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Impacts of Pastured Poultry on Soil Fertility in a Mixed Silvopasture System in Western North Carolina

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Abstract

Current land management techniques practiced in conventional agriculture such as crop-livestock specialization, excessive tillage, and excess synthetic fertilizer application have degraded soil health and inhibited ecosystem services. Many sustainable agriculture management techniques offer potential to restore degraded soil and improve ecosystem services - one being silvopasture. Silvopasture, the incorporation of trees and animals for land management, is a non-conventional agriculture technique intended to improve soil health and fertility by promoting a closed - loop nutrient cycle that maintains essential ecosystem services. To determine the potential improvement in soil health from poultry rotation, a treatment - control block study was conducted in a no-till silvopasture farm system in Western North Carolina. The silvopasture consists of broiler (meat) chickens rotated daily through fruit and hazelnut tree lanes during the spring, summer, and fall seasons. The purpose of rotation is for the poultry to have access to new bedding and grazing areas while fertilizing the field with their nutrient-rich waste, stimulating plant growth, and improving soil nutrient content. Soil health parameters of bulk density, organic carbon content, and nitrogen and phosphorus concentrations were assessed monthly from May to August 2025. The treatment fields in the silvopasture poultry system exhibited decreased bulk density and increased soil carbon content relative to the non-poultry control fields. This indicated that the broiler silvopasture system did improve the soil fertility, particularly in the shallow surface soil. Longer term studies are recommended to determine if improvements in soil fertility last beyond a single agricultural season and to measure the rate of deeper subsoil carbon sequestration as a result of multiple years of this silvopasture system. However, evidence of short-term soil carbon increase combined with the potential for long-term carbon sequestration provide quantifiable insight into the efficacy of this sustainable agriculture practice in improving ecosystem services and soil health.

Introduction

Industrialized agricultural systems, such as CAFOs (Controlled Animal Feeding Operations) and monocrop fields, are made possible with new scientific understandings, low-cost inorganic fertilizer, and rapid mechanization of farm equipment to allow high yield and outputs with lower labor inputs (Steiner & Franzluebbers 2009; Franzluebbers & Martin 2022). These large agribusiness farms not only account for the majorities of beef and grain production (~80%) in the U.S (Franzluebbers & Martin 2022) but also account for a proportional amount of land disturbance and soil degradation. Forty percent of global soil is considered degraded with twelve million hectares of global soil degradation being attributed to agriculture (UNCCD 2022; FAO 2015). Conventional management techniques practiced in large agribusiness farms can degrade fertile soils to a point where the soils cannot ecologically function and become dependent on intense synthetic inputs. Two land management practices that can negatively influence the ability of growing fields are tillage and overuse of inorganic fertilizer input. Frequent, continual tillage disrupts physical soil structure and promotes erosion or hardpanning (Al-Kaisi & Licht 2004). Disrupting the soil aggregation and forming a platy hardpan subsequently increases bulk density. Excessive inorganic fertilizer has also led to a reduction in microbial diversity and organic matter containing plant nutrients such as carbon, nitrogen, and potassium - both necessary for sustaining arable land (Tripathi et. al. 2020). Both of these practices are widely used in industrial agriculture compounds and can negatively affect soil fertility and therefore affect long-term crop yields. For these reasons, alternative techniques seek to minimize or even offset some of the environmental impacts driven by industrial agriculture.

An alternative farming strategy that is being scientifically assessed is silvopasture. Silvopasture is a farming technique that utilizes the relationships between trees, animals, and pasture as an integrated system. This differs from the dominant conventional strategy today where crop and animal production are exclusive to one another (Russelle and Franzluebbers 2007). By integrating animal and cropping systems, co-benefits such as waste nutrient cycling and biological tilling are present in a closed - loop system and a reliance on things such as outside farm input and extensive tillage are less necessary (Russelle and Martin 2022).

The purpose of this study was to evaluate the effects of poultry rotation through a silvopasture system consisting of fruit and hazelnut trees in WNC. Integrated rotational poultry is a type of animal-crop integration which consists of pasturing chickens, in this case broilers, through paddocks to graze. While grazing, the broiler chickens excrete litter which is high in plant nutrients such as phosphorus, carbon, and nitrogen. After the chickens are matured and processed, vegetables or crops are usually planted next in the rotation to uptake the nutrients left by the poultry litter (Hilimire et al 2012; Carey et al 2025).

