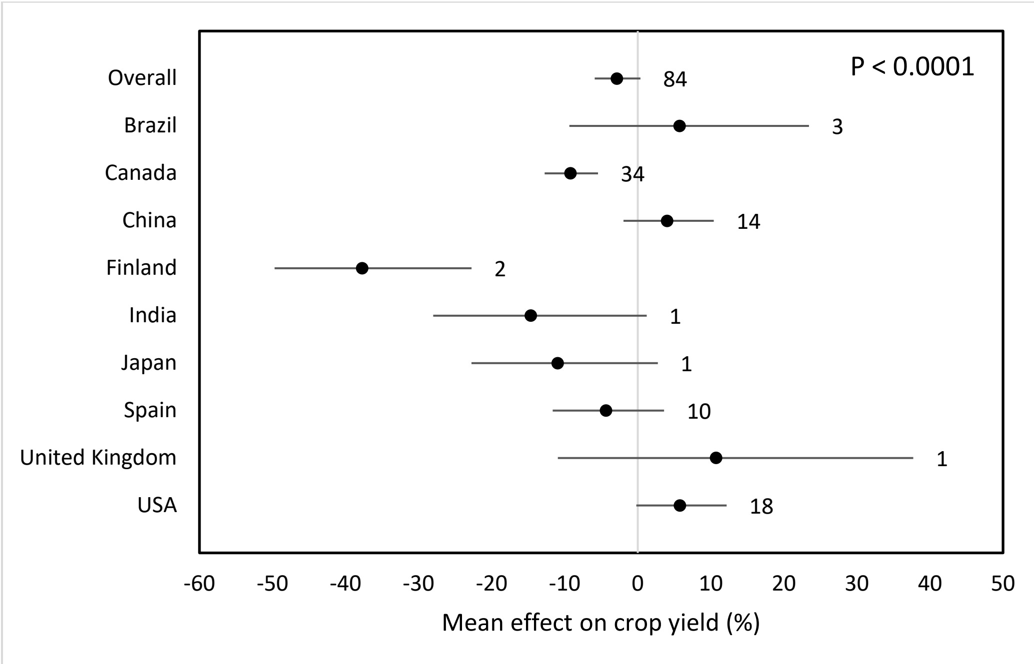

Figure 7. Comparison of crop yield in swine manure vs. synthetic N fertilizer applications for the entire dataset (overall) and for country subcategories of Brazil, Canada, China, Finland, India, Japan, Spain, United Kingdom, United State of America (USA). The number of observation included in each category is shown next to the error bar. The error bar represent the 95% confidence intervals.

Effect of swine manure application on nitrous oxide emissions

Comparison of swine manure relative to commercial fertilizer did not significantly affect nitrous oxide emissions for any of the data subsets. The data shown in Fig. 8 reveal the only difference was on bare soil application in which seine manure application increased nitrous oxide emission; however, the variation among the observations was not significant. Application of swine manure did not increase nitrous oxide emission compared to synthetic N fertilizer. One caveat to these observations was found in which nitrous oxide emissions from soil with manure applied would increase where intensive and recurring soil wetting events are likely to occur (Hernandez-Ramirez et al., 2009).

