Soil Health

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Soil health is the capacity of the soil to provide an environment for optimum growth and development of plants, while also ensuring the health of animals and humans. Animal manure has been used for centuries as a source of nutrients in agriculture. However, many other soil properties that contribute to soil health are affected when manure is applied. Bulk density, aggregate stability, infiltration, water holding capacity, soil fertility, and biological properties are impacted to various degrees with manure application. The goal of this paper was to compile the research findings on the effects of various livestock manure types on soil fertility, soil physical properties, soil biology and the yield of various cereal crops. Specifically, this paper summarizes results for poultry, cattle, and swine manure used in various cropping systems. Although there are conflicting results in the literature with regards to the effect of manure on various soil properties, the literature offers convincing evidence of beneficial impacts of manure on soil and the growth of crops. The degree to which manure affects soil depends on the physical and chemical properties of the manure itself and various management and environmental factors including rate and timing of application, soil type, and climate.

Keywords: manure ; soil fertility ; nutrients ; soil organic carbon

1. Introduction

Manure was applied to crops as a slow release fertilizer by European farmers as early as 6000 B.C. [1]. Since the early years of agricultural development in the United States (U.S.), the 16th through the 19th century, manure has been considered an agricultural resource of significance [2]. Early publications from the United States Department of Agriculture (USDA) showed that it was believed that the neglect of this resource would lead to significant losses for the farm [3]. In these records, the fertilizing value of manure produced by the number of cattle in the U.S. at that time was estimated to be over 1 billion U.S. dollars [3]. These early records indicate that the USDA worked to increase the awareness of the nutrient value of manure among farmers. It also sought to encourage farmers to use manure rather than completely replacing it with commercial fertilizers. Economic and demographic developments after the second world war brought about an increase in agricultural production efficiency which resulted in the rise of large concentrations of livestock operations at the same time that commercial fertilizer production was also increasing [2]. In today's world, land degradation as a result of erosion, desertification, tillage, and unsustainable agricultural practices have caused a significant decline in productivity on some land [4]. On the other hand, the growth in world population has increased food demand, which requires an increase in agricultural production. These developments necessitate the implementation of practices that improve or restore the quality of agricultural land. Manure has been known to have beneficial effects on soil fertility and many other soil properties, contributing to the overall soil health. The Natural Resources Conservation Service (NRCS) defined soil health or soil quality as the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans [5]. One of the reasons that there has been an increasing interest in the use of organic nutrient sources and soil amendments is the fact that they are a source of carbon (C) which plays a role in improving soil quality and climate change mitigation. Heightened public and consumer's interest in organically produced crops and sustainable agriculture have also contributed to an increasing demand in organic soil amendments [6][7]. Sources of animal manure that are most used in the U.S. are cattle and chicken manure [8]. However, the use of other livestock manure such as horse, sheep, goat, turkey, and rabbit among others are not uncommon around the world. The USEPA (2013) [9] estimated that 900 million Mg of manure was generated from 2.2 billion livestock in 2007. In 2012, manure was applied to 275,000 farms translating to roughly 8.9 million hectares of cropland in the U.S. [10]. In an analysis of global data, Zhang et al. [11] showed a steady increase in manure nitrogen (N) production, globally, between 1998 and 2014 to 131 Tg N yr^{-1}. This study also showed that on a global scale, cattle contributed the most to global manure N production, contributing 43.7% to the total manure N production in 2014, while goats and sheep together produced one third of the global manure N in that same year [12]. More recent statistics published by the FAO [8] show that globally, most manure N applied to cropland came from poultry (chicken, duck, and turkey); contributing 7132 × 10^3 Mg of N to cropland (Figure 1). From these data we can infer that manure remains an important source of nutrients in agricultural production. Ultimately, the amount of manure applied to fields depends on different factors including the composition of the manure, the soil available nutrients, the crop to be grown, and environmental conditions [13].

