Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2020.124019

Effect of animal manure, crop type, climate zone, and soil attributes on greenhouse gas emissions from agricultural soils—A global meta-analysis

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Abstract

Agricultural lands, because of their large area and exhaustive management practices, have a substantial impact on the earth's carbon and nitrogen cycles, and agricultural activities consequence in discharges of greenhouse gases (GHGs). Globally, greenhouse gases (GHGs) emissions especially carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from the agricultural sector are increasing due to anthropogenic activities. Although, the application of animal manure to the agricultural soil as an organic fertilizer not only improves soil health and agricultural production but also has a significant impact on GHGs emissions. But the extent of GHGs emissions in response to manure application under diverse environmental conditions is still uncertain. Here, a meta-analysis study was conducted using field data (48 peer-reviewed publications) published from 1989 to 2019. Meta-analysis results showed that poultry manure considerably increased CO_2, CH_4, and N_2O emissions than pig and cattle manure. Furthermore, application of poultry manure also increased ($\overline{lnRR}$ =0.141, 95% CI =0.526-0.356) GWP (global warming potential) of total soil GHGs emissions. While, the significant effects on CO_2, CH_4, and N_2O emissions also occurred at manure rate > 320 kg N ha^{-1} and > 60% water filled pore space. The maximum concentrations of CO_2, CH_4, and N_2O emissions were observed in neutral soils ($\overline{lnRR}$ =3.375, 95% CI =3.323-3.428), alkaline soils ($\overline{lnRR}$ =1.468, 95% CI =1.403-1.532), and acidic soils ($\overline{lnRR}$ =2.355, 95% CI =2.390-2.400), respectively. Soil texture, climate zone and crop type were also found significant factors to increase GHGs emissions. Thus, this meta-analysis revealed a knowledge gap concerning the consequences of animal manure application and rate, climate zone, and physicochemical properties of soil on GHGs emissions from agricultural soils.

Keywords: meta-analysis, animal manure, GHGs emissions, soil attributes, crop type

1. Introduction

Emissions of GHGs like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from the terrestrial environment have been renowned as the main contributor to global warming (Ren et al., 2017). Agriculture was seen as the first evidence of increased human-made greenhouse gas emissions into the atmosphere (Paustian et al., 2016). It contributes almost 10 to 14% of total global GHG emissions, which includes 50–60% of N_2O and CH_4 that are directly linked with agricultural soil and its inputs like manure application and synthetic fertilizers (Shakoor et al., 2020b).

Application of animal manure to agricultural lands as organic fertilizer improved crop productivity, soil fertility and boosts organic carbon (OC) reserves in the soil, but also affects GHGs emissions (Zhou et al., 2017b). Globally, 7.0 billion tons of animal manure is used annually for agricultural lands (Thangarajan et al., 2013). The total quantity of produced manure, for each type of animal, can be calculated as an average between the quantity of manure produced per animal, and the number of animals (IPCC, 2006). Animal manure contributes up to 37% of global GHGs emissions (Vac et al., 2013). Soil texture (Oertel, et al., 2016), soil pH (Wu et al., 2018), water filled pore space (WFPS) (Säurich, et al., 2019), crop type (Severin, et al., 2015) and crop duration (Tongwane et al., 2016) have also been documented important factors of CO_2, CH_4 and N_2O emissions from the terrestrial environment.

Atmospheric CO_2 plays an important role in the global carbon cycle in the atmospheric system. Human activities such as the burning of fossil fuel and deforestation significantly increased the CO_2 concentration in the atmosphere from around 280 to 387 ppm (parts per million) and, recently, have even exceeded 400 ppm (parts per million). This CO_2 concentration is projected to increase considerably by 2100 (Goldman et al., 2017). In the earth system, this global carbon cycle contributes to a large amount of carbon, which is connected through the exchange of carbon fluxes (Ciais et al., 2013). The terrestrial environment is intimately linked to atmospheric CO_2 levels by the sequestration of carbon in the soil and biomass, which is emitted by the decomposition of organic manure (Drigo et al., 2008). In a research study, it was found that the application of animal manure potentially enhances the carbon content in the soil and then converts into a net CO_2 sink (Gattinger et al., 2012).

Atmospheric CH_4 has received a lot of attention recently, simply because it is a very important and long-lasting GHG also contributing to global warming (Wang et al., 2016), which exhibits relative global warming potential of 265 (Weller et al., 2015), 34 times higher than that of CO_2 present in the atmospheric environment, considered on an equivalent mass basis. The total concentration of CH_4 in the atmosphere is approximately 1,780 ppb, which is higher than pre-industrial levels. Agricultural lands act as anthropogenic sources and contribute about 50% of the total flux of CH_4 emissions into the atmosphere (Wang et al., 2016). The application of animal manure and synthetic fertilizer can be considered the best predictor of CH_4 emission from agricultural lands (Shakoor et al., 2020a).

Following CO_2 and CH_4, N_2O is the third most important GHG, contributing up to 6% in global warming. While, N_2O has 298 times more GWP compared to CO_2 and also favors ozone (O_3) destruction (Charles et al., 2017). The emission of N_2O from agricultural sources is considered to be one of the main contributors to the global warming budget. Agricultural lands approximately contribute up to 68% in the atmospheric N_2O emissions (Shakoor et al., 2018). Application of animal manure cannot only enhance soil pH (Whalen et al., 2000) but also improved soil aggregation, porosity as well as hydraulic conductivity (Haynes & Naidu, 1998), which can control different biotic and abiotic processes leading N_2O production in soils (Shakoor et al., 2016). Several studies show the effects of different animal manures and synthetic fertilizers on N_2O emission from agricultural lands, indicating, that different manures and dung management practices, for example, manure storage, animal houses (Anitha & Bindu, 2016), and application of manure in the field (Ku et al., 2017), causes the emission of N_2O into the atmosphere.

Meta-analysis is a useful technique to quantitatively synthesize, analyze, and then summarize the final results of different studies (Ren et al., 2017). The analytical method suggests a proper statistical analysis to combine and compare the collected results of different studies and to draw general models at different spatial scales, and the outcomes of already published studies are treated as if they are subject to uncertainties of sampling (Freeman et al., 1986). Detailed information about how different animal manures affect GHGs is critical to assessing the potential of manure application to croplands for mitigation the GHGs emissions.

The climate sensitivity of all three GHGs (CO_2, CH_4, and N_2O) emissions is poorly known, which makes it difficult to project how changing manure and/or synthetic fertilizer use and climate will influence radiative forcing and the ozone (O_3) layer. A decent number of research scientists have conducted the meta-analysis about N_2O emissions from soils considering different parameters like animal manure application and rate (Zhou et al., 2017b), urine-derived (López-Aizpún et al., 2020), crop residues (Chen et al., 2013), no-tillage (Zhao et al., 2016), salinization (Zhou et al., 2017a) and climate (Van Kessel et al., 2013). But, a few numbers of meta-analysis studies are available considering the CO_2, CH_4, as well as N_2O emissions simultaneously under the application of animal manures and rates, climate, and soil attributes. So, we conducted a meta-analysis to fulfill this gap.

In this meta-analysis study, we systematically compared the GHGs emissions of the soil under different animal manures, the quantity of manure, climate zone, soil pH, water filled pore space (WFPS), soil texture, crop type, and crop duration. The main objectives of this study were to address the following questions: 1) Do the application and amount of different animal manures affect soil GHGs emissions as compared to control and/or no fertilizer? 2) Which GHG more affected by the application of animal manure and manure rate? 3) Do crop duration and crop species important factors for regulating the GHGs emissions? and finally, 4) How do soil attributes and different climate zones affect soil GHGs emissions?

2. Materials and methods

2.1. Data collection

A systematic literature search approach was followed to collect research articles for meta-analysis. To cover the main objectives of this meta-analysis, a total of 950 peer-reviewed research publications were collected that reported GHGs emissions in agricultural soils following application of animal manures into the search engines of Google Scholar, Scopus, and Web of Science to identify relevant research articles for inclusion in the meta-analysis, to a cut-off date of 31st December 2019. The keywords 'manure' 'animal manure' 'pig' 'swine' 'cattle' 'dairy' 'poultry' 'carbon dioxide or CO_2' 'methane or CH_4' and 'nitrous oxide or N_2O' were used to search the publications.

Peer-reviewed publications selected by using the following criteria: a) experiments who had at least one pair of data (control and treatment) and calculated cumulative CO_2, CH_4, and/or N_2O emission fluxes; b) clearly described experimental method with crop type and duration, and c) physiochemical properties of soil. In total, 48 peer-reviewed publications on manure application were selected published from 1989 to 2019 (Table 1, Data S1). Most research publications reported emission flux in tables that could easily be transferred into the dataset directly. Emission data presented in figures, GetData (version 2.26) Graph Digitizer software (http://www.getdata-graph-digitizer.com/download) was used to extract the data. From each research publication, we extracted the cumulative values (kg ha^{-1}) of all three GHGs emissions in the dataset. For manure application and/or synthetic fertilizer, kg N ha^{-1} unit was used and converted all other units (such as Megagram (Mg N ha^{-1})) into kg N ha^{-1} where it needed. We also collected the means, standard deviations (SD), and sample sizes from treatment and control for each research study. If research publications only presented standard errors (SE), then the SD values were calculated from SE.

Other informations that were used in the dataset included the following: type of manure, amount of manure, soil pH, WFPS, soil texture, crop type, crop duration time, and climate zone. The manure type grouped as pig, cattle, and poultry; amount of manure, grouped as $\leq$ 120 kg N ha^{-1} (low), $\leq$ 320 kg N ha^{-1} (medium) and > 320 kg N ha^{-1} (high) doses as did by Cayuela et al., (2017) ; soil pH, grouped to $\leq$ 6.5 (acidic), 6.6-7.3 (neutral), > 7.3 (alkaline) (Havlin et al., 2013); WFPS grouped as < 30%, 30-60%, > 60%; soil texture was grouped into different categories following the USDA, (1999) (clay, clay loam, loam, sandy, sandy clay loam, sandy loam, silt clay, silt loam, silty clay loam); crop type and crop duration time grouped as barley, fallow, grassland, maize, rice, soybean, sweet corn, wheat and $\leq$ 320 days, 321-725 days, > 725 days, respectively; and climate zone divided into 4 groups as cool temperate, semi-arid, tropical, sub-tropical and warm temperate (Zhou et al., 2017b).

2.2. Meta-analysis

For the meta-analysis, we used a response ratio (*RR*, natural log of the ratio) as the effect size to calculate the effects of manure application on GHGs emission from agricultural soils (Hedges et al., 1999) by using the following equation:

$$RR = \ln(\overline{xt}/\overline{xc}) = \ln(\overline{xt}) - \ln(\overline{xc}) \qquad (1)$$

Where the subscript of $\overline{xt}$ and $\overline{xc}$ represents the mean value of treatment and control, respectively. If the *RR* value is zero, *RR* > 1 and *RR* < 1, its mean that manure treatment had no, positive and negative effect on GHGs emissions, respectively.

The natural logarithm of *RR* (*lnRR*), the effect size, was calculated for each treatment in every trial/experiment (Hedges et al., 1999). The variance (ν) of each *lnRR* for each study was calculated by using the equation (2);

$$\nu = \frac{\mathrm{St}^2}{\mathrm{ntxt}^2} + \frac{\mathrm{Sc}^2}{\mathrm{ncxc}^2} \qquad (2)$$

where St and Sc are the standard deviation of a treatment and reference control, and nt and nc are the number of samples in a treatment and reference control, respectively. For each research study, the weighting factor (*ω*) was measured as the inverse of the pooled variance $(1/\nu)$.

The mean effect sizes were calculated as;

$$\overline{lnRR} = \frac{\sum(lnRRi \times \omega i)}{\sum \omega i} \qquad (3)$$

Where *ωi* and *lnRRi* were the weight and effect size from the i^{th} comparison, respectively.

The GWP was also calculated when fluxes for all three GHGs emissions (CO_2, CH_4, and N_2O) were reported in every single study. The IPCC factor was used to calculate the GWP (kg CO_2-eq ha^{-1} yr^{-1}) (IPCC, 2013) in over a 100-year time horizon:

$$\mathrm{GWP} = (\mathrm{CO_2} \times 1) + (\mathrm{N_2O} \times 298) + (\mathrm{CH_4} \times 34) \qquad (4)$$

2.3.Statistical analysis

A random-effects meta-analysis model was used to examine the dataset as early as explained by (Michael et al., 2009). METAWIN 2.1 (Rosenberg et al., 2000) and OpenMEE (Wallace et al., 2017) software were used to calculate the mean effect sizes of the dataset and 95% bootstrapped confidence intervals (CIs) were generated using 4999 iterations. The results were considered significant if the 95% CI of cumulative CO_2, CH_4, and N_2O emissions did not overlap with zero and the randomization tests resulted $P < 0.05$. Statistical results such as total heterogeneity (Q_t) in effect sizes among studies were also calculated using OpenMEE software. The relationship is significant if $P < 0.05$.