Limited investigations of integrating poultry in vegetable and orchard systems have shown increases in total nitrogen, carbon, and organic matter stocks (Hilimire et al 2012; Carey et al 2025), which indicate an improvement in soil fertility. However, these studies have been geographically limited to the west and midwest portions of the United States. The Southeastern U.S. has optimal conditions for high agricultural production with warm, humid climates in states such as the piedmont Georgia, Alabama, and North Carolina (Franzluebbers 2007). The Blue Ridge Mountains, however, present a different perspective with diverse microclimates in the valleys. These microclimates separate farming systems in the valleys from the southeastern climate classification and thus require targeted scientific investigation to see how intensive silvopasture practice affects soil properties. Moreover, research in the rotation of animals rather than crops throughout a field paddock is lacking. The mountainous regions of Western North Carolina also have unique soil and landscape processes that distinguish this region apart from the rest of the US. This study will explore how integrating animals within a fruit and nut tree system affects soil fertility in Western North Carolina. The objectives of the study are:

1) to determine how soil nutrients (carbon, nitrogen, and phosphorus) are affected by pastured poultry (treatment) compared to non-poultry areas (control) and

2) To determine how the soil property of bulk density is affected by pastured poultry (treatment) compared to non-poultry areas (control).

Methods

Site & Experimental Design

This study was conducted in partnership with Wild East Farms located in Marion, North Carolina (Figure 1). Prior to 2023, the land was used as grazeland for horse and cattle (Figure 2). In 2023, a portion of the land was converted to a silvopasture with a diverse mix of fruit and nut trees. The animals that were rotated through the pasture included turkeys, chickens, and sheep, although dominated by poultry (broiler) production. The soil in the test site is predominantly a Dillard loam (Fine-loamy, mixed, semiactive, mesic Aquic Hapludults). A hydrometer test was conducted in the silvopasture and in the surrounding edges to confirm similar soil textures. The project was conducted from May 2025 to August 2025 as a treatment - control comparison where the treatment field was the silvopasture affected by rotational pastured poultry and the control was not affected by poultry.

Both silvopasture treatment and control were replicated five times in 6 m x 9 m block plots. Control replications were selected along the edge of the silvopasture field and treatment replications were selected in the silvopasture field centrally (Figure 3). Each 6m x 9m plot was split into three equidistant sections for soil sampling. In each section, three soil probes were taken with an open - end soil probe and homogenized based on depth: 0-10cm is denoted as “shallow” and 10-30 cm is denoted as “deep” to evaluate short-term

Figure 1. Aerial view of Wild East Farms located in Marion, NC (2025).

Figure 2. North Field in April 2022 prior to Wild East Farm's arrival. Before food production, the farm was historically used for large animal grazing and recreation.

