Effect of Poultry Litter Application on Crop Yield, Nutrient Uptake and Soil Fertility: A Meta-analysis

Yaru Lin[1,2], Dexter B. Watts[1,2], Edzard van Santen[3]
[1]Auburn University, [2]National Soil Dynamics Laboratory, USDA-ARS, [3]University of Florida, IFAS

Abstract

Extensive research has shown that poultry litter (PL) can be used as a nutrient source for crop production. However, there has been conflicting results as to whether PL application increases crop production when compared to inorganic fertilizer (IF) which explains the need for a comprehensive quantitative review. This study aimed to conduct a meta-analytic assessment to elucidate the influence of PL on crop yield, plant nutrient uptake, and soil fertility as compared to IF. A meta-analysis based on 116 studies and 2293 observations compared agronomic responses to PL and IF application. The log transformed ratio of means was used as effect size (ES) to express differences in the effects of PL and IF. A random-effects model was used to test if the ES was significantly different from zero (α= 0.05). Crop yield was slightly less when evaluating PL additions during the 1st or 2nd year of application, while significant increases were observed with long-term PL application. PL's influence on yield was crop-specific, positive effects on soybean, peanut, corn, and cotton, while negative effects on wheat, barley, and forage production. Plant nutrient uptake was influenced by PL with a slightly negative effect being observed for N uptake, whereas a significant positive effect for P and K uptake. Positive effects on soil fertility were also observed with PL significantly increasing the CEC, pH and concentration of soil C, P, K, Ca, and Mg compared to IF. Overall, PL can be used as an alternative nutrient source to enhance crop yield, increase plant nutrient uptake, and improve soil fertility.

Introduction

Poultry litter is often used as a low-cost alternative nutrient source to inorganic commercial fertilizer in the southeastern U.S. Poultry litter contains all the nutrients essential for plant growth and has an approximate fertilizer equivalent of 3-3-2 (N-P_2O_5-K_2O). Extensive research on the use of PL under different agricultural practices has shown conflicting results as to the beneficial effects of PL on crop productivity and its influence on increasing the availability of soil nutrients. There is also a need to learn more about the fate of PL nutrients in plant-soil systems (Fig. 1) to effectively utilize and manage it under various field conditions.

Meta-analysis contrasts and combines results from independent studies to estimate treatment effects and to identify patterns among study results. It is now an important tool for this purpose because it incorporates formal statistical techniques for quantifying the effects observed in multiple independent experiments. The use of meta-analysis allows for increased objectivity of systematic reviews based on studies involving the arrangement of soil properties, and environmental or management conditions. Therefore, the objective of this study was to summarize and quantitatively describe the effects of PL on crop productivity, nutrient uptake, and soil fertility using a meta-analytic approach.

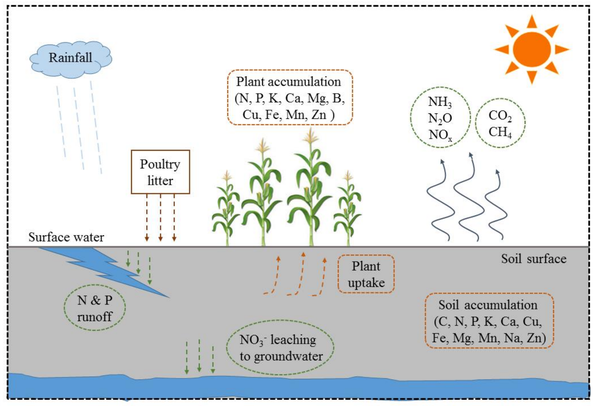

Fig. 1 Main nutrient pathways in the plant-soil system when poultry litter is applied.

Methods and Materials

A comprehensive literature review was conducted using the ISI Web of Science for published data up to February 2016. A total of 111 refereed articles were retained and 5 unpublished data sets included for meta-analysis (Fig. 2), totaling 2293 observations. Funnel plots were created to measure potential publication bias.

Meta-analysis performed for this study was based on the principals described by Hedges et al. (1999) with all data being analyzed using R ("metafor"; Viechtbauer, 2010). To determine the influence of PL vs. IF on crop yield, nutrient uptake, or soil fertility, the following equation was used to determine effect size:

$$\mathrm{ES}_i = ln(\mathrm{RR}) = ln(\frac{\bar{Y}_{PL}}{\bar{Y}_{IF}})$$

The corresponding variance (v_i) was calculated as:

$$v_i = \frac{SD_{PL}^2}{n_{PL}\times\bar{Y}_{PL}^2} + \frac{SD_{IF}^2}{n_{IF}\times\bar{Y}_{IF}^2}$$

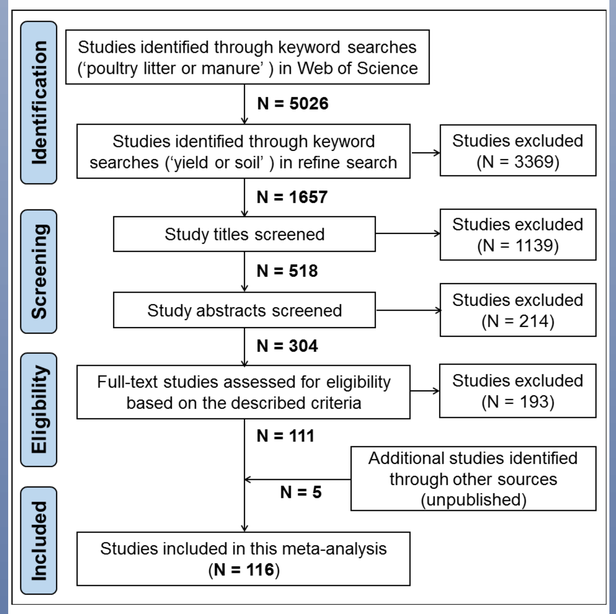

Fig. 2 PRISMA flow diagram showing the procedure for selecting studies for this meta-analytic review.