3. Results and discussion

3.1. Effects of manure type and manure rate on GHGs emissions

Of the total, 324 and 242 paired-wise observations were selected for manure type and manure rate, respectively. Three types of manure (pig (n=115), cattle (n=101) and poultry (n=28)) and three levels of manure rate (≤ 120 kg N ha^{-1} (n=71), ≤ 320 kg N ha^{-1} (n=134) and > 320 kg N ha^{-1} (n=37)) were chosen to check the effect on GHGs emissions. The application of different manure types and manure rates had significantly positive effects on CO_2, CH_4, and N_2O emissions. Based on meta-analysis results, the overall effect sizes ($\overline{lnRR}$) of manure type and manure rate on CO_2, CH_4, and N_2O emissions were significantly greater than zero (Figure. 1a, 1b and 1c), [but slightly negative effects on CO_2 emission related to manure rate was also observed (Figure. 1a (i))], showing that application of different manure type and manure rate considerably increased CO_2, CH_4 as well as N_2O emissions from the agricultural soil as compared to controls. Manure rate and manure type had a strong effect on CO_2 emission ($\overline{lnRR}$ =0.635, 95% CI =0.01-1.26) and ($\overline{lnRR}$ =0.125, 95% CI =-0.925-1.175), CH_4 emission ($\overline{lnRR}$ =2.31, 95% CI =1.161-3.481) and ($\overline{lnRR}$ =1.495, 95% CI =1.135-1.855), and N_2O emission ($\overline{lnRR}$ =1.123, 95% CI =1.004-1.241) and ($\overline{lnRR}$ =0.862, 95% CI =0.035-1.69), respectively (Table S2). The total heterogeneity (Q_t) was also calculated for both parameters (Table S3). The statistical results showed that the manure rate and manure type had a positive effect on CO_2 emissions.

In manure rate, > 320 kg N ha^{-1} ($\overline{lnRR}$ =0.891, 95% CI =0.84-0.942) had maximum effects on CO_2 emission than other rates while the negative effect was also observed at ≤ 320 kg N ha^{-1} ($\overline{lnRR}$ =-0.512, 95% CI =-0.546--0.479) (Figure. 1a (i), Table (S2)). Alternatively, poultry manure had the notably highest effects on CO_2 emission as compared to pig and cattle manures (Figure. 1a (ii)). On the other hand, a significant effect of manure rate and manure type were also observed on CH_4 emissions (Q_t=6445.801, $P < 0.011$) and (Q_t=389.849, $P < 0.001$) (Table S4), and on N_2O emissions (Q_t=27.879, $P < 0.001$) and (Q_t=757.926, $P < 0.027$) (Table S5), respectively. According to our meta-analysis, the application of poultry manure and manure at the rate of > 320 kg N ha^{-1} also had the maximum effect on CH_4 and N_2O emissions (Figure. 1b and 1c).

Animal manure contains nitrogen (N), phosphorus (P), and other micronutrients that plants need to grow. Farmers can often save money by properly using manure as a fertilizer (Cavalli et al., 2017). On the other hand, the application of animal manure has been a big concern worldwide because manure contributes up to 37% of global GHGs emissions (Vac et al., 2013).

The GHGs emissions from agricultural soils mostly depend on soil characteristics, environmental conditions and type and amount of manure. According to our meta-analysis, results revealed that the application of different animal manure significantly enhanced GHGs emissions (Figure. 1a, 1b and1c). Our meta-analysis showed that poultry manure significantly enhanced the GHGs emissions from the soil than pig and cattle manures. Emission of CO_2 from agricultural soils is mainly emitted through microbial activities. Autotrophic microbial communities significantly increase the decomposition of soil organic matter (SOM) results in increase soil organic carbon (SOC) as well as CO_2 emission (Watts et al., 2011) because CO_2 is mostly emitted from agricultural soil as a result of the soil microbial respiration and plant root respiration (Ray et al., 2020).

The CH_4 emission from croplands mostly due to anaerobic decomposition of organic matter (Praeg et al., 2016). The application of poultry manure significantly enhanced CH_4 emissions from croplands. This might be because of manure application increase soil microbial biomass and also activities. Therefore, manure application provides more oxidizable C content to the methanotrophs under oxygen limiting conditions, which would increase CH_4 emissions (Pathak, 2015).

Poultry manure also significantly increases N_2O emission from croplands mainly due to their easily decomposable SOC relative to other manures (Zhou et al., 2017b). One main reason for high N_2O emission from agricultural soils may be due to high rates of net N mineralization of the poultry manure (Akiyama et al., 2004), which possibly increased nitrification as well as denitrification rates and, subsequently, N_2O production (Hayakawa et al., 2009).

The manure and mineral nitrogen application rates were directly proportional to the GHGs emissions because C, N, phosphorus (P) and potash (K) contents were increased accordingly in the soil. Zhou, et al., (2017b) also conducted a global meta-analysis and proved that poultry manure produces more GHGs emission as compared to other manures (pig and cattle). Maris et al., (2016) had examined the response of GHGs emission using different animal manures and showed that poultry manure increased GHGs emission than pig and cattle mainly due to the higher application rate. Smith et al., (2010) also showed a similar trend in their research study. Because, poultry manure has high C and N contents than pig and cattle manure (Ahn, et al., 2010). Shen, et al., (2015) also proved that poultry manure has more N content than cattle and pig manure. The rate of manure is also a very important factor for getting the maximum production but the amount of manure is directly proportional to GHGs emissions. De Rosa et al. (2018) conducted research study using different animal manures with different rates. They all found that a higher amount of manure significantly affects GHGs emissions which were similar to our findings.

3.2. Water filled pore space (WFPS) and soil pH

Soil pH and WFPS have been recognized as important factors of GHGs emissions (Butterbach-Bahl et al., 2013). Figure 2 shows the effect sizes of WFPS and soil pH on GHGs emissions from agricultural soils after manure application. From the total, 260 and 408 observations were chosen for WFPS and soil pH, respectively. WFPS was classified as < 30% (n=53), 30-60% (n=144) and > 60% (n=63), on the other hand, soil pH was also categorized into three classes like ≤ 6.5 (n=189), 6.6-7.3(n=118) and > 7.3 (n=101).

The present meta-analysis showed that overall effect sizes of WFPS on CO_2 ($\overline{lnRR}$ =0.212, 95% CI =0.102-0.323), CH_4 ($\overline{lnRR}$ =0.841, 95% CI =-0.644-2.326), and N_2O ($\overline{lnRR}$ =0.394, 95% CI =-0.394-0.913) emissions were significantly greater than zero (Table S2), indicating that WFPS significantly enhanced CO_2, CH_4, and N_2O emissions. For CO_2, $\overline{lnRR}$ was positive when WFPS was greater than 30%, showing the positive effects on CO_2 emissions and 30-60% WFPS had more effect than > 60% WFPS (Figure 2a (i)). Otherwise, maximum emissions of CH_4 and N_2O were observed at > 60% WFPS (Figure. 2b (i) and 2c (i)). The maximum emission of CO_2 was observed when WFPS 35-55% (Alluvione et al., 2009) which was in the range of our findings. Our results were also similar to those estimates studied by Sakabe et al. (2015). While N_2O and CH_4 emissions were normally low at WFPS levels ≤ 60%.

The emission of CO_2 increased at < 50% WFPS indicating the microbial processes like mineralization were less affected by low moisture content. At > 70% WFPS values, soil CO_2 emissions were significantly inhibited by lack of available oxygen (Franco-Luesma et al., 2020), making soil conditions that promote denitrification (Rowlings et al., 2010).

Several factors are influencing CH_4 emissions in higher WFPSs. Soil conditions that support methanotrophic rather than a methanogenic activity which was favored by low temperature and the high percentage of WFPS (> 60%) (García-Marco et al., 2014). Another study found that in the anaerobic environmental conditions, a higher amount of SOM would also contribute to the low CH_4 absorption (Sakabe et al., 2015).

Maximum N_2O emissions with increasing the WFPS were frequently reported from different research studies (Ruser et al., 2001). A higher amount of water content significantly improved the denitrification process in soil and maximum activity was observed at a WFPS 70% (Ruser et al., 2006). Another study reported the soil with 90% WFPS had the maximum N_2O emissions. These results show that emissions of N_2O at higher WFPSs were significantly influenced by SOC contents. The greater specific substrate may have preferred the anoxic microsites formation, which is well-known to enhance N_2O emissions (Flessa and Beese, 2000).

The overall effect sizes of soil pH on CO_2 ($\overline{lnRR}$ =1.977, 95% CI =-1.434-5.388), CH_4 ($\overline{lnRR}$ =1.032, 95% CI =0.669-1.396) and N_2O ($\overline{lnRR}$ =0.686, 95% CI =-1.91-3.281) emissions were also significantly > 0 (Table S2), suggested that positive effects on GHGs emissions. The maximum concentrations of CO_2, CH_4, and N_2O emissions were observed in neutral soils (pH = 6.6-7.3), alkaline soils (pH > 7.3) and acidic soils (pH $\leq$ 6.5), respectively (Figure. 2a (ii), 2b (ii) and 2c (ii)). Wu et al., (2019) studied and showed that the maximum emissions of CO_2 were seen in acidic soils because the manure application increases soil pH.

The CO_2 emission increases in acidic soil after manure application because organic manure generally enhances soil pH and consequently promotes the CO_2 solubility and the formation of bicarbonate acid (Rochette and Gregorich, 1998). In acidic soils, the N_2O reductase (N_2OR) activities inhibited which results in the reduction of N_2O to N_2 (Bakken et al., 2012).

Consequently, in acid soils, the application of manure could significantly promote N_2O than N_2 by the denitrification process and consequently enhance N_2O emissions. Another research found that nitrification as well as denitrification processes are mainly affected by soil pH and result in N_2O emissions. Normally, autotrophic nitrifiers prefer neutral and/or slightly alkaline conditions for oxidizing NH_4^+ to NO_3^-, and consequently, the nitrification process is frequently low in acidic soils (Chen et al., 2013).

It would be needed for the anaerobic situation to activate methanogenesis bacteria (Ball, 2013). The best pH value for this situation is ranged from 6.6 to 7.6 and the ideal value would be at 7.2. The growth of these bacteria will be limited and eliminated less than 5 and more than 8.5 (Staley et al., 2011). Biological degradation of SOM is done with anaerobic bacteria and optimal activity was found with pH 7 (Horn et al., 2003). Wang et al., (1993) also studied and reported that the maximum CH_4 emissions were observed in the pH range of 6.9 to 7.1 (neutral soil pH) because methanogenic is acid sensitive. Normally, the best pH for methanogenesis is considered to be approximate 7.0. Thus, our results were similar to the previous findings of the researchers. According to our meta-analysis results, total heterogeneity showed that WFPS and soil pH had a significantly positive effect on GHGs emissions (Table S3, S4, and S5).

3.3. Soil texture

Effect sizes of soil texture on CO_2, CH_4 and N_2O emissions after manure application are shown in figure 3. According to our meta-analysis dataset, all soils were classified into different textural classes e.g. clay, clay loam, loam, sandy loam, sandy, sandy clay loam, silt loam, slit clay and silty clay loam.

The overall effect sizes of soil texture on CO_2 ($\overline{lnRR}$ =0.285, 95% CI =0.143-0.427), CH_4 ($\overline{lnRR}$ =0.706, 95% CI =0.342-1.069) and N_2O ($\overline{lnRR}$ =0.946, 95% CI =-0.004-1.897) emissions were significantly positive (Table S2), revealing that soil texture had a very strong effect on GHGs emissions from the terrestrial environment. All textural classes showed significantly positive response to CO_2 emission and maximum emission of CO_2 was observed in silt loam soil (Figure 3a). On the other hand, all textural classes also gave a considerably positive response to CH_4 and N_2O (except loamy soil) emissions. The highest concentration of CH_4 and N_2O emissions were found in silty clay loam and sandy loam soils, respectively (Figure 3b and 3c). The total heterogeneity (Q_t) was also suggested that soil texture had a positive effect on GHGs emissions (Table S3, S4, and S5).

The terrestrial environment serves as a source and sinks for GHGs emissions and soil attributes, in particular, the soil textural classes play a critical role in GHGs emissions (Oertel et al., 2016). Maximum emissions of CO_2 were observed in fine-textured soils compared to coarse-textured soils (Dilustro et al., 2005) which were similar to our results. The mineralization process depends on the bio-availability of organic matter contents. Soils with high clay contents significantly decreased CO_2 emissions because the high capacity of the clay fraction decreased mineralization process (Jäger et al., 2011).

Meta-analysis results show that maximum CH_4 emissions were emitted from fine-textured soils after manure application. Fine-textured soils have maximum water holding capacity (USDA, 2008), which alternatively produce anaerobic conditions in the soil. Under anaerobic terrestrial environmental conditions, biological decomposition of the organic material by methanogens emits a significant amount of CH_4 from agricultural soils (Lu, 2011). However, soils with fine pores support the emission of CH_4 under anaerobic conditions (Dutaur and Verchot, 2007). Chen et al., (2013) conducted a meta-analysis and showed that sandy loam soils were produced maximum N_2O emissions. Another research study also reported that sandy loam soil emitted higher N_2O (Manzali-D, 1994).

Soil texture significantly controls the emissions of N_2O through moderating the soil oxygen availability because soil texture has an important impact on the size as well as the distribution of soil pores (Corre et al., 1999). In coarse-textured soils, the nitrification process is the main factor of N_2O emissions (Zhou et al., 2014). Moreover, manure application to agricultural soils provides a sufficient amount of C substrate that can stimulate the denitrification process and consequently enhance N_2O emissions after manure application.