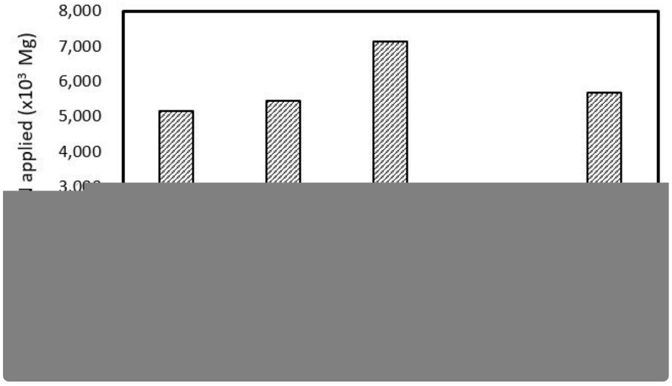

Figure 1. The nitrogen (N) applied to global land as manure coming from different livestock (Source: Food and Agriculture Organization (FAO, [8]).

2. Soil Nutrient Status

Soil fertility is defined as the available nutrient status of the soil and its ability to provide nutrients inherently and from external sources [15]. Various studies have reported an increase in macro- and micronutrients as a result of manure application [16][17][18], which in turn positively affects the growth and productivity of crops. Various chemical properties influence the overall fertility of soils including soil pH, cation exchange capacity (CEC), organic matter, and organic carbon (C). Manure application affects these different soil properties in addition to releasing nutrients through mineralization. The nutrient content of manure depends on several factors including animal type (Table 1), feed intake and water consumption by the animals [7], manure storage and management, and whether the manure is liquid or solid [19]. This section of the paper explores the effect of land applied manure on soil chemical properties, including selected nutrients and their availability.

Table 1. Total nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) concentrations in various manure types as reported in literature.

Manure Type	Total N	P_2O_5	K_2O	Reference
	g kg^{-1}			
Beef	3.7 (liquid) †	0.8	2.3	[20]
	5.5 (solid) † §	9	5	[21]
	10.5 (solid) † ¶	9	13	
	3.8 (1000- lbs. cow) †	2.0	3.2	[22]
	22.8 ‡	5.2	21.5	[23]
Dairy	3.9 (liquid) †	0.9	2.5	[20]
	5.5 (solid)	2.5	5.5	[24]

	4.5 (solid) †§	2	5	[21]
	12 (liquid) †	9	14.5	
	5.9 (1000-lbs dry cow)†	2.2	4.7	[22]
	3.3-8.8 (solid)	1.1–8.8	1.1–17.6	[25]
Swine	3.9 (solid) †	1.2	1.3	[20]
	5 (solid) † §	4.5	4	[21]
	4 (solid) † §	3.5	3.5	
	11.5 (300 lbs. finishing)	4.1	6.1	[22]
	2.2–15.4	1.1–34.2	1.1–9.9	[25]
Poultry	8.1 †	2.8	3.0	[20]
	16.5 (solid) † §	24	17	[21]
	28 (solid) † ¶	22.5	17	
	11.0 (broiler)	7.4	5.3	[22]
	19.3	28.9	14.7	[26]

† As-is basis, ‡ Dry weight; § No bedding or litter; ¶ Bedding or litter.

