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Organic Fertilizers in Alabama: Composition, Transformations, and Crop Response in Selected Soils of the Southeast United States

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Additional information is available at the end of the chapter

Abstract

Rapid growth in organic production in the past 20 years is due to consumer concerns about the impacts of conventional agriculture on the environment, food safety, and quality. There are considerable variations in nutrient concentration and the rate of mineralization among organic fertilizers. Some organic fertilizers and application rates are specific to soil types, which affect the nutrient potential. Two organic fertilizers produced in Alabama and added to soils are the chicken or poultry litter (1.8 million Mg annually) and the hydrolyzed liquid fish protein. The under- or overestimation of the total N content of the litter may result in its over- or underapplication with potential environmental consequences to surface waters. The overestimation of the total N may result in its inadequate application. The inorganic forms (ammonium, NH_4^+–N; nitrate, NO_3^-–N; and nitrite, NO_2^-–N) are found in small but sometimes significant amounts especially when broiler litter is stored under environmental conditions favorable to nitrification. Limited information is available on the usefulness of the various modifications of the regular Kjeldahl method in poultry litter analysis and transformations when added to soils. This chapter provides information and our experiences on the sources of organic fertilizers produced in the southeastern United States (Alabama).

Keywords: organic amendments, nitrogen, mineralization, organic carbon, sustainable agriculture

1. Introduction

An organic fertilizer is a soil amendment produced from plant materials and/or animal manures containing low levels of nitrogen (N), phosphorus (P), potassium (K), and some residues of micronutrients compared with synthetic chemical fertilizers. These plant byproducts include alfalfa meal or pellets (also used as animal feed), corn gluten meal (with allelophatic properties), cottonseed meal, and soybean meal (also used as animal feed). Animal byproducts include bat guano, blood meal (slaughterhouse waste product), bone meal, feather meal, enzymatically digested hydrolyzed liquid fish, fish emulsion, fish meal, and fish powder. In addition to these byproducts, compost of organic materials (mixture of leaves, food waste, and/or animal manures) and seaweed (valued for its micronutrient contents) are used as organic fertilizers. Contrary to synthetic chemical fertilizers for which nutrient contents are regulated, the term organic fertilizer is not regulated; theses organic fertilizers act as nutrients for plants and soil conditioners that feed soil microorganisms. Biosolids are another type of organic amendment or fertilizer used in agriculture. The United States Environmental Management Agency (USEPA) defines the term biosolids as treated sewage sludge that meets the USEPA pollutant and pathogen requirements for land application as well as surface disposal. As stated early, the term organic fertilizer is not regulated and therefore should not be confused with selected organic substances approved by the United States Department of Agriculture (USDA) for its National Organic Program (NOP) for use in organic production. An organic substance to be allowed in certified organic production must be approved by the Organic Materials Review Institute (OMRI) and the Washington Department of Agriculture.

In the southeastern states of the United States, the disposal of vast amounts of organic fertilizers in the form of animal waste can otherwise be used as organic fertilizer. More than 65% of US broiler production is concentrated in the southeastern states. In 2012, Alabama ranks second in the United States in broiler production and produced over 1 billion birds [1]. The litter that results annually from this broiler production averages 15 million metric tons, and its disposal represents a growing problem for the poultry industry.

In 2010, cash receipts in Alabama from poultry operations made up 68% of the total cash receipts for all commodities [2]. Mineralization of C, N, P, and S in poultry litter added to soil is the main cause of groundwater contamination in areas where mineral fertilizer application is limited [3].

In Alabama, there are only a few companies that transform raw poultry litter into organic fertilizers. MigthyGrow, Inc., produces OMRI approved organic fertilizers (4–3–4) as well as an AgBlend all-purpose fertilizer (3–3–3). Denali Organics, LLC, uses catfish byproducts with a proprietary digestive enzyme to produce an organic liquid fertilizer that can be top-dressed, banded with seeds, or foliar sprayed. Gulf Coast Organic is a distributor of liquid fertilizers such as Gator Perform SRN (30–0–0) for lawns, turf, and golf courses, and food crops, Primera one green fee super (15–0–0), Turf balance RSN (12–0–12), Medina has a Gro plant (6–12–6), and Medina hasta Gro lawn (12–4–8). It also distributes granular fertilizers such as Primera 3–3–3 crumbles and Primera 4–3–4 crumbles.

Concentrations of 15 trace and nontrace elements (silver, Ag; arsenic, As; barium, Ba; beryllium, Be; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; manganese, Mn; molybdenum, Mo; nickel, Ni; lead, Pb; antimony, Sb; selenium, Se; and zinc, Zn) were investigated by the United States Environmental Protection Agency [4] because of their potential toxicity Properties of chicken litter generated in Alabama have been investigated (**Table 1**).

Property[a]	Range	Median	Mean
Litter age, month	3.00–18.0	9.0	8.9
Moisture, %	7.9–28.5	12.7	13.7
pH	7.4–8.6	8	8.0
Organic C, g/kg	229–396	360	347
C/N ratio	6.86–11.4	8.35	8.56

[a] n = 33; pH was determined by a combination glass electrode (broiler litter/water ratio, 1:2.5), organic C by the method of Mebius (1960) (adapted from Kpomblekou A et al., 2002).

Table 1. Selected properties of chicken litter generated in Alabama.

2. Metal contents of chicken litter

Variations in trace element contents of chicken litter have been reported. These variations are attributed to trace elements contained in ingredients fed to chicks (feedstuffs, drugs, feed spillage, and drinking water). Compounds and elements added to chicken diets to stimulate growth and feed efficiency include arsenilic acid, copper sulfate in addition to argon, cadmium, calcium, chlorine, cobalt, cerium, dysprosium, iron, lanthanum, manganese, samarium, selenium, titanium, uranium, vanadium, and zinc [5–8]. Moreover, for disease resistance, more than 20 antibiotics are often added to animal diets. All these elements and compounds have been found at elevated concentrations in chicken litter because those are not completely metabolized in their digestion system. Investigation of 33 chicken litter samples from 12 Alabama counties showed large variations in barium (0.014–0.038 g/kg), calcium (18.9–40.2 g/kg), magnesium (4.8–10.0 g/kg), potassium (18.1–36.5 g/kg), and sodium (3.6–9.2 g/kg). Means of these elements [9] are shown in **Table 2**. Although these means are similar to those previously reported for 106 broiler litter samples from Alabama, USA [9], they are not comparable to those published for Georgia, USA [10] where 86 samples were analyzed. Differences in these results could be attributed to variations in chicken diets in Alabama and Georgia. Other investigators [8, 10–14] confirmed that concentrations of trace elements in animal waste depend on animal diets. The concentration of arsenic in the Alabama samples varied considerably (<2.0–70.4 mg/kg) with a median of 19.1 mg/kg and a mean of 20.6 mg/kg (**Table 2**). However, at a detection limit of 2.0 mg/L, no arsenic was found in four samples reported in Alabama.

| Total elemental content[a]	Range	Median	Mean
Nontrace element	g/kg		
Aluminum	0.4–8.4	1.4	2.2
Barium	0.014–0.038	0.025	0.024
Calcium	18.9–40.2	27.3	26.6
Magnesium	4.8–10.0	6.1	6.3
Potassium	18.1-36.5	25.9	25.5
Sodium	3.6–9.2	7.1	6.9
Trace element/micronutrient	mg/kg		
Arsenic	<2.0–70.4	19.1	20.6
Cadmium	<2.0–1.7	<0.2	0.3
Cobalt	<2.0–2.3	<0.2	0.4
Chromium	<2.0–17.6	3.2	3.7
Cupper	211–840	410	450
Iron	718–6691	1596	2073
Manganese	254–720	356	388
Molybdenum	<2.0–4.9	0.2	0.9
Nickel	<2.0–25.1	1.0	5.2
Selenium	<2.0–24.3	<2.0	5.5
Zinc	224–706	371	399

[a]n = 33; samples digested using the microwave-assisted acid digestion EPA 3052 method (adapted from Kpomblekou A et al., 2002).