3.4. Crop duration and type

The crop species and study duration also played an important role in the differences in GHGs emissions (Huang et al., 2018). Different crop species like barley, grassland, maize, rice, soybean, sweet corn, wheat, and the fallow period between crops were chosen for meta-analysis, while, the study duration was categorized as ≤ 320 days, 321-725 days, > 725 days (Figure. 4). In this meta-analysis, the overall effect sizes of crop duration and crop type on CO_2, CH_4 and N_2O emissions were $\overline{lnRR}$ =0.517, 95% CI =0.226-0.807 and $\overline{lnRR}$ =1.138, 95% CI =-0.445-3.00, $\overline{lnRR}$ =0.876, 95% CI =-0.141-1.893 and $\overline{lnRR}$ =0.919, 95% CI =0.336-1.502 and $\overline{lnRR}$ =0.645, 95% CI =-0.271-1.561 and $\overline{lnRR}$ =1.097, 95% CI =-0.547-2.741, respectively (Table S2).

Based on the results of meta-analysis, the overall effect size for both crop duration and type was significantly greater than zero, presenting that both parameters had positive effects on CO_2,

CH_4 and N_2O emissions. Crop duration is also a very important factor in controlling GHGs emissions. Crops that having > 321 days had more CO_2 and N_2O emissions (Figure. 4a (i) and 4c (i)). While, a higher concentration of CH_4 was observed when crop duration was ≤ 320 days (Figure. 4b (i)). Our meta-analysis findings were similar to previous research study (Leytem et al., 2019). According to our meta-analysis, barley produced maximum emission of CO_2 (Figure. 4a (ii)) which was similar to Gan et al., (2012) research study. Smith et al., (2019) also studied and reported that barley, which normally requires less manure and/or synthetic fertilizer than other cereals crops, have greater CO_2 emissions per unit production.

The CO_2 emission was produced through microbial respiration after manure application in the agricultural soils (Li et al., 2016). The effects of the heterotrophic microbial community on SOM decomposition significantly increase CO_2 emissions (Bore et al., 2017). Manure application to the cereal crops is capable of stimulating the organic C pool and, in turn, increases CO_2 emissions (Triberti et al., 2008). The decomposition of SOM significantly increased the C mineralization process and consequently increased CO_2 emissions from croplands (Hossain et al., 2017). Terhoeven-Urselmans et al., (2009) studied and assessed that the C mineralization process significantly increased CO_2 emissions from barley crop after manure application.

The maximum concentration of CH_4 was observed in the fallow and rice crop (Figure. 4b (ii)). Rice paddies are considered among the main sources of man-caused CH_4 emission, contributing up to 6% to 20% of the total anthropogenic CH_4 release to the atmosphere (Wang et al., 2017). Wu et al., (2019) also studied and found that rice paddies are significant source of CH_4 emissions. The CH_4 in rice fields is emitted through microbes that respire CO_2, similar humans respire oxygen. The CH_4 emissions from rice paddies depend on the availability of SOC content and anaerobic conditions (Tariq et al., 2017). Continuous flooding in rice paddies significantly affects the microbial activities in the terrestrial environment (Gebremichael et al., 2017) and increases anaerobic conditions. This process significantly affects the decomposition rate of SOM and ultimately alters the CH_4 emissions. Different researchers also studied and explained that CH_4 emission produced as a result of decomposition of SOM by microbial activates in the absence of oxygen (Conrad, 2009). Under anaerobic conditions, flooded rice paddies are considered one of the most important anthropogenic sources of CH_4 emissions (Hurkuck et al., 2012).

In this meta-analysis, grasslands have been found as a significant source of N_2O emissions (Figure. 4c (ii)). According to Rafique et al. (2011) research study that approximately 28% of global N_2O was emitted from grasslands. Van Beek et al. (2010) also found similar findings. Maize crop didn't show any significant positive effects on all three GHGs emissions while it showed significantly negative effects on N_2O emissions (Figure. 4c (ii)). Microbial nitrification, nitrifier-denitrification (Xu et al., 2017), respiration, and denitrification are the most important processes affecting the N_2O emission from the terrestrial environment (Case et al., 2015). Intensively managed grasslands are considered the main source of N_2O emissions contributing for almost 10% of the global N_2O emissions (He et al., 2020) and this is mainly attributed to higher manure application as well as animal excreta deposition on grassland surface (Dangal et al., 2019). Application of manure in grassland influences soil biochemical conditions and increases microbial activities which significantly affects the nitrification as well as denitrification process and ultimately changes N_2O emissions (Schirmann et al., 2020). The GHGs emissions are strongly affected by the amount as well as properties of manure added to the crops.

According to our meta-analysis results, total heterogeneity also showed that crop duration (Q_t=84.736 with $P < 0.001$ for CO_2, Q_t=8006.292 with $P < 0.001$ for CH_4 and Q_t=3522.244 with

$P < 0.001$ for N_2O emissions) and crop type (Q_t=31780.765 with $P < 0.001$ for CO_2, Q_t=1443.669 with $P < 0.001$ for CH_4 and Q_t=18495.592 with $P < 0.001$ for N_2O emissions) had significantly positive effect on GHGs emissions (Table S3, S4 and S5).

3.5. Climate zone

Figure 5 shows the effect sizes of climate zones on CO_2, CH_4, and N_2O emissions. Climate zones were divided into warm temperate (n=134), cool temperate (n=132), tropical (n=29), sub-tropical (n=131) and semi-arid region (n=4). The overall effect sizes of climate zones were ($\overline{lnRR}$ =0.345, 95% CI =0.218-0.471), ($\overline{lnRR}$ =1.65, 95% CI =-0.302-3.602) and ($\overline{lnRR}$ =0.506, 95% CI =-0.273-1.285) for CO_2, CH_4 and N_2O emissions, respectively (Table S2).

Climate zones had shown significantly positive effects on CO_2, CH_4, and N_2O emissions because the overall effect sizes of climate zones were significantly great than 0. According to our meta-analysis results, tropical and sub-tropical regions emitted more CO_2 and N_2O but on the other hand, the higher concentration of CH_4 was found in cool temperate zone (Figure. 5). Van der Werf et al. (2009) found that the maximum concentration of CO_2 is emitted from the tropical zone.

Agricultural soils contain large concentrations of organic C, reaching approximately 1,500 petagrams (Pg) (at 1 m depth) (Paustian et al., 2016) and tropical environment provides favorable conditions to microbial communities for the decomposition of organic C, ultimately increase the CO_2 emissions. Globally, the average temperature is expected to rise (1.5 to 3.9 ºC) near the end of 21st century (IPCC, 2014), so, tropical soils could cause roughly a 9% increase in CO_2 emissions this century (Nottingham et al., 2019).

Different research studies were found that higher N_2O emission emitted from the warm temperate zone (Luo et al., 2013) due to microbial activities (Pärn et al., 2018) but this meta-analysis study revealed that sub-tropical and cool temperate zones produced higher N_2O concentration than other regions (Figure. 5c). Welti et al. (2017) also found the higher N_2O emissions from agricultural soils under sub-tropical zones. The sensitivity of climatic conditions of N_2O emission is not well-known, so, it is difficult to project how manure application and climatic conditions will impact the N_2O emission (Griffis et al., 2017). Therefore, there is future research is needed to conduct for better understating how climate zone effects GHGs emissions after manure application. The tropical and sub-tropical climate zones may favor microbial nitrification as well as denitrification processes (Barnard et al., 2005) that are directly linked with CO_2 and N_2O emissions (Xu et al., 2012). Fangueiro et al. (2008) studied and reported that cool temperate also significantly increase N_2O emissions from soils. According to Müller et al., (2003), the emission of N_2O was observed between −1.0 °C to 10.0 °C, the maximum N_2O emission was occurred near 0 °C, probably from increasing the activity of N_2O reductase. Cool temperate soils cause waterlog conditions in the terrestrial environment, generating anaerobic conditions that help in the emissions of CH_4 and CO_2 (Jorgenson et al., 2006). Another study also proposed that maximum CH4 emissions are emitted by paddy fields in snowy temperate regions (Naser et al., 2007). The total heterogeneity between-groups were also showed significant positive effects on GHGs emissions (Table S3, S4, and S5).

3.6. Effect of manure application on GWP

With those research studies that simultaneously measured all three GHGs emissions fluxes, manure application positively affected GWP ($\overline{lnRR}$ =0.781, 95% CI =-0.55-2.512) (Figure. 6, Table S2). Meanwhile, the application of poultry and cattle manure to agricultural soils significantly increased GWP, whereas a minor negative effect was observed in pig manure (Figure. 6). However, with the realization that few research studies were reported fluxes of all three GHGs after manure application, these results were likely affected by publication biases, and therefore should be interpreted cautiously. Ren et al., (2019) also obtained coinciding results. GWP is a basic index to calculate the future impacts of GHGs based on their lifetime and radiative forcing (IPCC, 2013).

Agriculture and its related land use contribute to carbon (C) and nitrogen (N) dynamics, affecting the flux of CO_2, CH_4, and N_2O, which represent the GHGs principally linked to agricultural activities. Agricultural soils released a significant amount of GHGs emissions to the atmosphere (He et al., 2017), which estimated for approximately one-fifth of the annual increase in radiative forcing of climate change (Cole et al., 1997). GHGs emissions would increase significantly after animal manure was applied, particularly in croplands (Thers et al., 2020). In 2011, the emissions of GHGs from crops were approximately 5.3 Pg of CO_2eq (FAO, 2014). Agricultural management practices significantly change the GWP (Shang et al., 2011). Although the application of manure significantly increased the annual N_2O and CH_4 emissions, they increased the SOC sequestration in this cropping system through microbial activities, ultimately increased GWP.

4. Limitations and concluding remarks

In this meta-analysis, most of the experiments had been studied in China, Europe and North America. There remains a lack of experimental studies in other continents, like South America, South-East Asia, Africa and Australia. Therefore, long-term experimental research studies are needed with proper manure application rate in these regions to estimate the GHGs emissions. Several research studies had measured GHGs emissions using different animal manures but did not report the summary of statistics that are required for meta-analysis. So, we urge that research scientists must report the proper manure type, complete soil attributes like soil pH, bulk density, soil texture, WFPS, air temperature, proper climate zone, and rainfall, flux type and unit, number of observations and control treatment in their future research studies. This will greatly assist in future meta-analyses which can hopefully provide far greater insights into the range and variability of GHGs emissions than any individual study.

This meta-analysis provided a comprehensive and quantitative synthesis of animal manure, climate zone, and soil attributes effects on GHGs emissions. Evidence presented in this meta-analysis shows that the application of animal manure and N-mineral fertilizer significantly increased CO_2, CH_4 and N_2O emission as compared to control treatment from soils. Moreover, this meta-analysis study revealed that poultry manure had significantly positive effects on CO_2, CH_4, and N_2O emissions from the soil than pig and cattle manures. Moreover, the amount/rate of animal manure and N-mineral fertilization also had strong effects on CO_2, CH_4, and N_2O emissions. The effect of animal manure and N-mineral fertilize on CO_2, CH_4 and N_2O emissions were considerably depended on soil attributes like soil pH, WFPS, soil texture, crop types, and climate zones, indicating that these factors need to be fully considered to optimize the fertilization strategies to reduce the emissions of GHGs. Stimulatory positive effects occurred at the rate of > 60% WFPS, while negative effects were found at the rate of < 30% WFPS. Soil pH and soil texture are very important factors for predicting the GHGs emissions. Hence, this meta-analysis suggests that some experimental strategies, for example, selecting the manure type and proper rate need to be planned correctly to mitigate GHGs emissions from soil. Finally, the application of different types of animal manure in agricultural soils (as shown by our meta-analysis results) can be useful for calibrating and validating computer-based models and also filling the knowledge gaps about GHGs emissions that are derived from agricultural soils.

Acknowledgments

Awais Shakoor would like to express his gratitude for the grant provided by the University of Lleida, Spain. The authors would like to appreciate the valuable comments from the editors and anonymous reviewers to improve the quality of this study

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abagandura, G.O., Chintala, R., Sandhu, S.S., Kumar, S., Schumacher, T.E., 2019. Effects of Biochar and Manure Applications on Soil Carbon Dioxide, Methane, and Nitrous Oxide Fluxes from Two Different Soils. J. Environ. Qual. 0, 0. https://doi.org/10.2134/jeq2018.10.0374

Ahn, H.K., Smith, M.C., Kondrad, S.L., White, J.W., 2010. Evaluation of biogas production potential by dry anaerobic digestion of switchgrass-animal manure mixtures. Appl. Biochem. Biotechnol. 160, 965–975. https://doi.org/10.1007/s12010-009-8624-x

Akiyama, H., McTaggart, I.P., Ball, B.C., Scott, A., 2004. N 2O, NO, and NH 3 emissions from soil after the application of organic fertilizers, urea and water. Water. Air. Soil Pollut. 156, 113–129. https://doi.org/10.1023/B:WATE.0000036800.20599.46

Alemu, A.W., Ominski, K.H., Tenuta, M., Amiro, B.D., Kebreab, E., 2016. Evaluation of greenhouse gas emissions from HOG manure application in a Canadian cow-calf production system using whole-farm models. Anim. Prod. Sci. 56, 1722–1737. https://doi.org/10.1071/AN14994

Alluvione, F., Halvorson, A.D., Del Grosso, S.J., 2009. Nitrogen, Tillage, and Crop Rotation Effects on Carbon Dioxide and Methane Fluxes from Irrigated Cropping Systems. J.