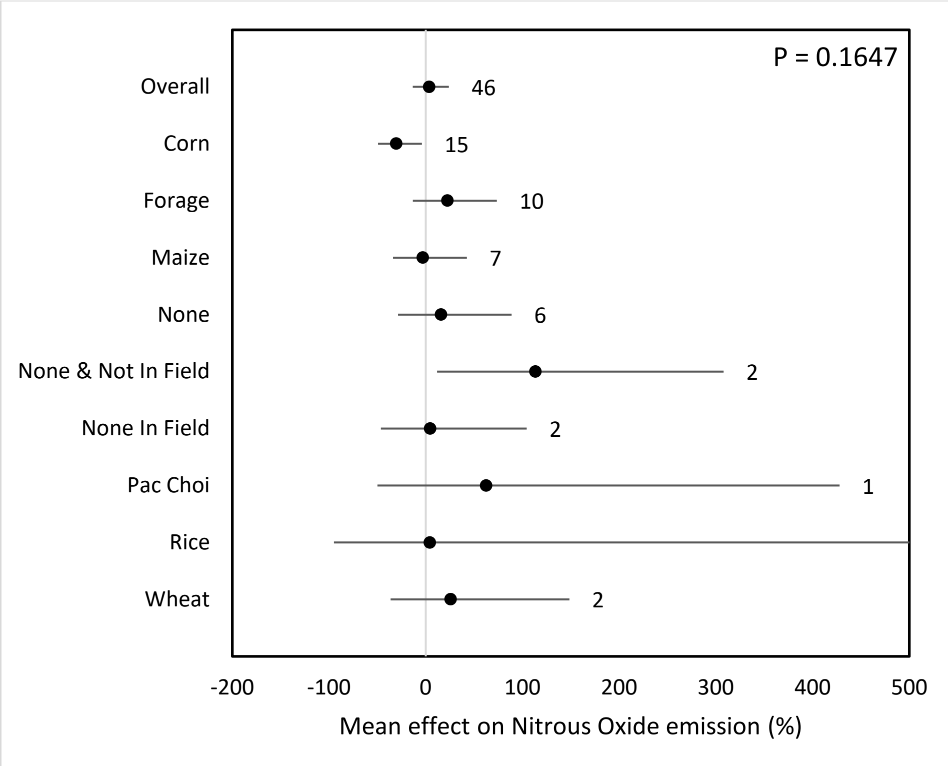

Figure 8. Comparison of nitrous oxide emissions from swine manure compared to synthetic N fertilizer for a range of crop production systems distributed around the world.

Water quality impacts from manure application is dependent upon a number of factors beyond the application of manure to the soil. Shober and Sims (2007) proposed the use of a phosphorus source index to determine the risk when manures are surface applied. This type of tool is useful because manure sources and fertilizers vary widely in their P solubility and as such would have different potentials of P loss from the application site.

Water quality impacts are related to the application amounts and when recommended rated followed, there has been no reported effect of swine manure application on NO_3^-N or P loads in drainage water (Salmerón et al., 2010). Potential N loses of swine manure were related to application time and excess rainfall in the spring after application (Woli et al., 2012). Tabbara (2003) observed that under a rainfall simulation study that swine manure produced less P less than fertilizer after incorporation. He recommended that incorporating manure in areas with intensive rainfall, recent tillage, and minimal surface residue would reduce the potential contamination of water. Impacts on water quality can be avoided with the use of management practices that ensure the proper application rate to meet crop requirements.

Effect of swine manure on soil properties

A recent meta-analysis by Zhang et al. (2017) based on 60 studies in China showed that fertilizers in combination with manure increased soil microbial biomass carbon while fertilizer alone decreased soil microbial biomass nitrogen compared to the control with no fertilizer added. This in contrast to the observations from Weyers et al. (2013) who found that tillage practices had the greater effect on soil microbial biomass compared to nutrient source. In many of the studies, we found in the course of the literature review, the study period was too short to determine if swine manure management had a positive effect and many of the factors that influence the response, e.g., tillage, weather conditions, time of application, are not well-documented.

In general, we can glean from the published literature that the addition of manures into the soil will have a positive impact on soil properties related to organic matter, aggregate stability, and nutrient cycling. The magnitude of these effects are influenced by the year-to-year variation in the weather during the study (Porter et al., 2003).

One of the positive responses of organic amendments is on the micronutrient concentrations in the soil. Swine manure application increased B, Cu, Mo, and Zn availability in the soil compared to commercial fertilizer (Richards et al., 2011).