Table 2. Range, median, and mean of trace and nontrace elements in chicken litter samples generated in Alabama.

Exposure of Cd to animals and humans at relatively high levels in food, water, or air has caused harmful effects. Almost all the samples tested did not contain or contained only trace amounts of Cd and varied from <0.2 to 1.7 mg/kg. Other researchers reported concentrations of 1 mg Cd/kg [15] and 6 mg Cd/kg [8] in single samples of chicken litter. Similarly, only trace amounts of Co were detected in the samples with a mean of 0.4 mg/kg (Table 2). The presence of Cr in the ecosystem must be carefully monitored. Chromium concentrations in tested samples in Alabama range from <2 to 17.6 mg Cr/kg with a median of 3.2 mg Cr/kg. Concentrations of other trace elements (Cu, Fe, Mn, Mo, Ni, Se, and Zn) are shown in Table 2 as well. The most abundant elements found in chicken litter are Cu (211–840 mg/kg), iron (718–6691 mg/kg), and manganese (254–720 mg/kg). Copper, Fe, and Zn are the most widely studied trace metals in chicken litter, probably because of their possible toxic effects on crops. In soils receiving excessive applications of chicken litter with high P content, there exists a possible P-induced

Zn deficiency. At detection limits of 0.2 and 2.0 mg/L, no measurable amounts of Ag and Pb, respectively, were found in chicken litter.

The use of chicken litter in agriculture as an organic fertilizer is not without challenges. The trace elements in the litter can accumulate in topsoil over time, can become a source of surface water pollution via water runoffs following storm events and depending on soil characteristics, and the elements may contaminate groundwater and may become bioavailable and phyto‐ toxic. Soil profile samples taken in selected Alabama soils demonstrate that depending on soil types the trace elements can move through soil profiles. Differences in Cr concentrations in Alabama amended and nonamended soils with chicken litter exceed 40 mg/kg at 45–60 cm and 60 mg/kg at 60–75 cm. This strongly suggests that Cr is fairly mobile in these soils. For example, in Fuquay and Madison soils, the increased Cr concentration in the amended soils over the nonamended soils at 90 cm depth exceeded 10 and 30 mg/kg, respectively (**Figure 1**). Just like Cu and Ni, chromic (Cr^{3+}) forms of Cr are strongly complex with soil organic matter as well as chemisorbs on sexquioxides and therefore immobile in soils. Chromate (CrO_4^{2-}) although more toxic than Cr^{3+} is less adsorbed and displays more mobility in soils under favorable environmental conditions. A complete different picture was obtained for cadmium in the soil profiles (**Figure 2**). A background concentration of Cd above 0.5 μg/g soil has been attributed to anthropogenic activities [16]. The cadmium concentration in the soils was relatively low (<5.63 mg/kg) with the exception of Madison soil where the Cd concentration achieved 10.2 mg/kg at 45 cm depth. The addition of poultry litter to Orangeburg soil did not change the Cd concentration it its profile. Mobility of trace elements in soil has been associated with presence of organic matter [17] For the mobility of other trace elements in Alabama soils, the reader is referred to Cadet et al. [18].
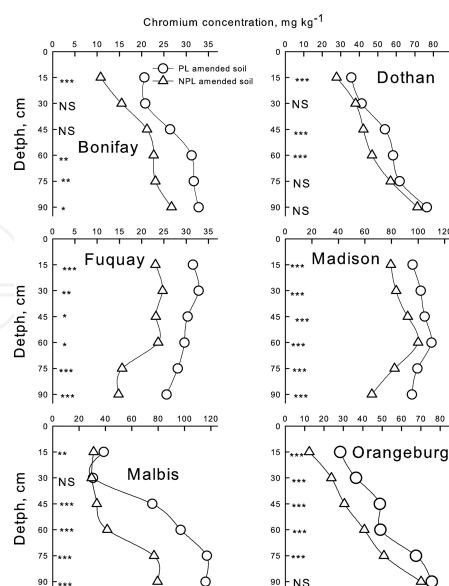
Figure 1. Mobility of Cr in benchmark Alabama soils after long-term poultry litter addition. *, **, *** indicate signifi‐ cance at 0.05, 0.01, and 0.001 levels of probability, respectively. NS: not significant at depth specified. From Cadet et al., 2012 [18].
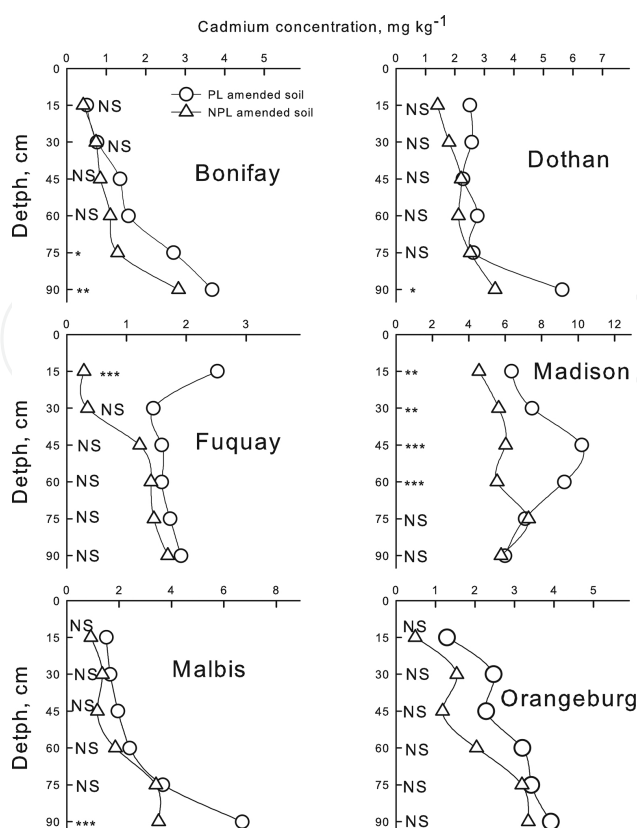
Figure 2. Mobility of Cd in benchmark Alabama soils after long-term poultry litter addition. *, **, *** indicate significance at 0.05, 0.01, and 0.001 levels of probability, respectively. NS: not significant at depth specified. From Cadet et al., 2012 [18].

3. Nitrogen contents of chicken litter

As organic fertilizer, chicken litter is valued because it contains macro- and micronutrients. A large majority of nitrogen in the litter (a mixture of chicken manure and bedding materials) exists in organic forms. Ammonium, NH_4^+–N; nitrate, NO_3^-–N; and nitrite, NO_2^-–N representing the inorganic form are found in small but sometimes significant amounts. This is especially true when chicken litter is stockpiled under environmental conditions conducive to nitrification (oxidation of NH_4^+–N to NO_3^-–N via NO_2^-–N). Failure to take this increase in N into account will lead to an underestimation of the total N in chicken litter.

3.1. Total nitrogen contents of chicken litter

The NO_3^-–N and NO_2^-–N contained in environmental samples are not recovered quantitatively by the regular Kjeldahl digestion procedure. A set of modifications of the regular Kjeldahl procedure have been developed to include NO_2^-–N and/or NO_3^-–N in soil and plant materials. As pretreatment, before Kjeldahl digestion, Asboth [19] reacted benzoic acid with nitric acid. Following this first attempt, several pretreatments of samples containing NO_3^-–N have been

suggested: phenolsulfuric acid [19], ferrosulfate [20], NaOH solution, and Devarda's alloy to reduce NO_3^-- and NO_2^-–N to NH_4^+–N with its subsequent distillation into a receiving flask containing concentrated H_2SO_4 [21], ferrum reductum [21], whereas $KMnO_4$ was used successfully to oxidize NO_2^-–N to NO_3^-–N and then ferrum reductum to reduce NO_3^-–N to NH_4^+–N, which was then followed by the Kjeldahl digestion [22]. The most widely used modifications today include the salicylic acid–thiosulfate modification method [23], the alkaline reduction modification method [24], and the permanganate-reduced iron modification method [25]. There are serious doubts about the ability of the salicylic acid–thiosulfate method to recover NO_2^-–N quantitatively, especially in undried soils [26]. None of the modifications has shown satisfactory results in recoveries of NO_3^-–N and NO_2^-–N across a wide range of soils and plant materials. The permanganate-reduced iron modification does not give satisfactory results for samples containing organic matter that resists complete digestion [27]. The underestimation of the total N content of chicken litter may result in its overapplication with potential environmental consequences of surface water eutrophication. On the other hand, an overestimation of the total N may result in its inadequate application.