Environ. Qual. 38, 2023–2033. https://doi.org/10.2134/jeq2008.0517

Arnell, N.W., Cannell, M.G.R., Hulme, M., Kovats, R.S., Mitchell, J.F.B., Nicholls, R.J., Parry, M.L., Livermore, M.T.J., White, A., 2002. The consequences of CO2 stabilisation for the impacts of climate change. Clim. Change 53, 413–446. https://doi.org/10.1023/A:1015277014327

Asgedom, H., Tenuta, M., Flaten, D.N., Gao, X., Kebreab, E., 2014. Nitrous oxide emissions from a clay soil receiving granular urea formulations and dairy manure. Agron. J. 106, 732–744. https://doi.org/10.2134/agronj2013.0096

Bakken, L.R., Bergaust, L., Liu, B., Frostegård, Å., 2012. Regulation of denitrification at the cellular level: A clue to the understanding of N2O emissions from soils. Philos. Trans. R. Soc. B Biol. Sci. 367, 1226–1234. https://doi.org/10.1098/rstb.2011.0321

Ball, B.C., 2013. Soil structure and greenhouse gas emissions: A synthesis of 20 years of experimentation. Eur. J. Soil Sci. 64, 357–373. https://doi.org/10.1111/ejss.12013

Ball, B.C., Ball, B.C., McTaggart, I.P., Scott, A., 2004. Mitigation of greenhouse gas emissions from soil under silage production by use of organic manures or slow-release fertilizer. Soil Use Manag. 20, 287–295. https://doi.org/10.1079/sum2004257

Barnard, R., Leadley, P.W., Hungate, B.A., 2005. Global change, nitrification, and denitrification: A review. Global Biogeochem. Cycles 19, 1–13. https://doi.org/10.1029/2004GB002282

Bertora, C., Alluvione, F., Zavattaro, L., van Groenigen, J.W., Velthof, G., Grignani, C., 2008. Pig slurry treatment modifies slurry composition, N2O, and CO2 emissions after soil incorporation. Soil Biol. Biochem. 40, 1999–2006. https://doi.org/10.1016/j.soilbio.2008.03.021

Bourdin, F., Sakrabani, R., Kibblewhite, M.G., Lanigan, G.J., 2014. Effect of slurry dry matter content, application technique and timing on emissions of ammonia and greenhouse gas from cattle slurry applied to grassland soils in Ireland. Agric. Ecosyst. Environ. 188, 122–133. https://doi.org/10.1016/j.agee.2014.02.025

Bore, E., Apostel, C., Halicki, S., Kuzyakov, Y., Dippold, M.A., 2017. Soil microorganisms can overcome respiration inhibition by coupling intra- and extracellular metabolism: 13C metabolic tracing reveals the mechanisms. ISME J. 1–11. https://doi.org/10.1038/ismej.2017.3

Brennan, R.B., Healy, M.G., Fenton, O., Lanigan, G.J., 2015. The effect of chemical amendments used for phosphorus abatement on greenhouse gas and ammonia emissions from dairy cattle slurry: Synergies and pollution swapping. PLoS One 10, 1–20. https://doi.org/10.1371/journal.pone.0111965

Butterbach-Bahl, K., Baggs, E.M., Dannenmann, M., Kiese, R., Zechmeister-Boltenstern, S., 2013. Nitrous oxide emissions from soils: How well do we understand the processes and their controls? Philos. Trans. R. Soc. B Biol. Sci. 368. https://doi.org/10.1098/rstb.2013.0122

Case, S.D.C., McNamara, N.P., Reay, D.S., Stott, A.W., Grant, H.K., Whitaker, J., 2015. Biochar suppresses N2O emissions while maintaining N availability in a sandy loam soil. Soil Biol. Biochem. 81, 178–185. https://doi.org/10.1016/j.soilbio.2014.11.012

Cayuela, M.L., Aguilera, E., Sanz-Cobena, A., Adams, D.C., Abalos, D., Barton, L., Ryals, R., Silver, W.L., Alfaro, M.A., Pappa, V.A., Smith, P., Garnier, J., Billen, G., Bouwman, L., Bondeau, A., Lassaletta, L., 2017. Direct nitrous oxide emissions in Mediterranean climate cropping systems: Emission factors based on a meta-analysis of available measurement data. Agric. Ecosyst. Environ. 238, 25–35. https://doi.org/10.1016/j.agee.2016.10.006

Chadwick, D.R., Pain, B.F., Brookman, S.K.E., 2000. Nitrous oxide and methane emissions following application of animal manures to grassland. J. Environ. Qual. 29, 277–287. https://doi.org/10.2134/jeq2000.00472425002900010035x

Chantigny, M.H., Rochette, P., Angers, D.A., Goyer, C., Brin, L.D., Bertrand, N., 2016. Nongrowing season N2O and CO2 emissions — temporal dynamics and influence of soil texture and fall-applied manure. Can. J. Soil Sci. 97, 452–464. https://doi.org/10.1139/cjss-2016-0110

Charles, A., Rochette, P., Whalen, J.K., Angers, D.A., Chantigny, M.H., Bertrand, N., 2017. Global nitrous oxide emission factors from agricultural soils after addition of organic amendments: A meta-analysis. Agric. Ecosyst. Environ. 236, 88–98. https://doi.org/10.1016/j.agee.2016.11.021

Chen, H., Li, X., Hu, F., Shi, W., 2013. Soil nitrous oxide emissions following crop residue addition: A meta-analysis. Glob. Chang. Biol. 19, 2956–2964. https://doi.org/10.1111/gcb.12274

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., Chhabra, a, DeFries, R., Galloway, J., Heimann, M., Jones, C., Quéré, C. Le, Myneni, R.B., Piao, S., Thornton, P., 2013. Carbon and Other Biogeochemical Cycles, Climate Change 2013 - The Physical Science Basis. https://doi.org/10.1017/CBO9781107415324.015

Cole, C. V., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., Mosier, A., Paustian, K., Rosenberg, N., Sampson, N., Sauerbeck, D., Zhao, Q., 1997. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutr. Cycl. Agroecosystems 49, 221–228. https://doi.org/10.1023/A:1009731711346

Collins, H.P., Alva, A.K., Streubel, J.D., Fransen, S.F., Frear, C., Chen, S., Kruger, C., Granatstein, D., 2011. Greenhouse gas emissions from an irrigated silt loam soil amended with anaerobically digested dairy manure. Soil Sci. Soc. Am. J. 75, 2206–2216. https://doi.org/10.2136/sssaj2010.0360

Conrad, R., 2009. The global methane cycle: Recent advances in understanding the microbial processes involved. Environ. Microbiol. Rep. 1, 285–292. https://doi.org/10.1111/j.1758-2229.2009.00038.x

Corre, M.D., Pennock, D.J., Van Kessel, C., Elliott, D.K., 1999. Estimation of annual nitrous oxide emissions from a transitional grassland-forest region in Saskatchewan, Canada. Biogeochemistry 44, 29–49. https://doi.org/10.1023/A:1006025907180

Cote, D., Ndayegamiye, A., 1989. EFFECT OF LONG-TERM PIG SLTJRRY AND SOLID CATTLE MANURE APPLI. CATION ON SOIL CHENIICAL AND BIOLOGICAL PROPERTIES. Can. J. Soil Sci. 69, 39–47.

Crombie, K., Mašek, O., Sohi, S.P., Brownsort, P., Cross, A., 2013. The effect of pyrolysis conditions on biochar stability as determined by three methods. GCB Bioenergy 5, 122–131. https://doi.org/10.1111/gcbb.12030

Dambreville, C., Morvan, T., Germon, J.C., 2008. N2O emission in maize-crops fertilized with pig slurry, matured pig manure or ammonium nitrate in Brittany. Agric. Ecosyst. Environ. 123, 201–210. https://doi.org/10.1016/j.agee.2007.06.001

Dangal, S.R.S., Tian, H., Xu, R., Chang, J., Canadell, J.G., Ciais, P., Pan, S., Yang, J., Zhang, B., 2019. Global Nitrous Oxide Emissions From Pasturelands and Rangelands: Magnitude, Spatiotemporal Patterns, and Attribution. Global Biogeochem. Cycles 33, 200–222. https://doi.org/10.1029/2018GB006091

Das, S., Adhya, T.K., 2014. Effect of combine application of organic manure and inorganic fertilizer on methane and nitrous oxide emissions from a tropical flooded soil planted to rice. Geoderma 213, 185–192. https://doi.org/10.1016/j.geoderma.2013.08.011

Davidson, E.A., 2009. to atmospheric nitrous oxide since 1860. Nat. Geosci. 2, 659–662. https://doi.org/10.1038/ngeo608

De Rosa, D., Rowlings, D.W., Biala, J., Scheer, C., Basso, B., Grace, P.R., 2018. N2O and CO2 emissions following repeated application of organic and mineral N fertiliser from a vegetable crop rotation. Sci. Total Environ. 637–638, 813–824. https://doi.org/10.1016/j.scitotenv.2018.05.046

Dendooven, L., Bonhomme, E., Merckx, R., Vlassak, K., 1998. N dynamics and sources of N2O production following pig slurry application to a loamy soil. Biol. Fertil. Soils 26, 224–228. https://doi.org/10.1007/s003740050371

Dilustro, J.J., Collins, B., Duncan, L., Crawford, C., 2005. Moisture and soil texture effects on soil CO2 efflux components in southeastern mixed pine forests. For. Ecol. Manage. 204, 87–97. https://doi.org/10.1016/j.foreco.2004.09.001

Dinuccio, E., Berg, W., Balsari, P., 2011. Effects of mechanical separation on GHG and ammonia emissions from cattle slurry under winter conditions. Anim. Feed Sci. Technol. 166–167, 532–538. https://doi.org/10.1016/j.anifeedsci.2011.04.037

Dobbie, K.E., Smith, K.A., 2001. The effects of temperature, water-filled pore space and land use on N2O emissions from an imperfectly drained gleysol. Eur. J. Soil Sci. 52, 667–673. https://doi.org/10.1046/j.1365-2389.2001.00395.x

Drigo, B., Kowalchuk, G.A., Van Veen, J.A., 2008. Climate change goes underground: Effects of elevated atmospheric CO 2 on microbial community structure and activities in the rhizosphere. Biol. Fertil. Soils 44, 667–679. https://doi.org/10.1007/s00374-008-0277-3

Dutaur, L., Verchot, L. V., 2007. A global inventory of the soil CH4 sink. Global Biogeochem. Cycles 21, 1–9. https://doi.org/10.1029/2006GB002734

Fangueiro, D., Senbayran, M., Trindade, H., Chadwick, D., 2008. Cattle slurry treatment by screw press separation and chemically enhanced settling: Effect on greenhouse gas emissions after land spreading and grass yield. Bioresour. Technol. 99, 7132–7142. https://doi.org/10.1016/j.biortech.2007.12.069

FAO, 2014. Agriculture , Forestry and Other Land Use Emissions by Sources and Removals by Sinks.

Flessa, H., Beese, F., 2000. Laboratory Estimates of Trace Gas Emissions following Surface Application and Injection of Cattle Slurry. J. Environ. Qual. 29, 262–268. https://doi.org/10.2134/jeq2000.00472425002900010033x

Franco-Luesma, S., Cavero, J., Plaza-Bonilla, D., Cantero-Martínez, C., Arrúe, J.L., Álvaro-Fuentes, J., 2020. Tillage and irrigation system effects on soil carbon dioxide (CO2) and methane (CH4) emissions in a maize monoculture under Mediterranean conditions. Soil Tillage Res. 196, 104488. https://doi.org/10.1016/j.still.2019.104488

Freeman, P.R., Hedges, L. V., Olkin, I., 1986. Statistical Methods for Meta-Analysis. Biometrics 42, 454. https://doi.org/10.2307/2531069

Gan, Y., Liang, C., May, W., Malhi, S.S., Niu, J., Wang, X., 2012. Carbon footprint of spring barley in relation to preceding oilseeds and N fertilization. Int. J. Life Cycle Assess. 17, 635–645. https://doi.org/10.1007/s11367-012-0383-1

Gao, X., Tenuta, M., Buckley, K.E., Zvomuya, F., Ominski, K., 2014. Greenhouse gas emissions from pig slurry applied to forage legumes on a loamy sand soil in south central Manitoba.