Results

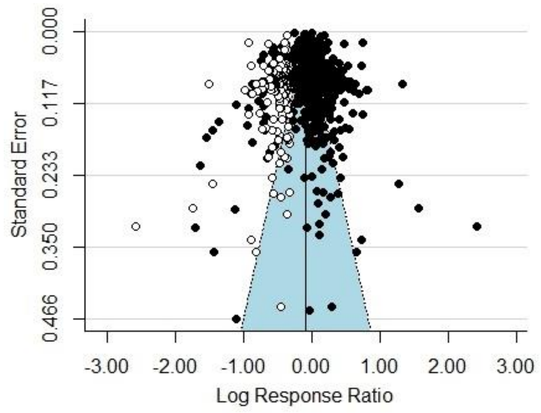

Fig. 3 Funnel plot for the yield dataset with filled-in data based on the trim and fill method.

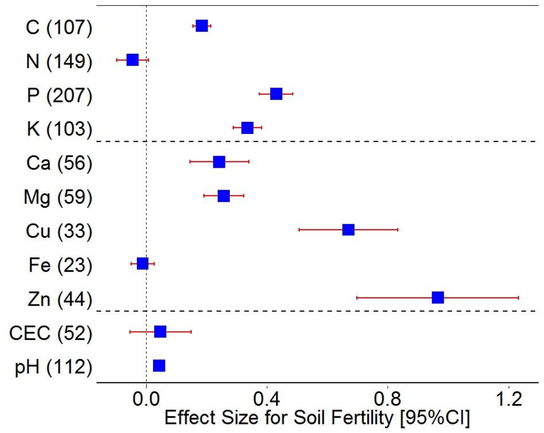

Fig. 5 Forest plot showing the results of 56 studies examining the effectiveness of PL application on soil fertility, CEC, and soil pH related to IF.

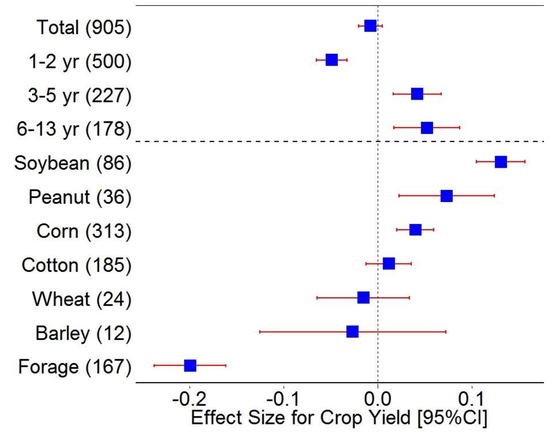

Fig. 4 Forest plot showing the results of 91 studies examining the effectiveness of PL application on crop yield based on study duration and crop types related to IF.

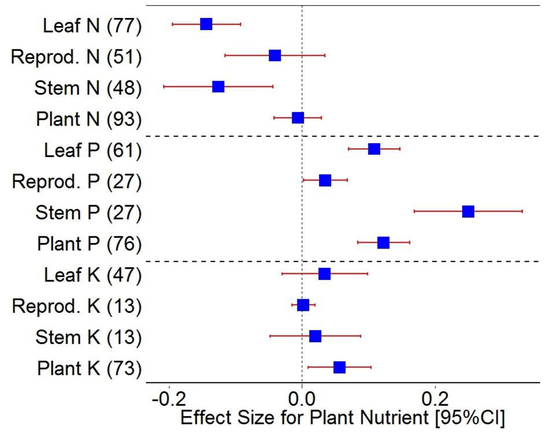

Fig. 6 Forest plot showing the results of 54 studies examining the effectiveness of PL application on plant nutrient content related to IF.

- The symmetrical funnel plot for yield (Fig. 3) and small Kendall tau values from the Begg and Mazumbar rank correlation test suggested that there was no publication bias. All response variables evaluated resulted in similar plots.
- The high heterogeneity for yield indicated the need for further analysis by introducing moderator variables, such as study duration and crop type, which modified the data to a low heterogeneity. All response variables evaluated resulted in low or moderate heterogeneity (I^2 ranges from 0 to 62%).
- Overall, PL can be used as an alternative nutrient source to IF, which can increase crop yield, improve crop nutrient content, and enhance soil residual nutrients compared to inorganic fertilizer (Fig. 4 - 6).

Discussions

- Crop nutrient and soil fertility management mainly depend on a complex long-term integrated approach rather than a short-term one. In this study, crop productivity with PL became more positive as the years of application increased. However, winter crops (e.g. wheat and barley) and forages showed a negative response to PL, most likely as a result of slow mineralization. This suggests that PL may not satisfy plant nutrient requirement during winter months.
- Poultry litter contains various macro and micronutrients and is slightly alkaline, thus, higher soil fertility, CEC, and pH was observed with PL compared to IF. Higher P and K concentrations were also observed in plant tissues, while N was lower likely due to PL's slow N release rate.
- The efficacy of PL to enhance crop production varies with management and cropping systems, in order to maximize crop productivity and minimize environmental problems, further research is warranted to thoroughly explore the fate of PL in various plant-soil systems (Fig. 1).