Statistics of the total N contents of chicken litter samples collected in Alabama and analyzed by various methods are shown in **Table 3**. The most unusual results obtained are those by the Leco-combustion method with an average total N content of 3.78%. This represents an underestimation of the total N by 13.5% as compared with the Devarda's alloy method. This could be attributed to partial oxidation and/or an ineffective oxidation of the samples. As compared with the regular Kjeldahl method, the Leco-combustion method underestimated all the chicken litter samples. The mean of samples by the regular Kjeldahl method was 41 g/kg, whereas that of the Leco-combustion was 37.7 g/kg [28]. One of the consequences of underestimation of the total N in chicken litter is its overapplication that would lead to the accumulation of nutrients such as nitrates and phosphates in topsoil. When not absorbed by plant roots, these nutrients may find their way into surface waters or groundwaters by percolation through soil profile. Reports [29] also indicated that Leco FP-428 Nitrogen Determinator underestimated N when compared with other methods (the regular Kjeldahl method, the phenyl acetate method, the salicylic acid method, and the NO_3^-–N prereduction method). The Leco FP-428 gave lower results of the total N for all the samples (Stockton soil, Copay soil, and in-house liver tissue standard) tested. A study showed that Leco FT-428 and CHN-600 provided slightly higher total N levels than the regular Kjeldahl methods [30]. Dry combustion methods have been widely used in laboratories because the procedures are automated and rapid (analysis time for C, H, and N <5 min/sample by the Leco CHN-600); as many as 80 samples can be performed in 24 h [31]. Seven pretreatments (salicylic acid–$Na_2S_2O_3$, aqueous $Na_2S_2O_3$, Devarda's alloy, Zn–$CrK(SO_4)_2$, H_2O_2–Fe, NaOCl–Fe, and $KMnO_4$–Fe) compared with the regular Kjeldahl method showed no significant difference between the N content in fresh manures [32]. The study, however, showed a significant difference between the modified methods and the regular Kjeldahl method in the case of composted poultry manure. It is well known that storage conditions may significantly affect the proportion of ammonium and nitrate in environmental samples. It is important to point out that the samples studied contained between 0.07 and 7.63 g NO_3^-–N/kg for poultry manures and the composted poultry manure with wood chips, respectively. Ratios of the total N determined by the $KMnO_4$ method

over the regular, the salicylic acid, the Devarda's alloy, or the Leco-combustion method have been published [28]. The $KMnO_4$:Devarda's alloy method mean ratio was 1.01 and implies that these two methods are also similar. Extremely high concentrations of ammonium were reported in the Delaware samples and implies that large portions of the organic N were converted into NH_4^+–N with potential to be oxidized to NO_3^-–N during storage. If not taking into account, one may expect an overapplication of the chicken litter to topsoil with serious environmental consequences.

Total N determination method	Range (%)	Median (%)	Mean (%)
Regular Kjeldahl	2.75–5.49	4.22	4.10
Potassium permanganate-reduced iron	2.93–5.71	4.42	4.35
Salicylic acid	3.02–5.24	4.11	4.09
Devarda's alloy	3.11–5.52	4.30	4.37
Leco-combustion	2.57–5.01	3.83	3.78

[a]n = 33 collected in 12 counties; litter age varied from 4 months to 18 months; bedding materials include: pine shavings, peanut hulls, pine chips, and sawdust (adapted from Kpomblekou A, 2006).

Table 3. Range, median, and mean of total N in chicken litter samples[a] generated in Alabama and digested by total N determination methods.

3.2. Inorganic nitrogen contents of chicken litter

Inorganic N found in chicken litter is small and could be extracted with 2 M KCl solution (litter/solution ratio, 1:20). Following the filtration and centrifugation of the mixture, ammonium–N and $(NO_3^- + NO_2^-)$–N in the filtrate could be determined by steam distillation [33] whereas NO_2^-–N could be determined by a modified Griess-Ilosvay colorimetric method [34]. Inorganic N contents of the chicken litter can vary significantly and may not be related to chicken litter age or bedding material types [28]. Ammonium is the most dominant inorganic N in chicken litter. The mean NH_4^+–N concentrations tested for samples from Alabama ranged from 1.61 to 5.39 g/kg (**Table 4**).

In general, NH_4^+–N contents of the samples were higher than those of $(NO_3^- + NO_2^-)$–N, which varied from 0.19 to 5.56 g/kg. Under the storage conditions ($4 \pm 1°C$) nitrification was effectively reduced. However, $(NO_3^- + NO_2^-)$–N contents of animal waste may be greater than those of NH_4^+–N [28]. Nitrite does not usually accumulate in animal waste because it is rapidly oxidized to NO_3^- unless its oxidation is inhibited by environmental conditions. Nitrite concentrations could vary from 0 to 0.58 g/kg in a sample, therefore one should not be very much concerned about the recovery of NO_2^-–N in chicken litter analysis since its concentration is negligible. Ammonium concentration may vary from 3.49 to 16.4% for total Kjeldahl-N and could totally be recovered in samples by almost all total N determination methods. On the other hand, the $(NO_3^- + NO_2^-)$–N content cannot be ignored. It represents 0.44–11.4% of the total organic N in chicken litter. A range of 60–97% and 3–40% of the total N in animal manures were reported

present as organic and inorganic N, respectively [32]. The authors also reported that most of the inorganic N was in the form of NH_4^+–N (77–89%) with only a small fraction present in NO_3^-–N (6–12%) and NO_2^-–N (0.2–2%). Bedding materials seem to influence the inorganic N content of the litter. The mean values of the total N (53.2 g/kg), NH_4^+–N (20.6 g/kg), and NO_3^-–N (308 mg/kg) were reported in 20 poultry manures collected from stockpiled manure and poultry houses in Delaware [35]. The following trend has been reported for Alabama bedding materials: pine chips (6.29 g N/kg) > pine shaving (5.34 g N/kg) > sawdust (4.53 g N/kg) > peanut hulls (4.32 g N/kg) > mixture pine shavings–sawdust (3.41 g N/kg) [28].

Inorganic N[b]	Range	Median	Mean
	g/kg		
Ammonium, NH_4^+–N	1.61–5.39	2.91	3.03
Nitrate + nitrite, $(NO_3^- + NO_2^-)$–N	0.19–5.56	1.45	1.57
Nitrite, NO_2^-–N	0–0.58	0.01	0.06
Percentage inorganic N of total Kjeldahl N	%		
NH_4^+–N	3.49–16.4	6.57	7.51
$(NO_3^- + NO_2^-)$–N	0.44–11.4	3.48	3.99
NO_2^-–N	–	–	–
Relative proportion of specified N of total inorganic N	%		
NH_4^+–N	41.1–92.2	68.9	68.4
$(NO_3^- + NO_2^-)$–N	6.28–58.3	30.6	30.3
NO_2^-–N	0.0–13.8	0.31	1.28

[a]n = 33 collected in 12 counties; litter age varied from 4 months to 18, and bedding includes: pine shavings, peanut hulls, pine chips, and sawdust.
[b]Ammonium–N and nitrate–N were determined in 2 M KCl filtrate by steam distillation (Keeney and Nelson, 1982) whereas nitrite–N was determined by a modified Griess-Ilosvay colorimetric method (Barnes and Folkard, 1951) (adapted from Kpomblekou A, 2006).

Table 4. Range, median, and mean of inorganic N in chicken litter samples[a] generated in Alabama.