Can. J. Soil Sci. 94, 149–155. https://doi.org/10.4141/CJSS2013-117

García-Marco, S., Ravella, S.R., Chadwick, D., Vallejo, A., Gregory, A.S., Cárdenas, L.M., 2014. Ranking factors affecting emissions of GHG from incubated agricultural soils. Eur. J. Soil Sci. 65, 573–583. https://doi.org/10.1111/ejss.12143

Gattinger, A., Muller, A., Haeni, M., Skinner, C., Fliessbach, A., Buchmann, N., Mäder, P., Stolze, M., Smith, P., Scialabba, N.E.H., Niggli, U., 2012. Enhanced top soil carbon stocks under organic farming. Proc. Natl. Acad. Sci. U. S. A. 109, 18226–18231. https://doi.org/10.1073/pnas.1209429109

Gebremichael, A.W., Osborne, B., Orr, P., 2017. Flooding-related increases in CO2 and N2O emissions from a temperate coastal grassland ecosystem. Biogeosciences 14, 2611–2626. https://doi.org/10.5194/bg-14-2611-2017

Goldman, J.A.L., Bender, M.L., Morel, F.M.M., 2017. The effects of pH and p CO 2 on photosynthesis and respiration in the diatom Thalassiosira weissflogii. Photosynth. Res. 132, 83–93. https://doi.org/10.1007/s11120-016-0330-2

Grave, R.A., Nicoloso, R. da S., Cassol, P.C., Aita, C., Corrêa, J.C., Costa, M.D., Fritz, D.D., 2015. Short-term carbon dioxide emission under contrasting soil disturbance levels and organic amendments. Soil Tillage Res. 146, 184–192. https://doi.org/10.1016/j.still.2014.10.010

Griffis, T.J., Chen, Z., Baker, J.M., Wood, J.D., Millet, D.B., Lee, X., Venterea, R.T., Turner, P.A., 2017. Nitrous oxide emissions are enhanced in a warmer and wetter world. Proc. Natl. Acad. Sci. U. S. A. 114, 12081–12085. https://doi.org/10.1073/pnas.1704552114

Havlin, J.L., Beaton, J.D., Tisdale, S.L., Nelson, W.R., Nelson, W.L., 2013. SOIL FERTILITY AND FERTILIZERS, An introduction to Nutrient Management Title Soil Fertility and

Fertilizers 50.

Hayakawa, A., Akiyama, H., Sudo, S., Yagi, K., 2009. N2O and NO emissions from an Andisol field as influenced by pelleted poultry manure. Soil Biol. Biochem. 41, 521–529. https://doi.org/10.1016/j.soilbio.2008.12.011

Haynes, R.J., Naidu, R., 1998. Influence of lime, fertilizer and manure applications on soil organic matter. Nutr. Cycl. Agroecosystems 51, 123–137. https://doi.org/10.1023/A:1009738307837

He, W., Dutta, B., Grant, B.B., Chantigny, M.H., Hunt, D., Bittman, S., Tenuta, M., Worth, D., VanderZaag, A., Desjardins, R.L., Smith, W.N., 2020. Assessing the effects of manure application rate and timing on nitrous oxide emissions from managed grasslands under contrasting climate in Canada. Sci. Total Environ. 716, 135374. https://doi.org/10.1016/j.scitotenv.2019.135374

He, Y., Zhou, X., Jiang, L., Li, M., Du, Z., Zhou, G., Shao, J., Wang, X., Xu, Z., Hosseini Bai, S., Wallace, H., Xu, C., 2017. Effects of biochar application on soil greenhouse gas fluxes: a meta-analysis. GCB Bioenergy 9, 743–755. https://doi.org/10.1111/gcbb.12376

Hedges, L. V., Gurevitch, J., Curtis, P.S., 1999. The meta-analysis of response ratios in experimental ecology. Ecology 80, 1150–1156. https://doi.org/10.1890/0012-9658(1999)080[1150:TMAORR]2.0.CO;2

Hernández, D., Polo, A., Plaza, C., 2013. Long-term effects of pig slurry on barley yield and N use efficiency under semiarid Mediterranean conditions. Eur. J. Agron. 44, 78–86. https://doi.org/10.1016/j.eja.2012.09.001

Herr, C., Mannheim, T., Müller, T., Ruser, R., 2019. Effect of cattle slurry application techniques on N 2 O and NH 3 emissions from a loamy soil . J. Plant Nutr. Soil Sci. 1–16.

https://doi.org/10.1002/jpln.201800376

Horn, M.A., Matthies, C., Küsel, K., Schramm, A., Drake, H.L., 2003. Hydrogenotrophic methanogenesis by moderately acid-tolerant methanogens of a methane-emitting acidic peat. Appl. Environ. Microbiol. 69, 74–83. https://doi.org/10.1128/AEM.69.1.74-83.2003

Hossain, M.B., Rahman, M.M., Biswas, J.C., Miah, M.M.U., Akhter, S., Maniruzzaman, M., Choudhury, A.K., Ahmed, F., Shiragi, M.H.K., Kalra, N., 2017. Carbon mineralization and carbon dioxide emission from organic matter added soil under different temperature regimes. Int. J. Recycl. Org. Waste Agric. 6, 311–319. https://doi.org/10.1007/s40093-017-0179-1

Huang, Y., Ren, W., Wang, L., Hui, D., Grove, J.H., Yang, X., Tao, B., Goff, B., 2018. Greenhouse gas emissions and crop yield in no-tillage systems: A meta-analysis. Agric. Ecosyst. Environ. 268, 144–153. https://doi.org/10.1016/j.agee.2018.09.002

Hurkuck, M., Althoff, F., Jungkunst, H.F., Jugold, A., Keppler, F., 2012. Release of methane from aerobic soil: An indication of a novel chemical natural process? Chemosphere 86, 684–689. https://doi.org/10.1016/j.chemosphere.2011.11.024

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Journal of Crystal Growth. https://doi.org/10.1016/S0022-0248(00)00575-3

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Clim. Chang. 2013 1535. https://doi.org/10.1017/CBO9781107415324

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use, Chapter 10 Emissions from livestock and manure management 4.

Iqbal, J., Hu, R., Lin, S., Hatano, R., Feng, M., Lu, L., Ahamadou, B., Du, L., 2009. CO2 emission in a subtropical red paddy soil (Ultisol) as affected by straw and N-fertilizer applications: A case study in Southern China. Agric. Ecosyst. Environ. 131, 292–302. https://doi.org/10.1016/j.agee.2009.02.001

Jäger, N., Stange, C.F., Ludwig, B., Flessa, H., 2011. Emission rates of N2O and CO2 from soils with different organic matter content from three long-term fertilization experiments-a laboratory study. Biol. Fertil. Soils 47, 483–494. https://doi.org/10.1007/s00374-011-0553-5

Jarecki, M.K., Parkin, T.B., Chan, A.S.K., Hatfield, J.L., Jones, R., 2008. Greenhouse gas emissions from two soils receiving nitrogen fertilizer and swine manure slurry. J. Environ. Qual. 37, 1432–1438. https://doi.org/10.2134/jeq2007.0427

Jeffery, S., Verheijen, F.G.A., Kammann, C., Abalos, D., 2016. Biochar effects on methane emissions from soils: A meta-analysis. Soil Biol. Biochem. 101, 251–258. https://doi.org/10.1016/j.soilbio.2016.07.021

Jonathan A. Patz, 2005. Impact of regional climate change on human health. Nature 438, 310–317. https://doi.org/10.1038/nature04188

Jorgenson, M.T., Shur, Y.L., Pullman, E.R., 2006. Abrupt increase in permafrost degradation in Arctic Alaska 33, 2–5. https://doi.org/10.1029/2005GL024960

Leytem, A.B., Moore, A.D., Dungan, R.S., 2019. Greenhouse gas emissions from an irrigated crop rotation utilizing dairy manure. Soil Sci. Soc. Am. J. 83, 137–152. https://doi.org/10.2136/sssaj2018.06.0216

Li, L.J., You, M.Y., Shi, H.A., Ding, X.L., Qiao, Y.F., Han, X.Z., 2013. Soil CO2 emissions from a cultivated Mollisol: Effects of organic amendments, soil temperature, and moisture. Eur. J. Soil Biol. 55, 83–90. https://doi.org/10.1016/j.ejsobi.2012.12.009

Li, P., Lang, M., Li, C., Hao, X., 2016. Nitrous oxide and carbon dioxide emissions from soils amended with compost and manure from cattle fed diets containing wheat dried distillers' grains with solubles. Can. J. Soil Sci. 97, 522–531. https://doi.org/10.1139/cjss-2016-0068

Liang, X.Q., Li, H., Wang, S.X., Ye, Y.S., Ji, Y.J., Tian, G.M., van Kessel, C., Linquist, B.A., 2013. Nitrogen management to reduce yield-scaled global warming potential in rice. F. Crop. Res. 146, 66–74. https://doi.org/10.1016/j.fcr.2013.03.002

Liu, R., Hayden, H.L., Suter, H., Hu, H., Lam, S.K., He, J., Mele, P.M., Chen, D., 2017. The effect of temperature and moisture on the source of N2O and contributions from ammonia oxidizers in an agricultural soil. Biol. Fertil. Soils 53, 141–152. https://doi.org/10.1007/s00374-016-1167-8

López-Aizpún, M., Horrocks, C.A., Charteris, A.F., Marsden, K.A., Ciganda, V.S., Evans, J.R., Chadwick, D.R., Cárdenas, L.M., 2020. Meta-analysis of global livestock urine-derived nitrous oxide emissions from agricultural soils. Glob. Chang. Biol. 1–12. https://doi.org/10.1111/gcb.15012

Lu, Y., 2011. Regulation of microbial methane production and oxidation by intermittent drainage in rice ¢eld soil 75, 446–456. https://doi.org/10.1111/j.1574-6941.2010.01018.x

Luo, G.J., Kiese, R., Wolf, B., Butterbach-Bahl, K., 2013. Effects of soil temperature and moisture on methane uptake and nitrous oxide emissions across three different ecosystem types. Biogeosciences 10, 3205–3219. https://doi.org/10.5194/bg-10-3205-2013

Malcolm, J.C., 2001. You'll need two things to see our benefits: Science (80-.). 293.

Manzali-D, 1994. The effect of soil texture and soil drainage onemissions of nitric oxide and nitrous oxide. Colt. 1994, 23 6, 39-41. 56–60. https://doi.org/10.1079/SUM2001101

Mapanda, F., Wuta, M., Nyamangara, J., Rees, R.M., 2011. Effects of organic and mineral fertilizer nitrogen on greenhouse gas emissions and plant-captured carbon under maize cropping in Zimbabwe. Plant Soil 343, 67–81. https://doi.org/10.1007/s11104-011-0753-7

Maris, S.C., Teira-Esmatges, M.R., Bosch-Serra, A.D., Moreno-García, B., Català, M.M., 2016. Effect of fertilising with pig slurry and chicken manure on GHG emissions from Mediterranean paddies. Sci. Total Environ. 569–570, 306–320. https://doi.org/10.1016/j.scitotenv.2016.06.040

Meehl et al., 2007. A New Era in Climate Change Research 1383–1394. https://doi.org/10.1175/BAMS-88-9-1383

Meijide, A., Díez, J.A., Sánchez-Martín, L., López-Fernández, S., Vallejo, A., 2007. Nitrogen oxide emissions from an irrigated maize crop amended with treated pig slurries and composts in a Mediterranean climate. Agric. Ecosyst. Environ. 121, 383–394. https://doi.org/10.1016/j.agee.2006.11.020

Michael, Borenstein, Larry V. Hedges, Julian PT Higgins, Rothstein, H.R., 2009. Introduction to Meta-Analysis. A John Wiley and Sons, Ltd.

Müller, C., Kammann, C., Ottow, J.C.G., Jäger, H.J., 2003. Nitrous oxide emission from frozen grassland soil and during thawing periods. J. Plant Nutr. Soil Sci. 166, 46–53. https://doi.org/10.1002/jpln.200390011

Naser, H.M., Nagata, O., Tamura, S., Hatano, R., 2007. Methane emissions from five paddy fields with different amounts of rice straw application in central Hokkaido, Japan. Soil Sci. Plant Nutr. 53, 95–101. https://doi.org/10.1111/j.1747-0765.2007.00105.x

Nottingham, A.T., Whitaker, J., Ostle, N.J., Bardgett, R.D., McNamara, N.P., Fierer, N., Salinas, N., Ccahuana, A.J.Q., Turner, B.L., Meir, P., 2019. Microbial responses to warming enhance soil carbon loss following translocation across a tropical forest elevation gradient.