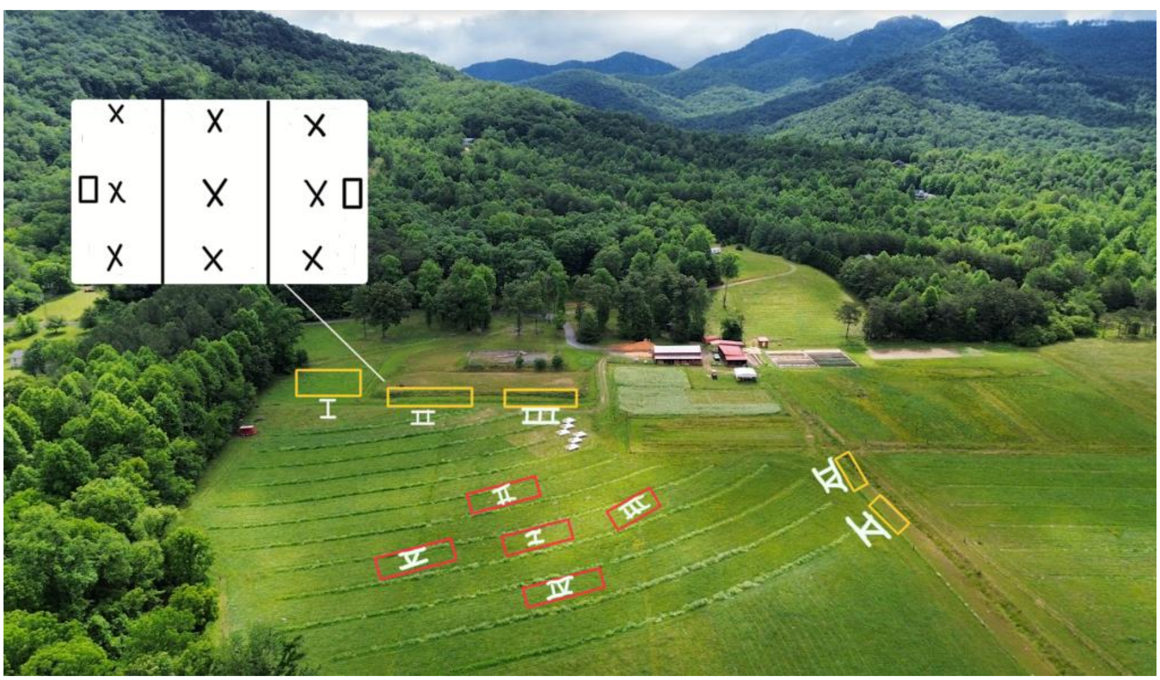

Figure 3. Experimental design schematic. Control plots are designated by the color yellow and silvopasture treatment plots are placed centrally in the silvopasture field designated red. A conceptual design for each plot is located on the top left of the figure, where the plot was separated in 3 equidistant transects. "X" marks where soil probes were taken, and boxes indicate bulk density samples.

and long-term soil nutrients (n=60; 30 shallow & 30 deep). Bulk density samples were taken with a 5 cm x 15.24 cm slide-hammer soil core sampler. A 5 cm x 15.24 cm cylinder plastic sleeve was put into the slide-hammer to preserve the soil structure and minimize aggregate disturbance during extraction. Two bulk density samples were taken in each replication (n=20). All soil samples were preserved in coolers in the field and transferred to a freezer to preserve for further analysis. Soil samples were collected once a month from May through August.

Broiler Chicken Rotation & Management

Meat chickens, otherwise known as broilers, were rotated throughout the silvopasture system during the spring and fall seasons. The rotation breaks during July or August to reduce risk of loss due to heat exposure. Broiler chickens were received in batches of 500 - 600 chicks per shipment. Chicks were matured in a broiler for three weeks before being pastured. Four batches of broilers from March 26 to June 30 were pastured for the spring rotation season. The fall rotation began on Aug 26 and ended late November. Paddocks for broilers were moved daily through the tree lanes. Per one rotational season, tree lanes received only one pass of broiler input.

Broiler chickens were contained with a low - volt electrical fence. Within the fence, a shade structure was provided for the chickens to reduce heat exposure risk (Figure 4). Due to the nature of broilers, shade structures do not require a roosting structure. Broilers were provided with water and enough feed to still encourage foraging.

Figure 4. Poultry shade structure, known as a poultry tractor, contained by a low voltage electrical fence (left) and a batch of broiler chickens when transferred from brooder to silvopasture (top).

Soil Analysis and Calculations

All frozen soil samples were air dried for analysis and sieved to 2 mm diameter to remove gravels and roots. Soil organic carbon (SOC) was estimated using the loss-on-ignition (LOI) method (Konen et. al. 2002). Inorganic nitrogen (nitrate) and phosphorus (phosphate) were quantified via spectrophotometry (Hach DR 3900) after a 2M potassium chloride extraction. Bulk density (BD) cores were air dried and extracted from the 5 cm x 15.24 cm cylindrical plastic sleeve to be weighed. Bulk density was calculated as mass divided by volume in grams per cm^3. SOC_{stock} was determined by the following equation: $SOC_{Stock} = BD * D * SOC (\%)$ where *BD* is bulk density (g/cm^3), *D* is depth in soil (cm), and *SOC (%)* is the percentage of soil organic content (Fowler et al 2023).

