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Bulk Density and pH Relationships on Sandy Soils in Three Florida Fields

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Abstract

Bulk density is an important physical property of soils as it impacts the airflow, water retention, and structure of a soil. Soil pH is a chemical property that affects the availability of nutrients in the soil. Both properties directly affect crop health and production and are often measured as indicators of soil health and crop suitability. Previous studies on this relationship between bulk density and pH focus on silty soils, and there is limited information on relationships between pH and physical soil properties on the sandier type of soils that are prevalent in Florida. This study aimed to investigate potential relationships between bulk density and pH in sandy soils by sampling the soils of three different crop production systems in north-central Florida: a silage corn field in Citra, a peanut field in Chiefland, and a turfgrass plot in Gainesville. Each of the sites were treated with pH-altering treatments, including ammonium nitrate, gypsum, and lime. While the soils in the turfgrass plot showed no observable relationship between bulk density and pH, the soils in the silage corn and peanut fields did show a slight positive relationship. In the peanut and silage corn fields, each plot was sampled both within the crop rows and between crop rows. In these fields, samples taken in the root area showed significant differences in pH ($p < 0.001$) and bulk density ($p < 0.01$) from the area between rows. Understanding relationships in the soil environment is important to maximize crop health and production, therefore further research is needed in this area.

Keywords: bulk density, pH, sandy soils, soil structure, spatial variation

Introduction

Bulk density is an important physical property measured in soils because of its ability to reflect the soil's aeration, water retention, and structural capabilities. A soil's capacity to adequately provide these levels of support to a crop directly affects its growth and yield (Sequeira et al., 2014). Soil pH (hereafter pH) is a chemical property that determines how a soil absorbs and reacts with nutrients, affecting crop growth as well. For instance, peanuts thrive best at a pH of 5.9-7 (Syed et al., 2021), while silage corn prefers a pH of 3.7-4.2 (Undi, 2021). Since pH influences these key chemical processes, it could potentially impact soil bulk density. There have been few studies conducted to observe any relationship between the two properties, especially in the southeastern United States. The few studies published that do address the topic of this relationship focus on siltier soils and show varying results that include limited data on sandy-textured soils like those found in north-central Florida (Bernoux et al., 1998).

Understanding soil indicators like bulk density and pH in sandy agricultural soils leads to better understanding of how to produce crops sustainably. For sandy-textured soils, bulk density values tend to be higher than that of silt or clay soils due to lower overall pore space (Brady, 2008), which affects the exchange of nutrients, water, and air to microbes and roots. Soils which are subject to heavy agricultural activity have weakened aggregates and structure, which can both increase bulk density and increase erosion. Eroded soil particles can fill pore spaces, increasing bulk density and limiting soil functions (Brady, 2008). Compact or unhealthy soils will produce poorer crops, restraining potential crop production (Radford et al., 2001). Practices that prioritize soil health and minimize compaction allow for continued production of healthy crops on those soils, minimizing the need for more land. Soil conservation is an aspect of sustainability that is often overlooked, even though healthy soil is the essential basis for successful food production.

A wide variety of pH treatments are applied to cropping systems worldwide to maximize production, altering the nutrients and organic matter in the soil. Organic matter content can have a strong correlation to bulk density, increasing pore space and contributing to better overall soil health (Arvidsson, 1998). In this study, the crop environments sampled were undergoing multiple pH treatments, including urea, gypsum, ammonium sulfate, and ammonium nitrate. By analyzing multiple sandy-soiled fields undergoing pH-altering treatments, there is potential to observe changes to physical properties, such as bulk density, in their soils. These changes could result from the compaction associated with fertilizer application via equipment or foot traffic, or through chemical processes changing the soil structure (Magdić et al., 2022; Radford et al., 2001).

In a few past studies that investigate relationships between soil physical and chemical properties, sandy soils caused more variation in results when compared to silts or clays (Bernoux et al., 1998; Jalabert et al., 2010). In one study pH was considered a sufficient predictor of bulk density when sandy soils are excluded from data analysis, following clay content and organic matter (Bernoux et al., 1998). These studies focused on forest soils, however, where soils may vary greatly from those of a crop field. Overall, studies focusing on bulk density, pH, and their relationship mainly come from outside of North America (Chen et al., 2017; Jiang et al., 2021), and lack consistency.

Proximity to the root area is another physical property that can affect the pH of a soil. Depending on how a fertilizer is applied, the soil directly surrounding the crop's roots can experience different effects than the soil in between crop rows (inter-row area). Few studies have touched on this relationship or included any speculation about inter-row differences. In one study, differences between root area and inter-row pH were significant in sandier soils but results were not as consistent as for bulk density (Magdić et al., 2022). Understanding spatial variation for soil properties in a field is important when producing crops because it lets producers or researchers in agriculture more efficiently grow their crops and plan soil sampling patterns.

This study aims to (1) address this lack of information by investigating the effect of altered pH on bulk density in sandy soils, and (2) investigate differences in soil bulk density and pH between the inter-row space and crop root zones. This was done by sampling the soils of three crop fields undergoing potentially pH-altering treatments. Potential relationships between bulk density and pH can help producers and researchers understand the impact of pH-altering fertilizers on soil structure. Additionally, highlighting differences in soil characteristics based on crop row location can further understanding on the small-scale spatial variability in a field.