3.3. Mineralization of organic nitrogen in chicken litter

Organic N to become available for plant uptake must be mineralized. The mineralization of organic N depends on several factors: soil types and litter bedding materials that could significantly alter N transformation in soils. Organic N mineralization in the 10 soils (amended or not) tested was best described by first-order kinetics, but the decomposition rates and half-life of remaining N vary significantly indicating that fractions of organic N in the chicken litter samples differ (**Table 5**). **Table 5** also shows that the decomposition was also affected by soil types.

Soil series	Broiler litter sample ID	Decomposition rate (week^{-1})[a]		Percentage of N mineralized at each phase		Half-life of N remaining (weeks)
		k_1	k_2	D_1	D_2	
Appling	None	0.00132	0.0003	6.73	1.38	75
Cecil	None	0.0127	0.0019	3.54	2.01	52
Colbert	None	0.004	0.002	2.27	1.34	50
Decatur	None	0.003	0.001	6.03	1.57	33
Dothan	None	0.006	0.002	3.80	1.78	50
Hartsells	None	0.0015	0.0006	1.85	0.78	66
Linker	None	0.007	0.003	5.10	0.37	33
Maytag	None	0.0105	0.0016	4.15	1.43	62
Sucarnoochee	None	0.012	0.001	4.68	2.31	38
Troup	None	0.0025	0.0026	2.49	0.95	40
Appling	1	0.0065	0.0023	18.8	1.10	15
Cecil	1	0.0026	0.0014	17.7	1.86	38
Colbert	1	0.0038	0.0025	18.2	3.32	26
Decatur	1	0.004	0.0018	11.3	2.40	25
Dothan	1	0.0028	0.0015	14.1	1.25	35
Hartsells	1	0.003	0.0014	20.7	2.29	33
Linker	1	0.0036	0.0012	20.4	2.32	28
Maytag	1	0.0044	0.0015	19.7	2.43	23
Sucarnoochee	1	0.003	0.0029	17.5	–	33
Troup	1	0.0023	0.00115	5.55	1.37	43
Appling	2	0.0039	0.0012	51.1	1.49	25
Cecil	2	0.0028	0.0014	29.9	–	35
Colbert	2	0.0031	0.0021	19.7	3.49	32
Decatur	2	0.0045	0.002	17.8	3.41	22
Dothan	2	0.0029	0.0018	33.7	1.56	34
Hartsells	2	0.0043	0.0021	28.6	2.69	23
Linker	2	0.0035	0.0014	26.6	2.58	28
Maytag	2	0.0044	0.0013	35.3	2.36	23
Sucarnoochee	2	0.0049	0.0018	28.7	2.93	20
Troup	2	0.0025	0.00095	18.5	1.29	40

[a]k_1 and k_2 were calculated from graphs prepared by plotting organic N remaining after each incubation time against time. No second phase was identified in Sucarnoochee and Cecil soils amended with broiler litter 2. From Kpomblekou-A and Genus, 2012.

Table 5. First-order rate constants for decomposition of organic N in soil alone and broiler titter-amended soils.

3.4. Total and inorganic phosphorus contents of chicken litter

Broilers are typically fed corn–soybean blend mix fortified diets with vitamins and minerals. Corn and soybean meal contain on average 1.88 and 3.88 g/kg phytate-P, corresponding to 71.6 and 59.9% of the total P in their grains, respectively. Because broilers in their digestive system

lack phytase, an enzyme that splits P from the phytate molecule, P of the grain is not absorbed by the birds and therefore released into chicken manure. The reduction of nonphytate P and utilization of phytase enzymes to hydrolyze phytic acid in corn grains fed to poultry birds enabled a significant decrease in the total P in litters by 3.4–8.8 g/kg relative to normal diets [35]. The hydrolysis of phytate by addition of phytase to animal feeds increases endogenous P availability. Phytase addition not only increases P absorption and promotes healthy broiler growth, but also saves money that could have been spent on supplement P in broiler diets. Although enzymes have been successful in catalyzing the hydrolytic degradation of phytic acid and its salts, their high anticipated production costs have not convinced producers of their use as a suitable profitable alternative.

Thus, a major portion of phosphorus (P) in chicken litter originates from phytic acid and its phytate salts. The total P content of chicken litter (n = 33) sampled in Alabama varied between 1.58 and 3.20%. Fractions of the P removed by sequential extraction showed that they contain 29.5, 32.5, and 38.0% of organic, inorganic, and residual P, respectively (**Figure 3**). The organic fraction (**Figure 4**) contains sodium bicarbonate soluble-P_o (44.6%), microbial-P_o (27.2%), and sodium hydroxide soluble-P_o (28.2%). The inorganic P (**Figure 5**) is made of water soluble-P_i (40.2%), sodium bicarbonate soluble-P_i (10.1%), microbial-P_i (2.85%), sodium hydroxide soluble-P_i (2.83%), and hydrochloric soluble-P_i (44.0%). Although broiler litter is an excellent soil amendment that improves soil fertility of farmers' fields, its high P content puts broiler litter amended soils at risk and susceptible to P accumulation. Applications of chicken litter have resulted in accumulation of P in topsoil and its movement to depths. Results of studies conducted on six soils of southern Alabama showed a significant increase in the total P (**Figure 6**). The total P concentrations are higher in the chicken litter-amended soils than in their nonamended counterparts. In Bonifay soil, however, throughout the profile the total P concentration was higher in the nonamended soil than the broiler litter-amended soil. In many cases, the observed differences were statistically ($P < 0.05$) significant. In Fuquay soil, the application of chicken litter increased the total P concentrations from 263 to 835, 165 to 805, 121 to 244, and 153 to 1555 in the 15–30, 30–45, 45–60, and the 60–75 cm depths, respectively. Madison soil showed that the total P concentrations in the chicken litter amended soils were significantly different from the nonamended soils throughout the soil profile. The Bray 1-P concentrations (**Figure 7**) were ≦10 mg/kg for Madison and Malbis soils, <40 mg/kg in Orangeburg soils, and >75 mg/kg in the Bonifay, Dothan, and Fuquay soils. The Bray-1 extractable P accumulated in the 0–15 cm depth of each of the six soils following broiler litter application. Bonifay, Fuquay, Malbis, and Orangeburg soils showed accumulation throughout the profile and decreased as depth increases. Dothan and Madison soils showed an accumulation only in the 0–15 cm depth, but the accumulation was not significant in Madison topsoil. Bonifay and Orangeburg soil showed considerable accumulation down to 45 cm, but the accumulation was significant ($P < 0.05$) only at the 0–15 and 15–30 cm depths. Fuquay soil showed significant accumulation throughout the soil profile, and Malbis and Orangeburg soils showed similar trends. Elevated Bray 1 soil test P levels following a long-term application of manures and wastes have been reported [36]. The study found that several Oklahoma soils receiving a long-term application of broiler litter reported Bray 1 soil test several P levels up to 279 mg/kg.

Figure 3. Average P fractions removed by sequential extraction from broiler litter.