3. Total Nitrogen and Nitrate

Various studies have evaluated the effect of manure on total N [26][27] and nitrate [28] in the soil. The studies evaluated for this review show a general increase in soil total N, as the rate of manure increased (Table 2). However, work by Ferreras et al. [29] showed that an increase in the rate of manure from 10 to 20 Mg ha^{-1} did not increase soil N. In a study, investigating the effect of dairy manure and tillage in maize, Khan et al. [30] reported that the addition of 10 Mg ha^{-1} and 20 Mg ha^{-1} of dairy manure in addition to inorganic fertilizer increased soil N by 24% and 27%, respectively, compared to inorganic fertilizer alone. The release of N or any other nutrient from manure depends on the rate of mineralization. In general, the amount of a nutrient that is mineralized in manure is a function of manure characteristics, environmental factors, soil properties, and microbial activity [13]. Eghball et al. [13] also noted that manures containing large amounts of organic N release less plant-available N, since the organic N needs to be converted to inorganic N first. A study conducted by Hou et al. [31] showed that the application of chicken manure in combination with inorganic fertilizer significantly increased the N content in plant parts. Conversely, manure application has been associated with increased nitrate (NO_3) leaching from soils [32]. Application of manure at a time when the plant does not absorb N can cause significant losses of nitrate, especially during high rainfall events. Various studies have evaluated nitrate leaching from manure [32][33]. Van Es et al. [33] confirmed that timing of manure application and soil type affected the amount of nitrate concentration in drainage waters; manure applications made in late fall reduced the concentration of nitrate N concentration by 4 mg L^{-1} relative to early fall applications made in maize. This study showed that the lowest nitrate N concentrations were achieved with spring applications. The dependence on environmental factors such as moisture and temperature and the potential losses make the availability of N from manure highly variable and unpredictable. As a result, producers often over apply manure to land which in turn becomes a potential problem to the environment. The studies that were reviewed showed a general increase in total N with increase in the rate of manure applied (Table 2), however, this increase was not consistent across all studies. A study by Mokgolo [34] showed that the addition of 20 Mg per ha produced a slight reduction or no change in total N. A study by Adeli et al. [35] however, showed that the application of 2.2 Mg of manure per ha increased the total soil N by 110 mg kg^{-1}; doubling the application to about 4.5 Mg ha^{-1} increased soil N by an additional 30 mg kg^{-1} relative to the control. Another study showed that increasing the poultry manure application rate from 5 to 10 Mg per ha did not cause a significant increase in total soil N [26] (Table 2). These findings confirm the unpredictability of the release of nutrients from manure.

Table 2. A review of total nitrogen (N), soil test P, and exchangeable potassium (K), relative to the control treatments (no manure and no fertilizer) as a function of manure application.

Study Site	Nutrient		Total N	Soil Test P	Exchangeable K	References
	Source	Quantity Mg ha^{-1}	mg kg^{-1}			
South Africa	-	0	450, 570 †	7.6, 2.0	156, 163.8	[34]
	Poultry	20	420, 570	9.3, 2.7	252.3, 417.3	
	Cattle	20	500, 650	31.0, 30,3	250.8, 265.2	
	Poultry + Cattle	20 + 20	370, 780	8.5, 29.4	223.1, 553.8	
United States	-	0	650, 600 †	22, 55		[35]
	Poultry	2.2	860, 700	38, 97		
	Poultry	4.5	890, 770	64, 119		
	Poultry	6.7	980, 890	97, 146		
China	-	0	980	5.8	144	[36]
	Cattle	75	1220	12.7	193	
Nigeria	-	0	900,1100 ‡	8.3, 9.9	44.9, 163.8	[37]
	Poultry	7.5	3100, 3600 ‡	13.5, 15.4	232.1, 368.6	
Nigeria		0	600	9.1, 6.9	50.4, 68.4	[26]
	Poultry	5	800,700 †	12.5, 14.2	82.8, 140.4	
	Poultry	10	900,800	13.2, 17.8	111.6, 151.2	

Nigeria	-	0	900, 1200 †	10.6, 9.0		
	Poultry	10	1700, 3500	18.2, 18.9		
	Poultry	25	5100, 4800	30.9, 37.1		[38]
	Poultry	40	2800, 5200	33.0, 44.3		
	Poultry	50	3100, 5600	32.6, 45.6		
Argentina	-	0	950, 1240 †			
	Poultry	10	1050, 1550			[29]
	Poultry	20	1080, 1490			
United States	-	0		51.8, 65.3 §	19.5, 29.4	
	Cattle	10		93.6, 101.3	45.9, 44.6	
	Cattle	20		153.6, 162.8	59.9,65.4	[23]
	Cattle	30		205.7, 155.4	75.6, 91.9	
	Cattle	40		236.1, 209.3	96.7, 126.4	
Canada	-	0	1300			
	Cattle	20	1400			[39]
	Cattle	40	1500			
	Cattle	60	1600			

† numbers separated by a comma indicate the numbers in different years or seasons at a single location; ‡ numbers separated by a comma indicate the numbers at two different locations averaged over multiple years; § numbers separated by a comma indicate the soil nutrient content immediately after manure application and 8 weeks after incubation.

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