Statistical Analyses

Statistical analyses and data visualizations were performed in statistical software R (version 2025.5.1.513.3) (Posit team, 2025) using *ggplot2* (Wickham & Sievert 2016). The data were aggregated and assessed by treatment (silvopasture) versus control (no silvopasture) for bulk density, extractable nitrate, extractable phosphate, and soil organic carbon. The depth factor (shallow versus deep) was analyzed for soil organic carbon. All data and statistical models were assessed for assumptions of normality and heteroskedasticity. If parametric statistics assumptions were met then an ANOVA was used to test differences between groups. If the parametric assumptions were not met then a non-parametric Wilcoxon rank sum test was used to evaluate statistical difference between groups. A p-value of $p < 0.05$ was used as the threshold for statistical significance.

Results

On average, bulk density in the silvopasture treatment plots ($\bar{x}$ = 1.24 g/cm^3 ± 0.06 g/cm^3) was found to be significantly lower than bulk density in the control plots (Figure 5) ($\bar{x}$ = 1.42 g/cm^3 ± 0.17 g/cm^3) (p =.00212). For soil organic carbon, a Wilcoxon rank sum test showed a significant difference between control and silvopasture treatment fields in the shallow depth soil samples (Figure 6) ($p=5.41e^{-6}$ r= 0.419). A Wilcoxon rank sum test also showed a significant difference between control and silvopasture treatment fields in the deep subsoil layer (Figure 6) (p = 0.005123, r = 0.267). SOC_{stock} was determined by using the mean averages of bulk density and SOC % (Table 1). The depth was set at 15 cm per the bulk density sample's max depth. SOC_{stock} for the silvopasture was 31.58 (Mg/ha). SOC_{stock} in the control field was 28.39 (Mg/ha). On average, nitrate concentration in treatment silvopasture was 7.23 ± 2.21 (mg/L) and 5.98 ± 2.27 (mg/L) in non-poultry control areas. The difference found in NO_3^- concentrations between control and silvopasture treatment was not statistically significant. (p=0.13) (Figure 7). An average concentration of .12 PO_4^- was found in the treatment silvopasture. There was no detectable PO_4^- found in control fields.

Table 1. Nitrate concentrations, phosphate concentrations, soil organic carbon (SOC), bulk density, and SOC_{stock} means (± S.D.).

	Nitrate (mg/L)	Phosphate (mg/L)	SOC (%)*	Bulk Density (g/cm^3)*	SOC_{stock} (Mg/ha)
Treatment	7.23 ± 2.21	0.12 ± .18	1.67 ±0.1	1.25 ± 0.06	31.58
Control	5.98 ± 2.27	No detection	1.33 ± 0.3	1.45 ± 0.17	28.39

* $p < 0.05$ shows statistical significance in the differences between "Treatment" and "Control" in respective columns.