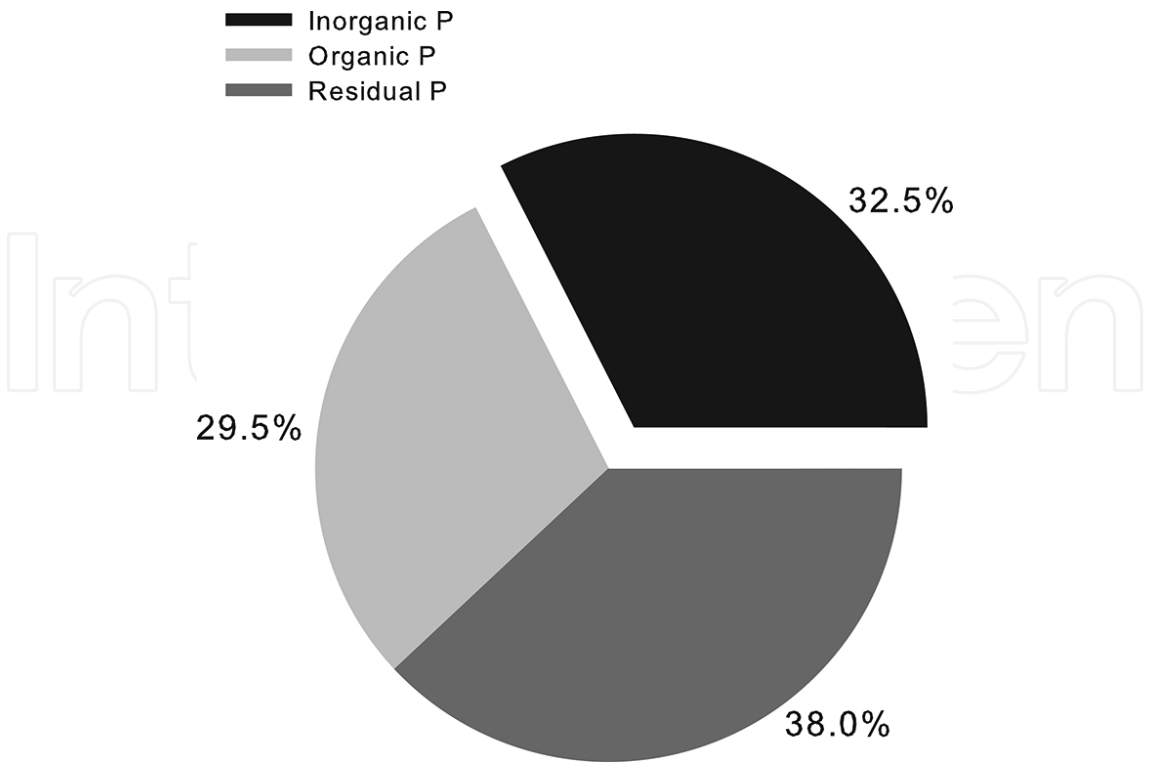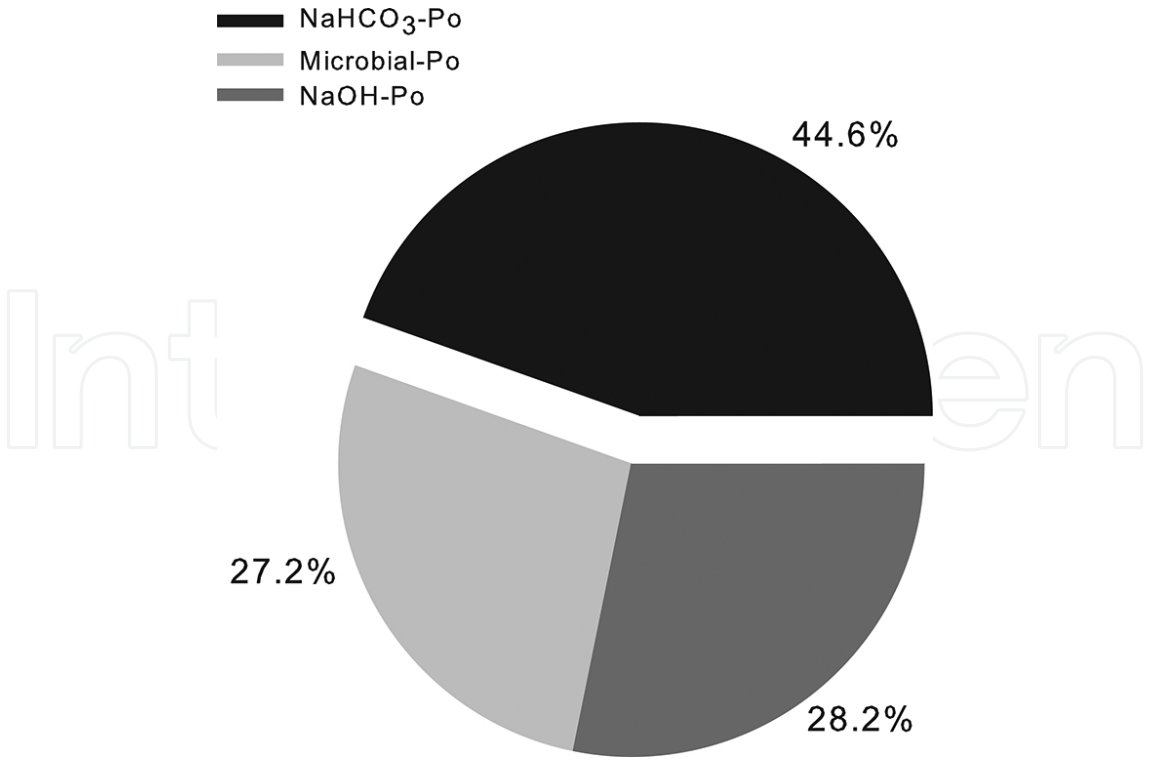**Figure 4.** Average organic P fractions removed by sequential extraction from broiler litter.
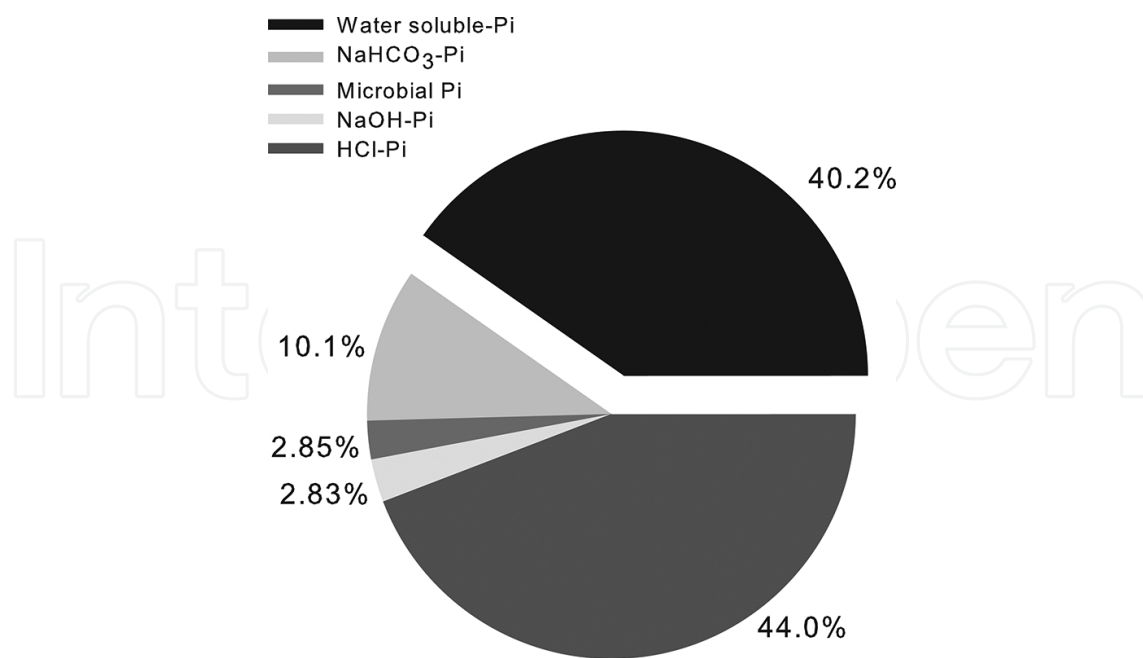
Figure 5. Average inorganic P fractions removed by sequential extraction from broiler litter.
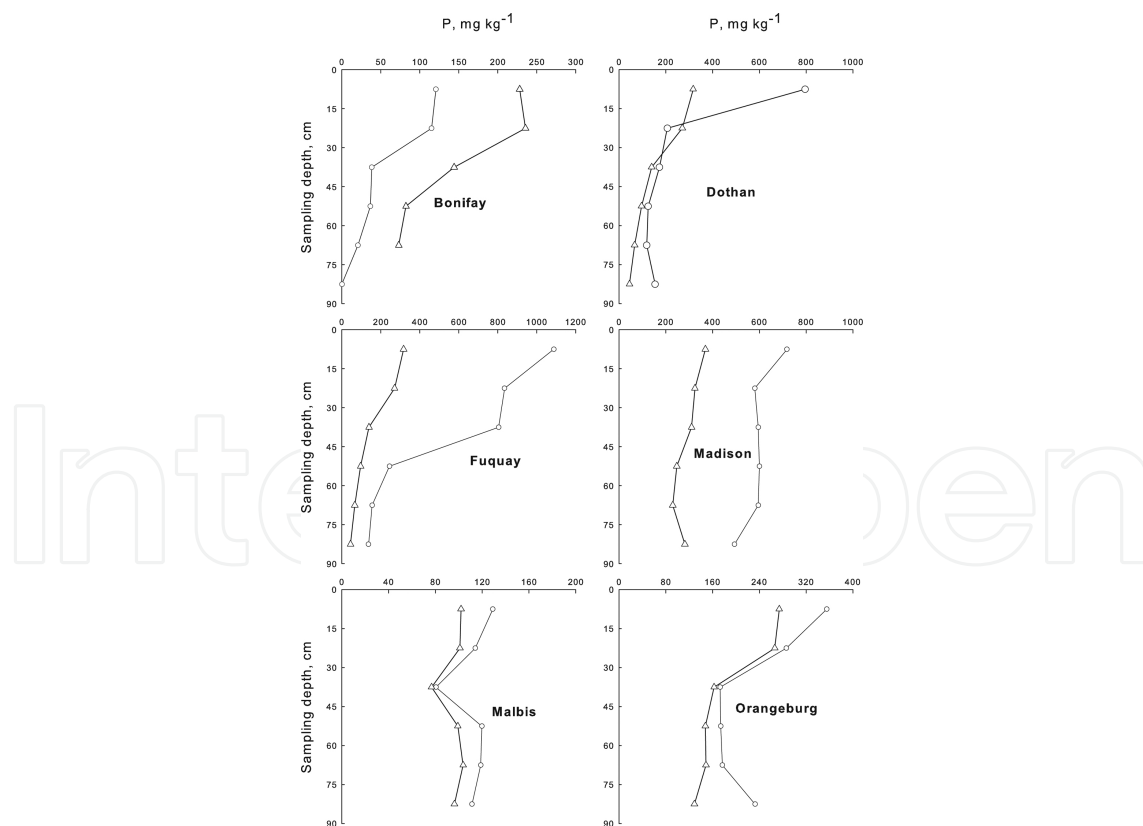