Ecol. Lett. 22, 1889–1899. https://doi.org/10.1111/ele.13379

O' Flynn, C.J., Healy, M.G., Lanigan, G.J., Troy, S.M., Somers, C., Fenton, O., 2013. Impact of chemically amended pig slurry on greenhouse gas emissions, soil properties and leachate. J. Environ. Manage. 128, 690–698. https://doi.org/10.1016/j.jenvman.2013.06.020

Oertel, C., Matschullat, J., Zurba, K., Zimmermann, F., Erasmi, S., 2016. Greenhouse gas emissions from soils—A review. Chemie der Erde 76, 327–352. https://doi.org/10.1016/j.chemer.2016.04.002

Pärn, J., Verhoeven, J.T.A., Butterbach-Bahl, K., Dise, N.B., Ullah, S., Aasa, A., Egorov, S., Espenberg, M., Järveoja, J., Jauhiainen, J., Kasak, K., Klemedtsson, L., Kull, A., Laggoun-Défarge, F., Lapshina, E.D., Lohila, A., Lõhmus, K., Maddison, M., Mitsch, W.J., Müller, C., Niinemets, Ü., Osborne, B., Pae, T., Salm, J.O., Sgouridis, F., Sohar, K., Soosaar, K., Storey, K., Teemusk, A., Tenywa, M.M., Tournebize, J., Truu, J., Veber, G., Villa, J.A., Zaw, S.S., Mander, Ü., 2018. Nitrogen-rich organic soils under warm well-drained conditions are global nitrous oxide emission hotspots. Nat. Commun. 9, 1–8. https://doi.org/10.1038/s41467-018-03540-1

Pathak, H., 2015. Review: Common attributes of hydraulically fractured oil and gas production and CO2 geological sequestration. Greenh. Gases Sci. Technol. 2, 352–368. https://doi.org/10.1002/ghg

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P., Smith, P., 2016. Climate-smart soils. Nature 532, 49–57. https://doi.org/10.1038/nature17174

Petersen, S.O., 1999. Nitrous oxide emissions from manure and inorganic fertilizers applied to spring barley. J. Environ. Qual. 28, 1610–1618. https://doi.org/10.2134/jeq1999.00472425002800050027x

Praeg, N., Wagner, A.O., Illmer, P., 2016. Plant species, temperature, and bedrock affect net methane flux out of grassland and forest soils. Plant Soil 1–14. https://doi.org/10.1007/s11104-016-2993-z

Rafique, R., Hennessy, D., Kiely, G., 2011. Nitrous Oxide Emission from Grazed Grassland Under Different Management Systems. Ecosystems 14, 563–582. https://doi.org/10.1007/s10021-011-9434-x

Ray, R.L., Griffin, R.W., Fares, A., Elhassan, A., Awal, R., Woldesenbet, S., Risch, E., 2020. Soil CO2 emission in response to organic amendments, temperature, and rainfall. Sci. Rep. 10, 1–14. https://doi.org/10.1038/s41598-020-62267-6

Ren, F., Zhang, X., Liu, J., Sun, N., Wu, L., Li, Z., Xu, M., 2017. A synthetic analysis of greenhouse gas emissions from manure amended agricultural soils in China. Sci. Rep. 7, 1–13. https://doi.org/10.1038/s41598-017-07793-6

Ren, X., Wang, Q., Awasthi, M.K., Zhao, J., Tu, Z., Li, R., Wen, L., Zhang, Z., 2019. Effect of tertiary-amine bentonite on carbon transformation and global warming potential during chicken manure composting. J. Clean. Prod. 237, 117818. https://doi.org/10.1016/j.jclepro.2019.117818

Rochette, P., Côté, D., 2000. CH4 fluxes and soil CH4 concentration following application of pig slurry for the 19th consecutive year. Can. J. Soil Sci. 80, 387–390. https://doi.org/10.4141/S99-068

Rochette, P., Gregorich, E.G., 1998. Dynamics of soil microbial biomass C, soluble organic C and CO2 evolution after three years of manure application. Can. J. Soil Sci. 78, 283–290. https://doi.org/10.4141/S97-066

Rodhe, L.K.K., Abubaker, J., Ascue, J., Pell, M., Nordberg, åke, 2012. Greenhouse gas emissions from pig slurry during storage and after field application in northern European conditions. Biosyst. Eng. 113, 379–394. https://doi.org/10.1016/j.biosystemseng.2012.09.010

Rosenberg, M.S., Adams, D.C., Gurevitch, J., 2000. MetaWin: statistical software for meta-analysis.

Rowlings, D., Grace, P., Kiese, R., Scheer, C., 2010. Quantifying N 2 O and CO 2 emissions from a subtropical pasture. Aust. J. Exp. Agric. 2008–2010.

Ruser, R., Flessa, H., Russow, R., Schmidt, G., Buegger, F., Munch, J.C., 2006. Emission of N2O, N2 and CO2 from soil fertilized with nitrate: Effect of compaction, soil moisture and rewetting. Soil Biol. Biochem. 38, 263–274. https://doi.org/10.1016/j.soilbio.2005.05.005

Ruser, R., Flessa, H., Schilling, R., Beese, F., Munch, J.C., 2001. Effect of crop-specific field management and N fertilization on N2o emissions from a fine-loamy soil. Nutr. Cycl. Agroecosystems 59, 177–191. https://doi.org/10.1023/A:1017512205888

Sakabe, A., Kosugi, Y., Takahashi, K., Itoh, M., Kanazawa, A., Makita, N., Ataka, M., 2015. One year of continuous measurements of soil CH4 and CO2 fluxes in a Japanese cypress forest: Temporal and spatial variations associated with Asian monsoon rainfall. J. Geophys. Res. Biogeosciences 120, 585–599. https://doi.org/10.1002/2014JG002851

Sampanpanish, P., 2012. Effect of organic fertilizer on CO2, CH4 and N2O emissions in a paddy field. Mod. Appl. Sci. 6, 13–21. https://doi.org/10.5539/mas.v6n12p13

Sanz-Cobena, A., Misselbrook, T.H., Hernáiz, P., Vallejo, A., 2019. Impact of rainfall to the effectiveness of pig slurry shallow injection method for NH3 mitigation in a Mediterranean soil. Atmos. Environ. 216, 116913. https://doi.org/10.1016/j.atmosenv.2019.116913

Säurich, A., Tiemeyer, B., Dettmann, U., Don, A., 2019. How do sand addition, soil moisture and nutrient status influence greenhouse gas fluxes from drained organic soils? Soil Biol. Biochem. 135, 71–84. https://doi.org/10.1016/j.soilbio.2019.04.013

Schirmann, J., Bastos, D.F. De, Weiler, D.A., Veloso, M.G., Dieckow, J., Carvalho, P.C.D.F., Bayer, C., 2020. Nitrous oxide emission factor from cattle urine and dung in native grassland of the Pampa biome, South Brazil. Soil Res. 58, 198–206. https://doi.org/10.1071/SR19095

Severin, M., Fuß, R., Well, R., Garlipp, F., Van den Weghe, H., 2015. Soil, slurry and application effects on greenhouse gas emissions. Plant, Soil Environ. 61, 344–351. https://doi.org/10.17221/21/2015-PSE

SHAKOOR, A.–GAN, M.Q.–YIN, H.X.–YANG, W.–HE, F.–ZUO, H.F.–MA, Y.H.–YANG, S.Y., 2020. INFLUENCE OF NITROGEN FERTILIZER AND STRAW RETURNING ON CH 4 EMISSION FROM A PADDY FIELD IN CHAO LAKE BASIN , CHINA. Appl. Ecol. Environ. Res. 18, 1585–1600.

Shakoor, A., Abdullah, M., Yousaf, B., Amina, Ma, Y., 2016. Atmospheric emission of nitric oxide and processes involved in its biogeochemical transformation in terrestrial environment. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-016-7823-6

Shakoor, A., Ashraf, F., Shakoor, S., Mustafa, A., Rehman, A., Altaf, M.M., 2020. Biogeochemical transformation of greenhouse gas emissions from terrestrial to atmospheric environment and potential feedback to climate forcing. Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-020-10151-1

Shakoor, A., Xu, Y., Wang, Q., Chen, N., He, F., Zuo, H., Yin, H., Yan, X., Ma, Y., Yang, S., 2018. Effects of fertilizer application schemes and soil environmental factors on nitrous oxide emission fluxes in a rice-wheat cropping system, east China. PLoS One 13, 1–16.

https://doi.org/10.1371/journal.pone.0202016

Shang, Q., Yang, X., Gao, C., Wu, P., Liu, J., Xu, Y., Shen, Q., Zou, J., Guo, S., 2011. Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: A 3-year field measurement in long-term fertilizer experiments. Glob. Chang. Biol. 17, 2196–2210. https://doi.org/10.1111/j.1365-2486.2010.02374.x

Shen, X., Huang, G., Yang, Z., Han, L., 2015. Compositional characteristics and energy potential of Chinese animal manure by type and as a whole. Appl. Energy 160, 108–119. https://doi.org/10.1016/j.apenergy.2015.09.034

Sherlock, R.R., Sommer, S.G., Khan, R.Z., Wood, C.W., Guertal, E.A., Freney, J.R., Dawson, C.O., Cameron, K.C., 2000. Ammonia, Methane, and Nitrous Oxide Emission from Pig SlurryApplied to a Pasture in New Zealand. J. Environ. Qual. 1491–1501.

Sistani, K.R., Simmons, J.R., Jn-Baptiste, M., Novak, J.M., 2019. Poultry Litter, Biochar, and Fertilizer Effect on Corn Yield, Nutrient Uptake, N2O and CO2 Emissions. Environments 6, 55. https://doi.org/10.3390/environments6050055

Skinner, C., Gattinger, A., Muller, A., Mäder, P., Fliebach, A., Stolze, M., Ruser, R., Niggli, U., 2014. Greenhouse gas fluxes from agricultural soils under organic and non-organic management - A global meta-analysis. Sci. Total Environ. 468–469, 553–563. https://doi.org/10.1016/j.scitotenv.2013.08.098

Smith, D.R., Owens, P.R., 2010. Impact of time to first rainfall event on greenhouse gas emissions following manure applications. Commun. Soil Sci. Plant Anal. 41, 1604–1614. https://doi.org/10.1080/00103624.2010.485240

Smith, L.G., Kirk, G.J.D., Jones, P.J., Williams, A.G., 2019. The greenhouse gas impacts of converting food production in England and Wales to organic methods. Nat. Commun. 10, 1–10. https://doi.org/10.1038/s41467-019-12622-7

Staley, B.F., de los Reyes, F.L., Barlaz, M.A., 2011. Effect of spatial differences in microbial activity, pH, and substrate levels on methanogenesis initiation in refuse. Appl. Environ. Microbiol. 77, 2381–2391. https://doi.org/10.1128/AEM.02349-10

Syväsalo, E., Regina, K., Turtola, E., Lemola, R., Esala, M., 2006. Fluxes of nitrous oxide and methane, and nitrogen leaching from organically and conventionally cultivated sandy soil in western Finland. Agric. Ecosyst. Environ. 113, 342–348. https://doi.org/10.1016/j.agee.2005.10.013

Tariq, A., Vu, Q.D., Jensen, L.S., de Tourdonnet, S., Sander, B.O., Wassmann, R., Van Mai, T., de Neergaard, A., 2017. Mitigating CH4 and N2O emissions from intensive rice production systems in northern Vietnam: Efficiency of drainage patterns in combination with rice residue incorporation. Agric. Ecosyst. Environ. 249, 101–111. https://doi.org/10.1016/j.agee.2017.08.011

Terhoeven-Urselmans, T., Scheller, E., Raubuch, M., Ludwig, B., Joergensen, R.G., 2009. CO2 evolution and N mineralization after biogas slurry application in the field and its yield effects on spring barley. Appl. Soil Ecol. 42, 297–302. https://doi.org/10.1016/j.apsoil.2009.05.012

Thangarajan, R., Bolan, N.S., Tian, G., Naidu, R., Kunhikrishnan, A., 2013. Role of organic amendment application on greenhouse gas emission from soil. Sci. Total Environ. 465, 72–96. https://doi.org/10.1016/j.scitotenv.2013.01.031

Thers, H., Abalos, D., Dörsch, P., Elsgaard, L., 2020. Nitrous oxide emissions from oilseed rape cultivation was unaffected by flash pyrolysis biochar of different type, rate and field ageing. Sci. Total Environ. 724, 138140. https://doi.org/10.1016/j.scitotenv.2020.138140

Thornton, F.C., Shurpali, N.J., Bock, B.R., Reddy, K.C., 1998. N2O and NO emissions from poultry litter and urea applications to Bermuda grass. Atmos. Environ. 32, 1623–1630. https://doi.org/10.1016/S1352-2310(97)00390-7

Tongwane, M., Mdlambuzi, T., Moeletsi, M., Tsubo, M., Mliswa, V., Grootboom, L., 2016. Greenhouse gas emissions from different crop production and management practices in South Africa. Environ. Dev. 19, 23–35. https://doi.org/10.1016/j.envdev.2016.06.004

Triberti, L., Nastri, A., Giordani, G., Comellini, F., Baldoni, G., Toderi, G., 2008. Can mineral and organic fertilization help sequestrate carbon dioxide in cropland? Eur. J. Agron. 29, 13–20. https://doi.org/10.1016/j.eja.2008.01.009

USDA, 2008. Soil quality inidicators.

USDA, 1999. Soil taxonomy—a basic system of soil classification for making and interp-reting soil surveys. US Gov. Print. Off. Washingt. DC. 336–337.