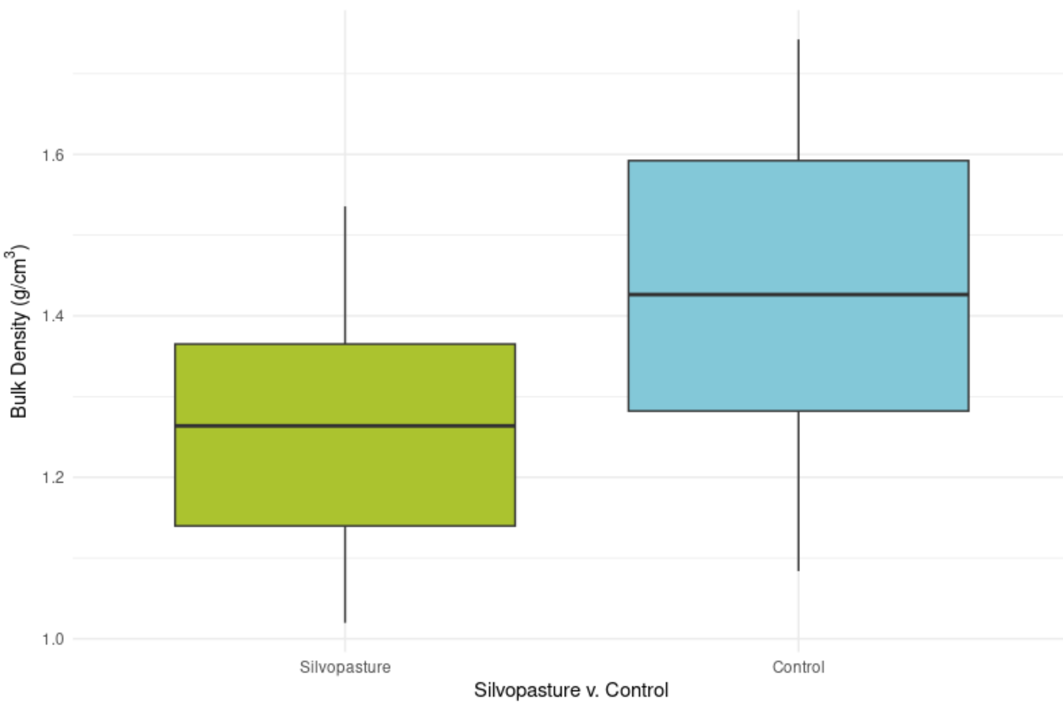

Figure 5. Boxplot comparing the bulk densities (g/cm^3) between silvopasture treatment and control fields. There was a statistically significant difference between silvopasture treatment and control.

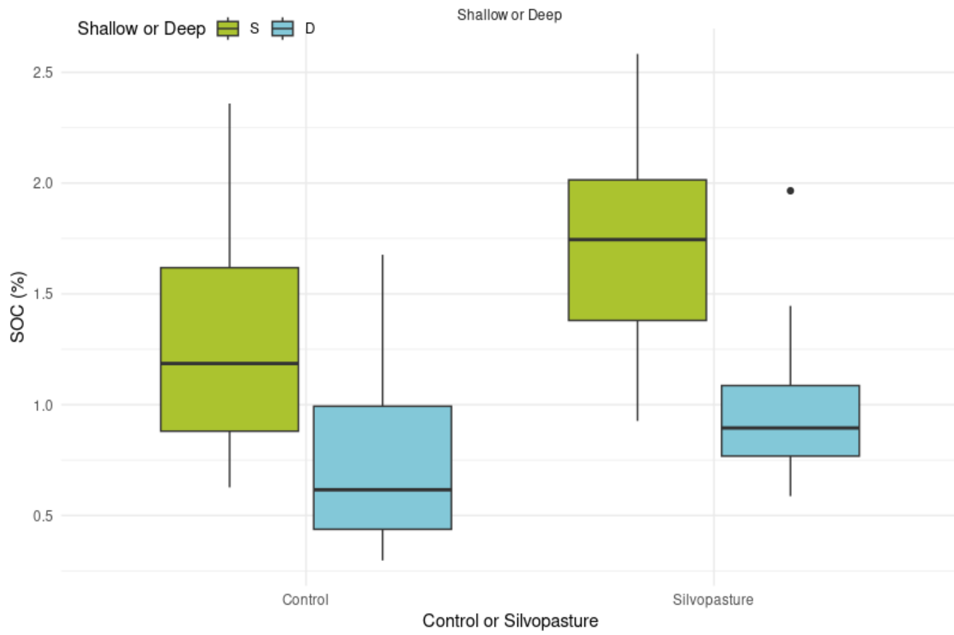

Figure 6. Boxplot comparing soil organic carbon (%) in both control and silvopasture treatment. Shallow (0-10 cm) carbon (green) and deep (10-30 cm) carbon (blue) concentrations are also shown. There was a statistically significant difference in SOC % between shallow and deep in both control and treatment. The shallow silvopasture treatment SOC % was also significantly higher than the shallow control SOC %.