Figure 6. Distribution of total P in poultry littered (open circle) and nonlittered (open triangle) soils. Adapted from Dotson, 2000.
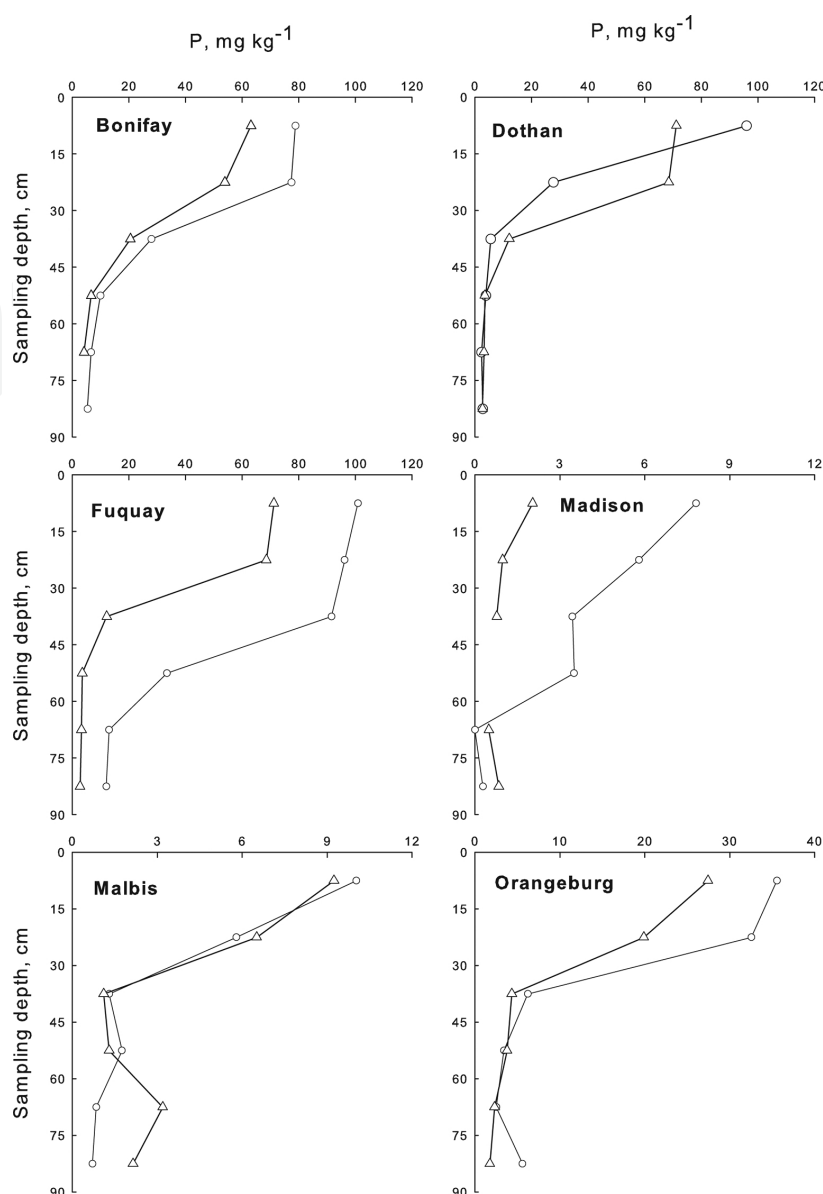
Figure 7. Distribution of Bray 1-P in poultry littered (open circle) and nonlittered (open triangle) soils. Adapted from Dotson, 2000.

The USEPA required Concentrated Animal Feeding Operations (CAFO) to develop and implement Best Management Practices that minimize phosphorus and nitrogen transport from fields to surface waters. The standard requires soil phosphorus not to exceed 200 ppm by 2018 and soil with greater than 400 ppm not to receive any poultry litter applications. It is in light of these requirements of the CAFO regulations that emerged the need to develop a chemical method that would reduce phosphorus content of poultry litter before its application to agricultural land in order to avoid a long-term builds up of phosphorus in soil. An extraction procedure was developed at Tuskegee University and includes steps of equilibrating an amount of chicken litter with an extracting solution [37]. After a contact time, the solution removes a significant amount of the phosphorus from the chicken litter. The chicken litter is

then separated from the solution to obtain phosphorus-depleted chicken litter. Phosphorus contained in the phosphorus-rich solution can be precipitated and recovered to fertilize soils that are phosphorus-depleted. The extracting solutions proposed removes excess quantities of phosphorus (about 90%) in the chicken litter while retaining other essential elements (e.g., carbon, nitrogen, and sulfur) needed for plant growth and development.

4. Crop responses to organic fertilizers

Conventional farming has evoked fears of pesticide residues in food and declining energy resources [38] and organic fertilizers such as poultry litter and fish emulsions improve crop vigor and yields, increase disease and insect resistance, extend shelf life of produce and enhance microbial activity and soil nutrients [39]. Organic nutrients such as manure or cover crops provide balanced nutrient combinations over a longer period because they are slowly released based on microbial transformation in the soil [40]. Studies on the influence of poultry litter and hydrolyzed fish fertilizer on various vegetable crops to determine impact on yield and quality, phytochemical contents and on soil microbial community, and chemical properties in the rhizospheres were conducted. These crops included Vegetable Amaranth (*Amaranthus hybridus*), a leafy vegetable similar to spinach [41], Celosia (*Celosia argentea*) commonly known as lagos spinach, quail grass, soko, celosia, or feather [42], and Gboma eggplant (*Solanum macrocarpon*) is grown for its fruit production as well as its leaves [43]. West African Okra (*Abelmoschus caillei*), a multipurpose herb grown either as an annual [44], Long Bean (*Vigna unguiculata*) popular in Asian countries, African Eggplant (*Solanum aethiopicum*) is high yielding, adaptable and can be grown and harvested in a wide range of climates [44], and sweetpotato [Ipomoea batatas (L.) Lam.]. (45, 46).