Discussion

Across the studies compiled in this analysis with sufficient information to conduct a meta-analysis, application of swine manure did not significantly affect crop yield compared to commercial fertilizer. There are instances in which swine manure has shown a large impact on crop yield because of improved nutrient availability during the growing season and other instances in which there is no difference between swine manure and commercial fertilizer (e.g., Kwaw-Mensah and Al-Kaisi, 2006). Optimization of the impact of swine manure nutrients on production and environmental quality is increased when application rates are determined through soil tests (Ball Coelho et al., 2005). The value of the meta-analysis is the ability to subdivide the data into a number of categories and subcategories to further determine the potential affects. Overall, the effect of swine manure does not have a negative effect on crop yield; however, there may be differences in the response by how the manure is applied, the soil type, the crop, and climate of the production region. For example, surface application of manure exhibited a significant negative effect on yield attributed to the nutrients not being available to the crop or potential volatilization of the nitrogen. There is a wide variation in the response of crop yields to manure among the studies with the response being lack of the response related to factors affecting yield, e.g., rainfall, temperature, etc, that are independent of nutrient source. There are differences among crops and soil types in the response with no effect on corn, wheat, or forages and positive effects on lighter textured soils than on heavier textured soils. It is interesting that differences in response among countries with a positive effect occurring in the United States. Pork producers in the United States are taking advantage of this nutrient source for their crop production systems and using the manure source as an effective nutrient source in their crop production systems.

There is a contrast in the response of soils to commercial fertilizer and conventional cropping systems compared to manure applications. Zhou et al. (2017) found that long-term inorganic fertilization decreased aggregate stability, decreased soil macroporosity, but did not change soil organic matter content or the soil water holding capacity. However, the addition of swine manure into commercial fertilizers increased soil structure. They found swine manure increased soil organic matter, labile organic matter, CEC, total N, available P, decreased pH, and decreased bulk density. These are all positive attributes for soil health. The increase in soil organic matter is needed because recent observations from central Iowa have revealed that conventional corn-soybean rotations are losing an average of a 1000 lbs C per acre per year (Dold et al., 2016). There is a positive aspect of swine manure application to meet crop needs. For example, Park et al. (2010) found swine manure application to irrigated corn in the Oklahoma increased crop yields and economic returns compared to the use of anhydrous ammonia. A study by Nyiraneza et al. (2010) found in cattle manure applied to a silage corn-cereal cropping system the application of manure increased the nitrogen supply to the crops. The similar response would be expected to occur with application of swine manure and an increase in soil organic matter. One of the limitations to conducting a robust meta-analysis on the soil health effects of swine manure is that the majority of the studies are of insufficient length to observe changes in soil properties or that was not the focus of the study.

To take advantage of the positive effects of swine manure for crop yield, soil properties, and water quality requires that swine manure applications be at the proper rate to meet crop requirements. Avoiding surface application was found to reduce the potential for water quality impacts from manure application. There is a continual development of technology where manure is applied at different rates across a field. For example, Mallarino and Wittry (20100 found that variable rate technology increased yields in areas of the field with low soil-test P levels and overall decreased the amount of manure applied to areas of the field with high soil-test P levels and reduced the variability of soil-test P across fields. The positive aspects of manure is the continual improvement in the soil which aids in the cycling of nutrients.

Meta-analysis has a tool presented a powerful technique for being able to evaluate the effect of different subcategories of information about a particular practice. In this study, we used four major categories of information and a number of subcategories to evaluate the potential differences in the response of swine manure compared to commercial fertilizer. These results shown in different figures illustrate the power of this technique but also the potential of continuing the add information into this analysis.

A note of caution in all of these studies and their interpretation, crop yield differences in a given study may not be directly related to the source of fertilizer and studies utilizing swine manure may not have been of sufficient duration to evaluate changes in soil properties. Evaluation of specific studies requires caution in terms of extracting information and gleaning from the study the exact measurements made and more importantly the prior conditions of the experimental site.

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