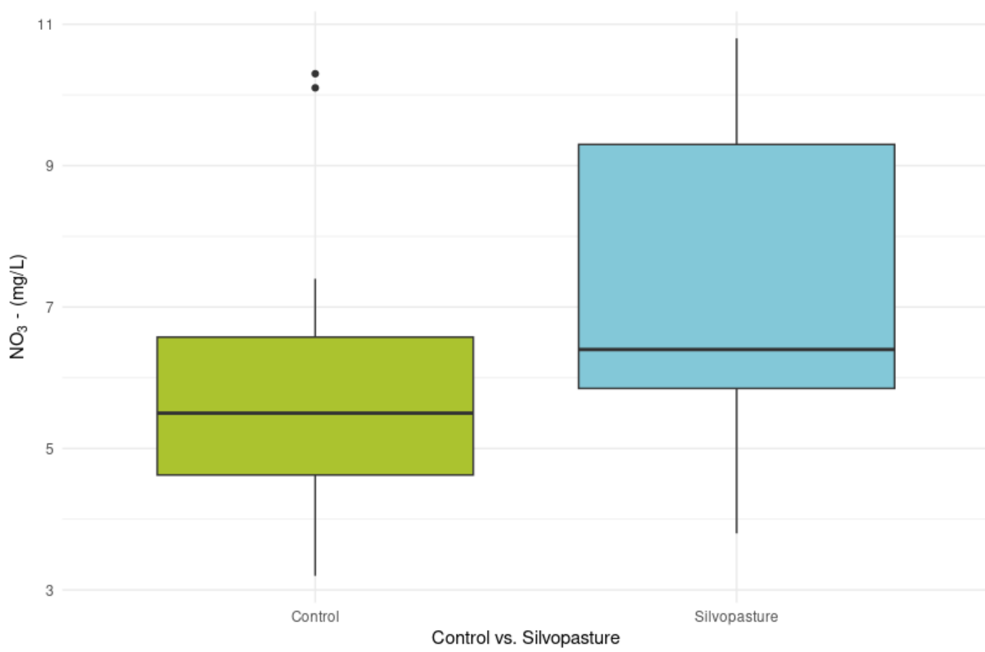

Figure 7. Boxplot comparing nitrate (mg/L) (NO_3^-) concentrations between control and silvopasture treatment plots. The difference in nitrate concentrations between control and silvopasture was not significant ($p = 0.13$).

Discussion

Nitrogen (N) and phosphorus (P) in soil is associated with soil fertility that enhances plant growth and organic matter accumulation but in excess, these nutrients can cause pollution. Nitrate, NO_3^-, and phosphate, PO_4^-, can contaminate water from runoff due to an excess of the compounds that flora cannot uptake fast enough. In the case of pastured poultry, N and P from the poultry waste applied on a silvopasture field could enhance soil fertility. Though if too highly concentrated then excess N and P could be a pollutant concern via runoff (Carey et al. 2025). In this study, the only detectable extractable soil phosphate concentrations were found in the pastured poultry treatment. There were no detectable phosphate concentrations found in the non-poultry control fields in the control area. This indicates that poultry litter is a source of phosphorus contributing to soil fertility. Extractable nitrate concentrations were detected in both treatment and control plots but did not show a statistical difference between treatment silvopasture and control. Though indicating no significant difference, nitrate on average was higher in the silvopasture compared to the control. This likely indicates that while poultry could add excess N and P to a soil system, in this case, the rotational pattern was not overwhelming the treatment field with concentrations high enough to cause pollution issues. Some of the N and P could have been incorporated into biological processes forming more soil organic matter too. Organic colloids can increase pore space and pore connectedness, allowing for water to go deeper into the soil system which could allow for plants to have more time to uptake those nutrients.

Soil carbon is a critical soil fertility measurement associated with carbon sequestration and productivity. Measuring SOC is complex and it is important to note that the loss on ignition protocol is an indirect measure and has many documented biases; so, coupled with natural spatial heterogeneity of soil systems, variations in SOC content can be expected, and were observed (Hoskins 2002). Higher SOC content in the shallow (0 cm-10 cm) of soil compared to the deeper (10 cm - 30 cm) soil was expected and was confirmed. As soil microfauna decomposes fresh organic matter, ultimately turning it into soil organic matter, it accumulates and is reintroduced into the soil from the top down explaining why more organic carbon was found in the soil surface layer as opposed to sublayers. A significant difference in soil organic carbon was found in the shallow (0 cm-10 cm) soil layer between the silvopasture treatment and control field, indicating that the poultry litter additions were actually contributing to measurable soil carbon accumulation. Furthermore, the silvopasture had a significant difference in deeper (10 - 30 cm) organic carbon compared to the control site. Both control and pastured poultry silvopasture had similar amounts of above ground vegetative biomass which leads to the conclusion that the dominant process contributing to carbon difference was the impact from pastured poultry. Accumulation of SOC in the subsoil was indicative of healthy soil capable of long-term carbon sequestration. This contributes to the idea that pastured poultry does have a significant impact on carbon dynamics and can restore ecosystem services while contributing to soil fertility.