4.1. Materials and methods

Experiments were conducted on the Small Model Research Farm at the George Washington Carver Agricultural Experiment Station, Tuskegee University, on Norfolk sandy loam (fine, siliceous, thermic Typic, Paleudults) with a pH of 5.9 and organic matter content of less than 1%. The field was prepared conventionally and soil samples were collected for elemental analysis according to the method of [47] at 15 cm depths in a zig-zag pattern using an auger. The cores were composited and analyzed by the Plant and Soil Testing Laboratory at Auburn University, Alabama, USA, for mineral constituents (Ca, Mg, P, K, and pH).

Seeds for all species (or 15 cm long stem cuttings for sweetpotato) were sown in polystyrene trays filled with moistened Jiffy mix (Ferry Morse Fulton, Kentucky, USA) in a greenhouse. One seed was placed into each cell and covered with approximately 0.6 cm of medium. Trays were watered as needed and fertilized once per week with Peters 20–20–20 at the rate of 15 g per 3.78 L of water. Temperature in the greenhouse averaged about 36°C, and relative humidity and photosynthetic photon flux (PPF) were 40% and 1159 μmol/m^2 s, respectively.

4.2. Treatment calculations and planting

Treatment rates for each of the six species were based on soil test recommendations. Sources of nutrients were ammonium nitrate (34% N), triple superphosphate (46% P), muriate of potash (60% K), poultry litter (54% N), and Megabloom (2% N), a fish protein fertilizer. Organic amendments were calculated based on the total N content.

Poultry litter, unlike commercial fertilizers, is quite variable and according to ref. [48] can vary up to 50% based on animal sources. The available values of litter nutrients using data from Fulhage and Pfost [47] were total N of 54 lb/ton, comprised of 48 lb/ton organic·N and 6 lb/ton NH_4N, 59 lb/ton P_2O_5, and 38 lb/ton K_2O. In addition, the amount of organic N available was based on days from collection to incorporation, which is 20% beyond 7 days. The calculations were based on the following equation:

$$\frac{\text{crop N - residual N}}{\text{available } NH_4N + \text{available organic N}}$$

Ten plants from each species were transplanted into three-row plots 1.2 m × 6 m at the recommended within- and between-row spacing for each species and drip irrigation applied. Fertilizer treatments for each species were based on soil test recommendations and were applied in single bands approximately 15–20 cm away from the plants. Six plants of each species from the middle row only were harvested. Physiological measurements were performed once per week, starting approximately one week after planting. These included stem diameter, plant height, and leaf area. Plant height and stem diameter were measured on each species starting at 2 cm above the soil stem interface to the terminals (for the former) and at the widest section for the latter, and recorded as cumulative growth over time. Leaf area was determined from leaf samples collected at each harvest every two weeks, using a LICOR-1800 leaf area meter (LI-COR, Lincoln, Nebraska, USA). All species were harvested periodically throughout the growing season (succulent stems of Amaranth and Celosia of approximately 15 cm length were harvested every two weeks) and once over at the end of the season. Fresh weights of harvested samples were recorded and subsamples collected for nutritional analysis. Samples were dried in ovens at 65°C for 72 h and the dry weights recorded. These data were used to estimate fresh and dry biomass yield per unit area.

The sweetpotato study was conducted as a randomized complete block design with a 4 × 4 factorial treatment arrangement in three replications. The treatment factors were conventional NPK fertilizer, poultry litter, Megabloom (fish fertilizer; FSH), and an untreated check (O). The sweetpotato cultivars were J6/66, NCC-58, TU Purple, and Whatley-Loretan. Treatments were split-applied at the rate of 134–67–67 kg/ha NPK equivalent based on soil tests recommendations one and four weeks after planting as single bands 15 cm from the plants.

Triplicate rhizosphere soil samples from each plot were taken at harvest, composited and analyzed for pH, organic carbon (SOC), and enzyme activity. pH was determined using 1:2.5 soil/water and SOC using the wet oxidation method [49]. Phosphomonoesterases activity was determined by the method of ref. [50]; β-glucosidase and N-acetyl-β-glucosaminidase activity

by assay [51, 52]; and whole DNA by Power Soil Extraction Kit and quantified using spectro-photometer. Pooled DNA samples were tested for PCR optimization and pyrosequencing analysis (Research and Testing Labs, Lubbock, TX, USA).

5. Results and discussion

Organic amendments had no significant influence on fresh and dry biomass production, while species exerted a greater impact, and there were no significant interaction between organic amendments and species for any biomass variable (data not shown). Plants treated with Megabloom produced greater fresh fruit biomass (774, 572, 345 kg/ha, for Megabloom, NPK, and poultry litter, respectively), whereas NPK-treated plants produced greater dry biomass (302, 297, and 226 kg/ha, for NPK, Megabloom, and poultry litter, respectively). Although Amaranth, Celosia, and Okra produced greater total biomass, it was not statistically different from that of either Gboma or Longbean. Gboma plants had larger leaves than Amaranth and Celosia but similar to Longbean, Okra, and Eggplant. Amaranth and Okra plants were taller than the other species, with Amaranth having the greatest stem diameter but Okra having the highest total number of fruits than the other species (**Table 6**).

Species	Fresh (kg/ha)	Dry (kg/ha)	Fruit (kg/ha)	Leaf area (cm^2)	Plant height (cm)	Stem diameter (cm)
Amaranth	2015ab	357ab	–	36b	52b	1a
Celosia	2094ab	455a	–	35b	42b	1a
Gboma	911b	111c	–	53a	8d	0.5d
Longbean	2471a	1078a	1354a	48a	8d	0.6d
Okra	1490ab	269bc	898b	46ab	55a	0.7cd

[a]Mean separation within columns followed by the same letter are not significant based on LSD, 5% level.

Table 6. Main effect of species on the total biomass yield, leaf area, plant height, and the stem diameter of vegetables[a].

There were significant interactions between organic amendment and the different species for contents of vitamin C, betacarotene, total phhenolics, and total antioxidant capacity (**Table 7**). Effects of the interaction between Amaranth and fertilizer amendments on vitamin C showed the highest content among plants receiving NPK compared to the other two treatments. The betacarotene content was similar among plants receiving both Megabloom and poultry litter and substantially greater than plants receiving NPK (**Table 7**). The total phenolic content was higher with NPK whereas plants receiving Megabloom had higher 2,2-diphenyl-1-picrylhy-drazyl (DPPH) activity. Results of the interaction between Celosia and organic amendments on nutrient content show that NPK enhanced vitamin C content and, along with Megabloom, betacarotene content. There were greater total phenolics among plants receiving Megabloom followed by those receiving poultry litter, and DPPH activity was similar among plants receiving Megabloom or NPK. For Gboma, vitamin C content and DPPH activity were

enhanced among plants treated with Megabloom, whereas NPK significantly increased the betacarotene content compared to those of the other treatments.

ORAMD[a]	Vitamin C (mg/100g)	Betacarotene (mg/100g)	Total phenolics (mg/100 g)	antioxidant capacity[b] (μmol AAE/g)
Amaranth				
Megabloom	156	91.6	467	30.6
NPK	188	77.9	542	25.3
Poultry	133	93.5	362	24.5
Significance	***c	***	***	***
Celosia				
Megabloom	163	81.1	400	30.7
NPK	197	87.9	420	31.8
Poultry	185	54.2	440	19.8
Significance	***	**	***	***
Gboma				
Megabloom	160	189.4	200	77.2
NPK	102	200.2	304	68.6
Poultry	102	157.8	453	57.2
Significance	***	***	***	***
Longbean				
Megabloom	–	–	556	47.1
NPK	–	–	592	37.1
Poultry	–	–	401	39.8
Significance	–	–	***	***

[a]ORAMD, organic amendments (poultry litter, Megabloom-fish protein-based).
[b]2,2-Diphenyl-1-picrylhydrazyl (DPPH) % radical scavenging quenched.
[c]Significant at $P = 0.01$ (*), $P = 0.001$ (**), $P = 0.0001$ (***).