Vac, S.C., Popiţa, G.E., Frunzeti, N., Popovici, A., 2013. Evaluation of greenhouse gas emission from animal manure using the closed chamber method for gas fluxes. Not. Bot. Horti Agrobot. Cluj-Napoca 41, 576–581. https://doi.org/10.15835/nbha4129259

Vallejo, A., Skiba, U.M., García-Torres, L., Arce, A., López-Fernández, S., Sánchez-Martín, L., 2006. Nitrogen oxides emission from soils bearing a potato crop as influenced by fertilization with treated pig slurries and composts. Soil Biol. Biochem. 38, 2782–2793. https://doi.org/10.1016/j.soilbio.2006.04.040

Van Beek, C.L., Pleijter, M., Jacobs, C.M.J., Velthof, G.L., van Groenigen, J.W., Kuikman, P.J., 2010. Emissions of N2O from fertilized and grazed grassland on organic soil in relation to groundwater level. Nutr. Cycl. Agroecosystems 86, 331–340. https://doi.org/10.1007/s10705-009-9295-2

Van der Werf, G.R., Morton, D.C., DeFries, R.S., Olivier, J.G.J., Kasibhatla, P.S., Jackson, R.B., Collatz, G.J., Randerson, J.T., 2009. CO2 emissions from forest loss. Nat. Geosci. 2, 737–738. https://doi.org/10.1038/ngeo671

Van Kessel, C., Venterea, R., Six, J., Adviento-Borbe, M.A., Linquist, B., van Groenigen, K.J., 2013. Climate, duration, and N placement determine N2O emissions in reduced tillage systems: A meta-analysis. Glob. Chang. Biol. 19, 33–44. https://doi.org/10.1111/j.1365-2486.2012.02779.x

Van Zwieten, L., Kimber, S.W.L., Morris, S.G., Singh, B.P., Grace, P.R., Scheer, C., Rust, J., Downie, A.E., Cowie, A.L., 2013. Pyrolysing poultry litter reduces N2O and CO2 fluxes. Sci. Total Environ. 465, 279–287. https://doi.org/10.1016/j.scitotenv.2013.02.054

Velthof, G.L., Mosquera, J., 2011. The impact of slurry application technique on nitrous oxide emission from agricultural soils. Agric. Ecosyst. Environ. 140, 298–308. https://doi.org/10.1016/j.agee.2010.12.017

Verdi, L., Mancini, M., Napoli, M., Vivoli, R., Pardini, A., Orlandini, S., Marta, A.D., 2019. Soil carbon emissions from maize under different fertilization methods in an extremely dry summer in Italy. Ital. J. Agrometeorol. 5625, 3–10. https://doi.org/10.13128/ijam-648

Wallace, B.C., Lajeunesse, M.J., Dietz, G., Dahabreh, I.J., Trikalinos, T.A., Schmid, C.H., Gurevitch, J., 2017. OpenMEE: Intuitive, open-source software for meta-analysis in ecology and evolutionary biology. Methods Ecol. Evol. 8, 941–947. https://doi.org/10.1111/2041-210X.12708

Wang, Z. P., DeLaune, R. D., Masscheleyn, P. H., and Patrick, J.W.H., 1993. Soil Redox and pH Effects on Methane Productionin a Flooded Rice Soil. Soil Redox pH Eff. methane Prod. a flooded rice soil 382–385.

Wang, C., Lai, D.Y.F., Sardans, J., Wang, W., Zeng, C., Peñuelas, J., 2017. Factors Related with CH4 and N2O Emissions from a Paddy Field: Clues for Management implications. PLoS One 12, e0169254. https://doi.org/10.1371/journal.pone.0169254

Wang, J., Chen, Z., Ma, Y., Sun, L., Xiong, Z., Huang, Q., Sheng, Q., 2013. Methane and nitrous oxide emissions as affected by organic-inorganic mixed fertilizer from a rice paddy in southeast China. J. Soils Sediments 13, 1408–1417. https://doi.org/10.1007/s11368-013-0731-1

Wang, W., Wu, X., Chen, A., Xie, X., Wang, Y., Yin, C., 2016. Mitigating effects of ex situ application of rice straw on CH4 and N2O emissions from paddy-upland coexisting system. Sci. Rep. 6, 37402. https://doi.org/10.1038/srep37402

Watts, D.B., Torbert, H.A., Way, T.R., 2011. Evaluation of poultry litter fertilization practices on greenhouse gas emissions. ACS Symp. Ser. 1072, 473–492. https://doi.org/10.1021/bk-2011-1072.ch025

Weller, S., Kraus, D., Ayag, K.R.P., Wassmann, R., Alberto, M.C.R., Butterbach-Bahl, K., Kiese, R., 2015. Methane and nitrous oxide emissions from rice and maize production in diversified rice cropping systems. Nutr. Cycl. Agroecosystems 101, 37–53. https://doi.org/10.1007/s10705-014-9658-1

Welti, N., Hayes, M., Lockington, D., 2017. Seasonal nitrous oxide and methane emissions across a subtropical estuarine salinity gradient. Biogeochemistry 132, 55–69. https://doi.org/10.1007/s10533-016-0287-4

Whalen, J.K., Chang, C., Clayton, G.W., Carefoot, J.P., 2000. Cattle Manure Amendments Can Increase the pH of Acid Soils. Soil Sci. Soc. Am. J. 64, 962–966. https://doi.org/10.2136/sssaj2000.643962x

WHO, 2003. Climate Change and Human Health - Risks and Responses. World Heal. Organ. 38.

Wood, S., Cowie, A., 2004. for Fertiliser Production .

Wu, D., Senbayram, M., Zang, H., Ugurlar, F., Aydemir, S., Brüggemann, N., Kuzyakov, Y., Bol, R., Blagodatskaya, E., 2018. Effect of biochar origin and soil pH on greenhouse gas emissions from sandy and clay soils. Appl. Soil Ecol. 129, 121–127. https://doi.org/10.1016/j.apsoil.2018.05.009

Wu, K., Gong, P., Zhang, L., Wu, Z., Xie, X., Yang, H., Li, W., Song, Y., Li, D., 2019. Yield-scaled N 2 O and CH 4 emissions as affected by combined application of stabilized nitrogen fertilizer and pig manure in rice fields. Plant, Soil Environ. 2019, 497–502.

X.M.Yang, C.F.D., 2017. Effects of biochar and straw return on CO 2 and N 2 O emissions from farmland in the North China Plain. Shengtai Xuebao/ Acta Ecol. Sin. 37, 6700–6711. https://doi.org/10.5846/stxb201607281546

Xu-Ri, Prentice, I.C., Spahni, R., Niu, H.S., 2012. Modelling terrestrial nitrous oxide emissions and implications for climate feedback. New Phytol. 196, 472–488. https://doi.org/10.1111/j.1469-8137.2012.04269.x

Xu, W., Cai, Y.-P., Yang, Z.-F., Yin, X.-A., Tan, Q., 2017. Microbial nitrification, denitrification and respiration in the leached cinnamon soil of the upper basin of Miyun Reservoir. Sci. Rep. 7, 42032. https://doi.org/10.1038/srep42032

Xu, X., Wu, Z., Dong, Y., Zhou, Z., Xiong, Z., 2016. Effects of nitrogen and biochar amendment on soil methane concentration profiles and diffusion in a rice-wheat annual rotation system. Sci. Rep. 6, 38688. https://doi.org/10.1038/srep38688

Zhang, T., Liu, H., Luo, J., Wang, H., Zhai, L., Geng, Y., Zhang, Y., Li, J., Lei, Q., Bashir, M.A., Wu, S., Lindsey, S., 2018. Long-term manure application increased greenhouse gas emissions but had no effect on ammonia volatilization in a Northern China upland field. Sci. Total Environ. 633, 230–239. https://doi.org/10.1016/j.scitotenv.2018.03.069

Zhao, X., Liu, S.L., Pu, C., Zhang, X.Q., Xue, J.F., Zhang, R., Wang, Y.Q., Lal, R., Zhang, H.L., Chen, F., 2016. Methane and nitrous oxide emissions under no-till farming in China: A meta-analysis. Glob. Chang. Biol. 22, 1372–1384. https://doi.org/10.1111/gcb.13185

Zheng, J., Zhang, X., Li, L., Zhang, P., Pan, G., 2007. Effect of long-term fertilization on C mineralization and production of CH4 and CO2 under anaerobic incubation from bulk samples and particle size fractions of a typical paddy soil. Agric. Ecosyst. Environ. 120, 129–138. https://doi.org/10.1016/j.agee.2006.07.008

Zhou, M., Butterbach-Bahl, K., Vereecken, H., Brüggemann, N., 2017a. A meta-analysis of soil salinization effects on nitrogen pools, cycles and fluxes in coastal ecosystems. Glob. Chang. Biol. 23, 1338–1352. https://doi.org/10.1111/gcb.13430

Zhou, M., Zhu, B., Brüggemann, N., Bergmann, J., Wang, Y., Butterbach-Bahl, K., 2014. N 2 O and CH 4 emissions, and NO 3- leaching on a crop-yield basis from a subtropical rain-fed wheat-maize rotation in response to different types of nitrogen fertilizer. Ecosystems 17, 286–301. https://doi.org/10.1007/s10021-013-9723-7

Zhou, M., Zhu, B., Wang, S., Zhu, X., Vereecken, H., Brüggemann, N., 2017b. Stimulation of N2O emission by manure application to agricultural soils may largely offset carbon benefits: a global meta-analysis. Glob. Chang. Biol. 23, 4068–4083. https://doi.org/10.1111/gcb.13648

Figure legends

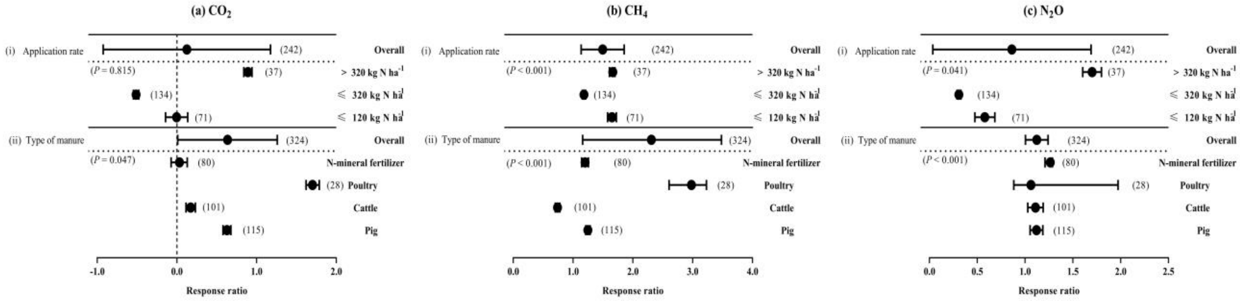

Fig. 1. Impact of (i) animal manure and mineral fertilizer application rate (kg N ha^{-1}) and (ii) manure type on (a) CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the *P* values are shown in the panel.

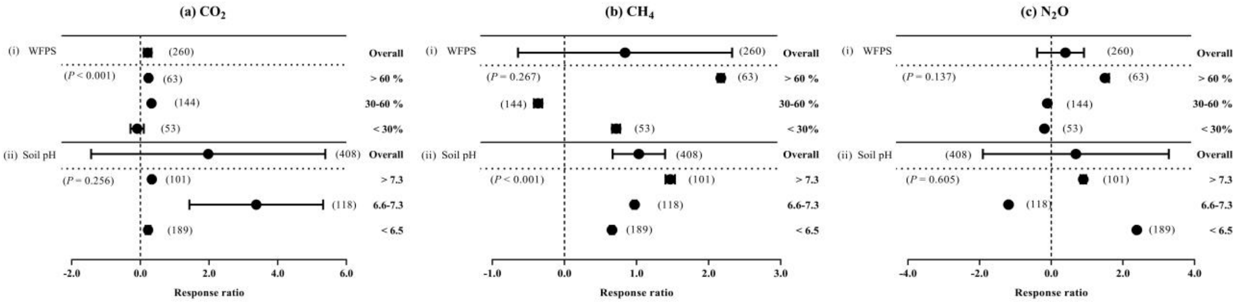

Fig. 2. Effect of (i) WFPS (%) and (ii) soil pH on (a) CO_2, (b) CH_4 and (c) N_2O emissions from agricultural soils. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the *P* values are shown in the panel.

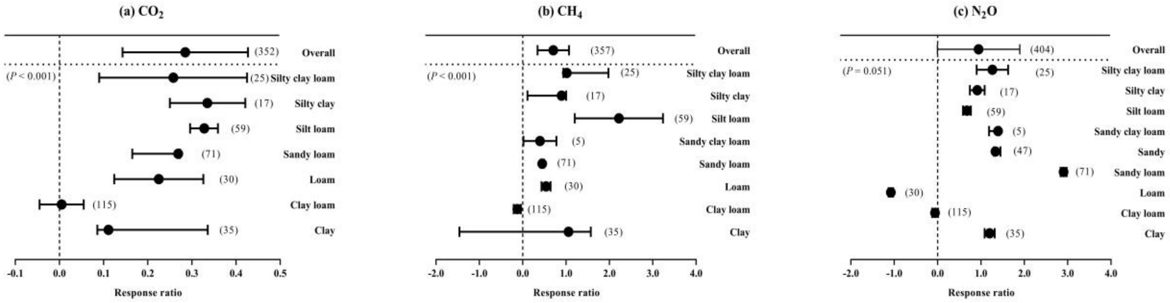

Fig. 3. (a) CO$_2$, (b) CH$_4$ and (c) N$_2$O emissions from agricultural soils affected by soil textural class. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the *P* values are shown in the panel.

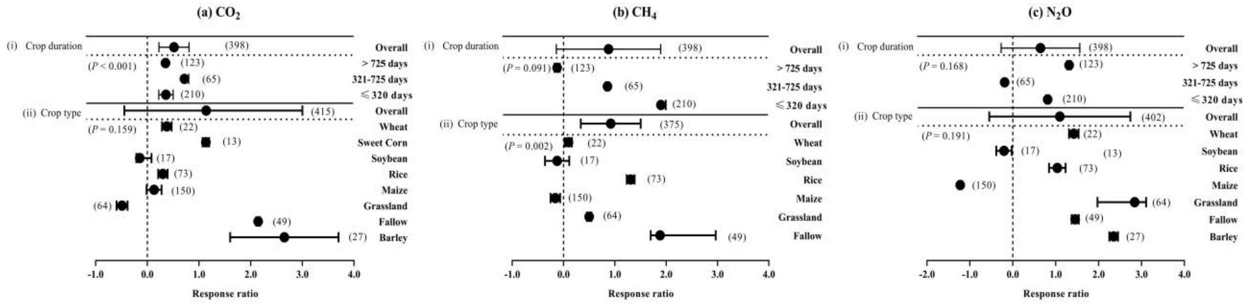

Fig. 4. Influence of (i) crop duration (days) and (ii) crop type on (a) CO$_2$, (b) CH$_4$ and (c) N$_2$O emissions from agricultural soils. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the *P* values are shown in the panel.