Another indicator of soil fertility is the physical property of bulk density. Bulk density is a way to measure the compaction of a soil system (Arshad et al 1996) and necessary for determining SOC_{stock} (Fowler et al 2023). Soil compaction is commonly attributed to intensive land use, such as overtillage and heavy traffic from large livestock over long periods of time. For these reasons, the potential advantage of having smaller livestock in a silvopasture system is a reversal of previous compaction. Organic colloids created from the addition of poultry litter are less dense than the mineral contents of the soil (Sharma and Warren 2024). Root channels from silvopasture trees could have affected bulk density values in the surface layer, but are only 1 year old. Therefore, it was assumed the trees had minimal impact on soil aggregation in that time period. Literature on the effects of broiler chicken litter on bulk density has shown either a decrease or no change to bulk density values, supporting the finding in this study (Feng et al, 2019; Carey et al 2025). Further investigations indicate that another soil property of soil texture plays a role in determining how pronounced the impacts of chicken litter is on physical properties (Carey et al. 2025; Liu et al., 2020; Fu et al., 2022; Yan et al., 2023). This study was conducted in a Dillard loam type soil where a significant difference was observed in the bulk densities of the control plots and silvopasture treatment plots. Treatment silvopasture plots showed lower bulk densities than control plots. This indicates that Hydric, moderately drained, alluvial soil type can be a viable soil type for poultry litter addition to impact soil physical properties. Furthermore, how the litter is applied to the system could result in differing impacts as well. For example, fresh chicken litter from pastured poultry might have a more sustained impact on soil organic carbon as opposed to mechanically applied poultry litter.

SOC_{stock} can be used to evaluate how well a soil system can effectively accumulate carbon. It is integral to understanding its capability at achieving larger ecosystem services like sequestering carbon long-term. In this case, the SOC_{stock} 15cm deep in the treatment field (31.58 Mg/ha) was 3.2 Mg/ha more than the SOC_{stock} in the control fields (28.39 Mg/ha). Soils across North Carolina in no-till systems have been cited to have SOC_{stocks} averaging 28.9 Mg C ha^{-1} 0 to 10cm in depth when including surface residue C, corroborating the possibility of poultry litter increasing SOC_{stocks} (Franzluebbers 2023). Neither silvopasture nor control fields received surface tillage, eliminating possible source surface SOC loss. These SOC_{stock} changes can possibly be attributed to the broiler's direct input added to soil. As the poultry passed through the tree lane, the layer of litter effectively compressed and shaded some vegetation which likely led to greater incorporation and decomposition of aboveground biomass into the surface soil, increasing

Figure 8. Photo showing the accumulation of poultry litter on topsoil. A portion of litter was extracted to show the depth of the litter layer. Grass around the litter layer will be subsequently reintroduced into the soil profile as soil microfauna decompose and process it.

SOC content (Figure 8). This contribution, coupled with the carbon addition from the litter itself contributes to soil carbon accumulation.

Conclusion

Rotational pastured poultry in this silvopasture system caused a decrease in soil bulk density and increase in soil organic carbon. This finding suggests that pastured poultry improves soil fertility by holding more carbon and reducing compaction. SOC_{stock} also shows a small increase in the poultry silvopasture management compared to the control, however, longer investigation is likely required to confirm how variable these changes in the SOC_{stock} might be over many years. Phosphate, a component of poultry litter that could be concerning in high concentrations, also showed minimal impact but should be monitored continuously for long-term accumulations. This study ultimately serves as a foundation for subsequent studies for WNC silvopasture systems that practice pastured poultry. Changes in SOC_{stock} and accumulation in SOC in the subsoil layers usually take years to be detectable via standard soil measurement methods. Furthermore, a continuous practice of pastured poultry in silvopasture and tracking how this system impacts soil will allow for insight on the efficacies of this practice in revitalizing ecosystem services and repairing soils. However, the results of this study indicate a positive impact (higher soil carbon and lower bulk density) of this pastured poultry management practice after only two years of implementation.

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