Table 7. Effect of interaction between species and fertilizer amendments on nutrient content of vegetables.

Interaction between Longbean and fertilizer amendments on nutrient content was not determined for vitamin C and betacarotene due to sample size. The total phenolic content was similar among plants receiving megabloom and NPK, whereas DPPH activity was significantly greater among plants receiving Megabloom.

These results indicated that species exerted a stronger influence on yield than organic amendments. Longbean had a 44% greater fresh biomass than okra or eggplant and a 24% greater

fresh fruit yield. However, okra produced 52% greater total fruit number than longbean or eggplant. Eggplant had greater leaf area and stem diameter than the other fruit-bearing species whereas okra plants were taller. Among the leafy greens, Amaranth and Celosia produced a 39% greater fresh and dry biomass yield than Gboma that had a 19% greater leaf area. Amaranth and Celosia were taller than Gboma and had thicker stems. Although organic amendments had no significant impact on biomass, there were trends toward a positive response by the plants. For example, plants receiving poultry litter produced 10% greater fresh and dry biomass. Similarly, plants receiving Megabloom had 23% greater fresh fruit biomass than those treated with NPK, whereas the total fruit number and leaf area and NPK-treated plants were 15% higher (Table 6).

Nutrients in organic fertilizers are released through mineralization by soil microorganisms [53]. Depending on soil conditions such as pH and moisture content, mineralization rates can be impacted. It is probable that the lack of response to organic amendments in this study could be due in part to slow mineralization rates resulting in fewer nutrients available for plant uptake [53]. In fact, Whitmore [54] reported that 40% of the total N from composted chicken litter was available in the first year and the remainder at the rate of 6–12% per year thereafter because of the slow mineralization rates, and researchers have recommended applying 50% more organic fertilizer 14–20 days earlier than normal to compensate for slow mineralization rates.

Nutrient content of the vegetables varied with species. NPK enhanced vitamin C and total phenolics in Amaranth but not betacarotene or DPPH activity. These results are inconsistent with those of Wheeler et al. [55] and Muso and Ogaddiyo (in kale and hibiscus) [56] who reported lower vitamin C with increased nitrogen fertilization. The increase in vitamin C could be due in part to a decrease in protein production and an increase in carbohydrate production [54]. High vitamin C in the leaves may make plants more tolerant of stress since reducing vitamin C increases susceptibility to stresses [57].

All three amendments enhanced betacarotene content. Megabloom and poultry litter amendments produced similar levels in Amaranth similar to Megabloom and NPK in Celosia and Gboma. This increase is probably due to increased chlorophyll from nitrogen and or light-absorbing pigments including carotenoids that are critical in photosystems I and II of the photosynthesis process [54]. Indeed, research has shown that light enhances the biosynthesis of phenolics in the chloroplasts of the cells and thus tends to accumulate in high amounts in the vacuoles or deposits in secondary cell walls as lignin [58].

Betacarotene content of Amaranth, Celosia, and Gboma increased with time for all species up to 51 days after transplanting except for Amaranth and Gboma plants receiving NPK. The betacarotene content of Amaranth plants receiving NPK appeared to decline with time whereas Celosia plants receiving NPK increases substantially with time (data not shown).

Sweetpotato results showed an interaction between the fertilizer amendments and cultivar for rhizosphere pH that varied depending on cultivar and cultivar response varied with pH (data not shown). The pH was lowest in rhizospheres of Whatley/Loretan and NCC-58 receiving Megabloom, and generally, pH ranged from 6.1 to 6.8. Thus, fertilizer amendments lowered

rhizosphere pH values with TU Purple plots receiving PL and Whatley/Loretan and NCC-58 plots receiving Megabloom, having the lowest values, respectively. SOC was similar among amendments but was highest for TU Purple and J6/66 and ranged from 0.63 for Whatley/ Loretan to 1.07 for J6/66 (data not shown). Storage root yield was similar regardless of the amendment applied ranging from a low of 12.0, 10, 21.1 t/ha for control and plants receiving NPK, respectively (**Table 8**).

Fertilizer amendments	Root yield (t/ha)	ACP (µg p-nitrophenol (per g soil/h))	ALKP (µg p-nitrophenol (per g soil/h))	βNAG (µg p-nitrophenol (per g soil/h))	βGLU (µg p-nitrophenol (per g soil/h))
Con	12.0	172.89[a]	2.21a	16.56	13.05
PL	19.7	287.71[b]	7.06b	31.39	45.86
FSH	18.1	329.99[b]	7.41b	23.14	48.25
NPK	21.1	308.66[b]	7.69b	29.40	49.47
Significance	NS	*	**	***	**

[a]ACP, acid phosphatase; ALKP, alkaline phosphatase; βGLU, β-glucosidase; βNAG, β-glucosaminidase.
*, **, ***significant at 0.05, 0.01, 0.001 levels of probability.

Table 8. Main effect of fertilizer amendments on storage root yield soil enzyme activity[a].

Therefore, the addition of organic amendments increased both soil enzyme and microbial activity, which is consistent with the findings of others [59–61]. NPK-treated plots had higher enzyme activity compared to the controls and, the organic amendments as a nutrient source did not adversely affect enzyme activity relative to NPK treated plots.

In general, the addition of fertilizer and organic amendments had a significant impact on bacteria at every taxonomical level while TU Purple and Whatley/Loretan impacted the *Gemmatimonadetes* at every taxonomical level (**Table 9**).

Class	Con	BL	NPK	FSH
Actinobacteria	6.69b	6.60b	7.78ab	9.29a
Chloroflexi	1.83a	1.55a	1.50a	0.59b
Cytophagia	1.56a	1.36a	1.36a	0.75b
Δproteobacteria	4.80a	4.34ab	4.43a	3.06b
Rubrobacteria	1.82b	1.73b	2.26ab	3.03a
	Cultivars			
	TU Purple	J6/66	NCC-58	Whatley/Loretan
α-Proteobacteria	3.62b	4.17b	3.50b	5.34a
Gemmatimonadetes	3.10bc	3.44b	2.57c	4.34a

Means with same letters in rows are not significantly different Tukey's (0.05).

Table 9. Effect of fertilizer, organic amendments, and cultivars on class bacterial composition of sweetpotato rhizosphere.

The results indicated that *Proteobacteria* was the most dominant phylum and class identified, of which three of its classes (*alphaproteobacteria, betaproteobacteria,* and *gammaproteobacteria*), as well as the class *actinobacteria*, were the most prevalent in the class groups. This observation is consistent with the literature that proteobacteria are ubiquitous in the soil ecosystem. TU Purple and Whatley/Lortan significantly impacted *Gemmatimonadetes* at every taxonomical level suggesting that these cultivars produce exudates that may attract these bacteria. Bacteria belonging to phylum *Gemmatimonadetes* are frequently detected in a variety of environments and are noted as one of the nine most commonly found phyla in 16S rRNA genelibraries from soil [62, 63]. Further, *emmatimondetes* play a role in P cycling by improving P removal in wastewater and could play a similar role in soil.

6. Conclusions

The impact of organic amendments on biomass production varied based on the species that were grown as plant species exerted a stronger influence on biomass production than the organic amendments. Vitamin C content was enhanced by NPK fertilizers for Amaranth and Celosia and by Megabloom in Gboma, similar to what others reported [64]. Gboma also showed higher radical scavenging (DPPH) than the other species. DPPH values according to reference [65] showed that the normal values are 37.7–89.5 with Gboma and Longbean in range or surpassing these values. Overall, these results show that organic amendments exerted inconsistent influences on phytochemicals. Thus, based on yield and phytochemical content, these vegetables can potentially be produced successfully on these sandy loam soils in South Central Alabama using organic amendments, but more conclusive data through additional studies are required. For sweetpotato, the results show that bacteria associated with C and N cycling under aerobic conditions can dominate in their rhizosphere.

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