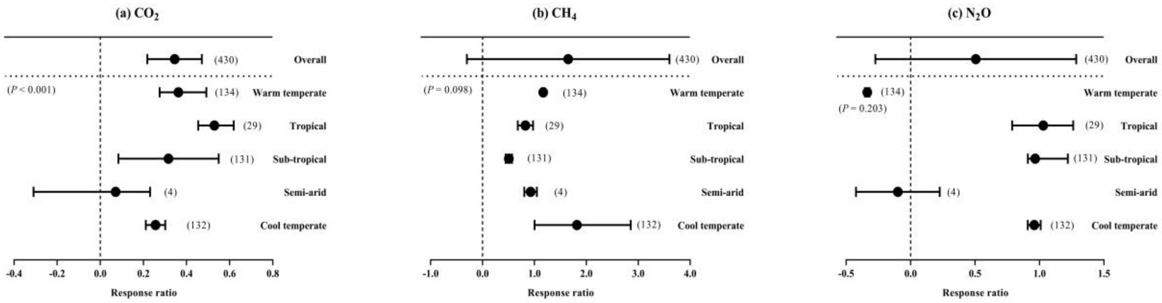

Fig. 5. Effect of climate zone on (a) CO$_2$, (b) CH$_4$ and (c) N$_2$O emissions from agricultural soils. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the *P* values are shown in the panel.

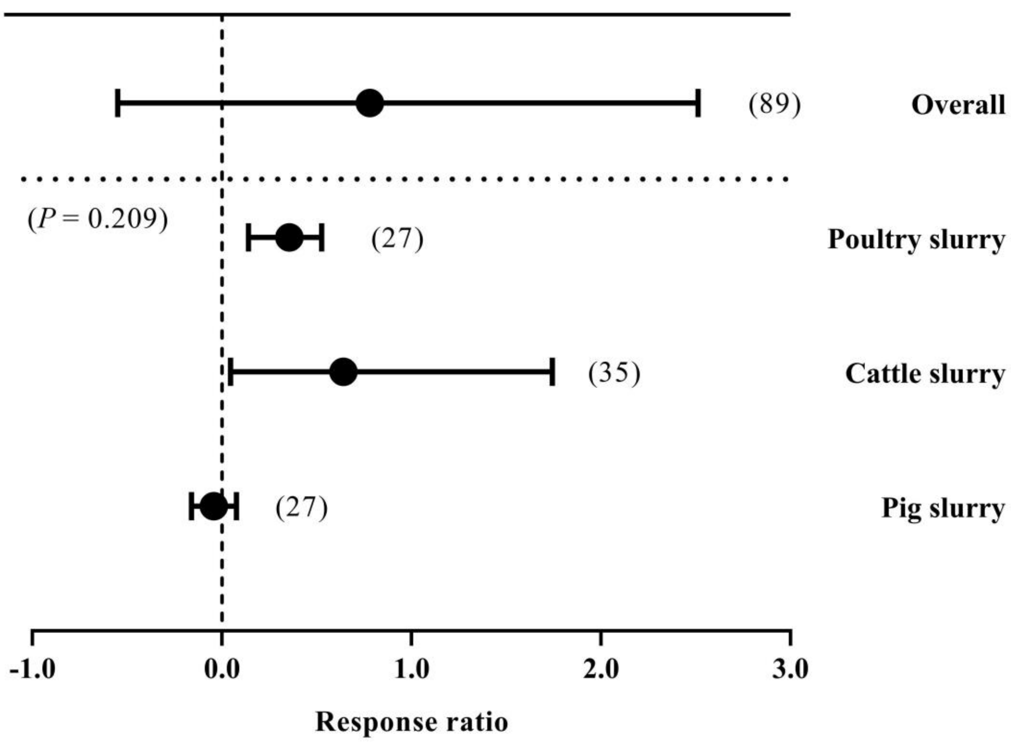

Fig. 6. Effect of manure application on the global warming potential (GWP) of greenhouse gas (GHG) emissions. Symbols represent mean effect sizes with 95% confidence intervals. Sample sizes are presented in parentheses and the *P* values are shown in the panel.

Table 1

Description of crop type, location, number of observation, soil attributes, manure type and rate included in this meta-analysis.

Study number	Study Reference	Journal	Country	Number of observations	Crop type	Soil pH	WFPS (%)	Soil textural class	Climate zone	Manure type	N rate (kg N ha^{-1})
1	Meijide et al., (2007)	AEE	Spain	7	Maize	8.1	46-70	Sandy loam	Warm temperate	Pig	0-250
2	Van Zwieten et al., (2013)	STE	Australia	4	Maize	4.8	_	Clay loam	Sub-tropical	Poultry	100-120
3	Maris et al., (2016)	STE	Spain	13	Rice	8.1-8.5	_	Silty clay loam and Silty loam	Warm temperate and Semi-arid	Poultry and Pig	0-170
4	Zhang et al., (2018)	STE	China	8	Wheat	7.3-8.7	20-79	Loam	Cool temperate	Pig	0-410
5	De Rosa et al., (2018)	STE	Australia	18	Green beans and Sweet corn	7.8	37-79	Clay loam	Sub-tropical	Poultry	0-367
6	Dambreville et al., (2008)	AEE	France	6	Maize	5.9-6.9	46	Silt loam	Warm temperate	Pig	0-180
7	(Velthof et al., 2011)	AEE	Netherlands	43	Grassland and Maize	4.8-7.1	_	Clay and sandy	Warm temperate	Cattle and Pig	0-460
8	Fangueiro et al., (2008)	BT	England	7	Grassland	6-6.7	_	Clay loam	Cool temperate	Cattle	0-354
9	Sanz-Cobena et al., (2019)	AE	Spain	2	Fallow	8.1	64-70	Sandy loam	Warm temperate	Pig	63-77
10	Thornton et al., (1998)	AE	USA	4	Grassland	5.5	77.3	Silty clay loam	Sub-tropical	Poultry	0-336
11	Rodhe et all., (2012)	BSE	Sweden	7	Fallow	7.1	23.4-31.6	Silty clay loam	Cool temperate	Pig	0-140

Study number	Study Reference	Journal	Country	Number of observations	Crop type	Soil pH	WFPS (%)	Soil textural class	Climate zone	Manure type	N rate (kg N ha^{-1})
12	Severin et al., (2015)	PSE	Germany	21	Maize	4.3-5.8	42-67	_	Warm temperate	Pig	0-150
13	Ball et al., (2004)	SUM	Scotland	6	Grassland	_	_	Clay loam	Cool temperate	Cattle	0-430
14	Collins et al., (2011)	SBB	USA	12	Maize	6.7	36.9-42.1	Silt loam	Warm temperate	Cattle	0-336
15	Chadwick et al., (2000)	JEQ	England	6	Grassland	6.9	38.1-55.1	Sandy loam	Cool temperate	Cattle and Pig	0-295
16	Jarecki etal., (2008)	JEQ	USA	6	Fallow	6.9-7.0	48-54	Sandy loam and Clay	Warm temperate	Pig	0-200
17	Chantigny et al., (2016)	CJSS	Canada	12	Barley	6.5-6.8	_	Sandy loam and Silty clay	Cool temperate	Pig	0-65
18	Li et al., (2013)	EJSB	China	6	Maize	5.76-6.01	47-52	_	Cool temperate	Pig	0-450
19	Mapanda et al., (2011)	PS	Zimbabwe	24	Maize	5.4-6.5	3.3-24.2	Clay and Sandy loam	Sub-tropical	Cattle	0-120
20	Rochette & Côté, (2000)	CJSS	Canada	3	Maize	_	_	Loam	_	Pig	0-252
21	Petersen, (1999)	JEQ	Denmark	10	Barely	5.9	55	Sandy	Cool temperate	Pig and Cattle	80-120
22	Zhou et al., (2014)	ES	China	8	Wheat and Maize	8.3	65-80	_	Sub-tropical	Pig	0-150
23	Das & Adhya, (2014)	GD	India	5	Rice	6.16	_	Sandy clay loam	Tropical	Poultry	0-120
24	Liang et al., (2013)	FCR	China	42	Rice	6.9	_	Clay loam	Sub-tropical	Pig	0-270

Study number	**Study Reference**	**Journal**	**Country**	**Number of observations**	**Crop type**	**Soil pH**	**WFPS (%)**	**Soil textural class**	**Climate zone**	**Manure type**	**N rate (kg N ha^{-1})**
25	Wu et al., (2019)	PSE	China	4	Rice	6.9-7.22	_	_	Cool temperate	Pig	180-266
26	Vallejo et al., (2006)	SBB	Spain	7	Potato	7.9	52-60	Clay loam	Warm temperate	Pig	0-300
27	Wang et al., (2013)	JSS	China	5	Rice	7.29-7.41	_	Clay loam	Sub-tropical	Pig	0-180
28	O' Flynn et al., (2013)	JOEM	Ireland	3	Fallow	6.26	53	Sandy loam	Cool temperate	Pig	0-90
29	Sherlock et al., (2000)	JEQ	NewZealand	3	Grassland	5.36	_	Silt loam	Sub-tropical	Pig	0-60
30	Li et al., (2016)	CJSS	Canada	5	Fallow	6.58	6.58	Loam	Cool temperate	Cattle	0-120
31	Grave et al., (2015)	STR	Brazil	5	Wheat	5.3	68	Silty clay loam	Sub-tropical	Pig	0-140
32	X.M.Yang, (2017)	ACS	Canada	14	Fallow	_	30	Clay loam	Cool temperate	Pig	0-165
33	Sampanpanish, (2012)	MAS	Thailand	4	Rice	5.3	_	Clay	Sub-tropical	Cattle	0-156
34	Dendooven et al., (1998)	BFS	Belgium	4	Fallow	6.2	18.7	Silt loam	Warm temperate	Pig	0-250
35	Dinuccio et al., (2011)	AFST	Italy	4	Fallow	7.43	9.8	Loamy sand	_	Cattle	0-21
36	Sistani et al., (2019)	Es	USA	10	Maize	4.7	37-42	Silty clay	Sub-tropical	Poultry	0-224
37	Brennan et al., (2015)	PO	Ireland	4	Fallow	7.45	_	Sandy loam	Sub-tropical	Cattle	295
38	Bourdin et al., (2014)	AEE	Ireland	6	Grassland	5.5	29.4	Sandy loam	Warm temperate	Cattle	0-275

Study number	**Study Reference**	**Journal**	**Country**	**Number of observations**	**Crop type**	**Soil pH**	**WFPS (%)**	**Soil textural class**	**Climate zone**	**Manure type**	**N rate (kg N ha^{-1})**
39	Leytem et al., (2019)	SBB	USA	20	Wheat - Barely-Sugar Beet	8	57-75	Silt loam	Tropical	Cattle	0-1315
40	Bertora et al., (2008)	SBB	Italy	6	Maize	7.9	63	Loam	_	Pig	0-170
41	Smith & Owens, (2010)	CSSPA	USA	4	Grassland	_	_	Silt loam	Tropical	Poultry and Pig	0-420
42	Gao et al., (2014)	CJSS	Canada	4	Alfalfa	7.8	50	Sandy loam	Cool temperate	Pig	0-410
43	Cote & Ndayegamiye, (1989)	CJSS	Canada	6	Maize	5.4	_	Silty loam	Cool temperate	Cattle and Pig	0-160
44	Herr et al., (2019)	JPNSS	Germany	8	Maize	7	28-30	Loam	Warm temperate	Cattle	0-170
45	Asgedom et al., (2014)	AJ	Canada	6	Rapeseed	7	_	Clay	Cool temperate	Cattle	0-137
46	Syväsalo et al., (2006)	AEE	Finland	4	Grassland-Cereal	_	_	Sandy	Cool temperate	Cattle	0-200
47	Verdi et al., (2019)	IJAM	Italy	3	Maize	_	_	Silty clay	Warm temperate	Pig	0-150
48	Abagandura et al., (2019)	JEQ	USA	24	Soybean-Maize-	5.2-6.1	28.9-45	Sandy loam-Clay loam	Cool temperate	Cattle	0-150

Journal: AEE (Agricultural, Ecosystems & Environment), STE (Science of the Total Environment), BT (Bioresource Technology), AE (Atmospheric Environment), BSE (Biosystems Engineering), PSE (Plant, Soil and Environment), SUM (Soil Use and Management), SBB (Soil Biology & Biochemistry), JEQ (Journal of Environmental Quality), CJSS (Canadian Journal of Soil Science), EJSB (European Journal of Soil Biology), PS (Plant and Soil), ES (Ecosystems), GD (Geoderma), FCR (Field Crops Research), JSS (Journal of Soils and Sediments), JOEM (Journal of Environmental Management), STR (Soil & Tillage Research), ACS (Acta Ecologica Sinica), MAS (Modern Applied Science), BFS (Biology and Fertility of Soils), AFST (Animal Feed Science and Technology), Es (Environments), PO (Plos One), CSSPA (Communications in Soil Science and Plant Analysis), JPNSS (Journal of Plant Nutrition and Soil Science), AJ (Agronomy Journal), IJAM (Italian Journal of Agrometeorology).