Materials and Methods

Study Area

Three distinct crop fields were included in this study to address potential differences across agricultural settings. Figure 1 shows the locations of the three different cropping systems in north-central Florida that were sampled: a turfgrass field in Gainesville, a silage corn field in Citra, and two close peanut fields in Chiefland. The soils are Arredondo sand, 0-5% slopes at Citra, Lake sand, 0-5% slopes at Gainesville, and Otela-Tavares complex, 1-5% slopes at Chiefland (Web Soil Survey, 2024). The three sites were all experiencing different pH-altering treatments for different research experiments with the University of Florida. All treatments were broadcasted in granular form. At Gainesville, treatments included urea, the commercial fertilizer Milorganite, and ammonium sulfate applied to turfgrass. At Citra, treatments included varying rates of urea and gypsum applied to silage corn. Urea is a fertilizer product applied to supply nitrogen to crops, and the uptake of urea can also decrease soil pH over time (Bouman et al., 1995). Similarly, ammonium sulfate is applied to supply crops with nitrogen and sulfur and can also lower soil pH over time (Samuels & González-Vélez, 1962). At Chiefland, treatments included elemental sulfur applied to peanuts. Elemental sulfur is applied to lower soil pH and provide sulfate to crops.

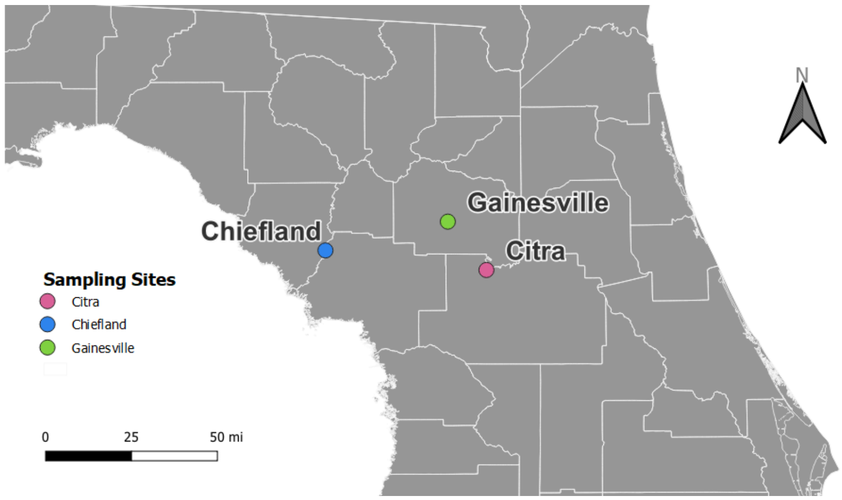

Figure 1. Map of Florida showing locations of three sampling sites.

Data Collection

Undisturbed soil core samples were collected with an AMS Soil Core Sampler (SCS) on June 16th, 2023 in Citra; July 26th, 2023 in Chiefland; and November 17th, 2023 in Gainesville. At the Citra (silage corn) and Chiefland (peanut) sites, two samples were taken at each plot: one within the root zone, and one between crop rows. Samples taken in Gainesville were not differentiated since the turfgrass plots were not planted in rows; two random samples were taken in each plot. In total, 60, 14, and 24 soil samples were taken in Citra, Chiefland, and Gainesville, respectively.

Data Analysis

Statistical analyses were conducted using R software. Soil pH and bulk density relationships across all sites were analyzed using a linear regression model. Soil bulk density at Citra and Gainesville were analyzed using an analysis of variance (ANOVA) where bulk density was considered the dependent variable, and treatment was considered the independent variable (v4.2.2; R Core Team, 2024). Chiefland was not analyzed here because there was no control treatment in the sampled plots. Soil pH and bulk density differences between the root zone and crop rows at Citra and Chiefland were analyzed with a paired t-test. For all tests, an alpha value of 0.05 was used to determine statistical significance.

Results and Discussion

Bulk Density and pH

Soil bulk density and pH values from all three sites were plotted against each other to observe any potential relationship. Figure 2 shows the scatterplot with pH on the x-axis and bulk density on the y-axis. Regression lines were plotted for each individual site. The figure shows a noticeable positive relationship between pH and bulk density at Citra (corn) and Chiefland (peanut), but not Gainesville (turfgrass). The p values for the three fields were 0.039, 0.098, and 0.992, respectively, showing that pH might explain some amount of the variation in bulk density found at Citra, but the corresponding R-squared value of 0.072 provides less support for such a claim.

It is important to note that this study was limited to three agricultural fields and lacked large sample sizes at these fields. The vastly different physiology, structure, and cultivation practices for each crop must also be noted. For instance, silage corn is planted earlier in the spring than peanuts, and the turfgrass used in this study was planted in the fall, therefore factors such as temperature and precipitation that vary year-round could have affected results. Further research into the variation of bulk density associated with pH treatments should be conducted at a larger scale with larger quantities of samples taken to properly analyze the potential variation in this relationship for sandy-textured soils.

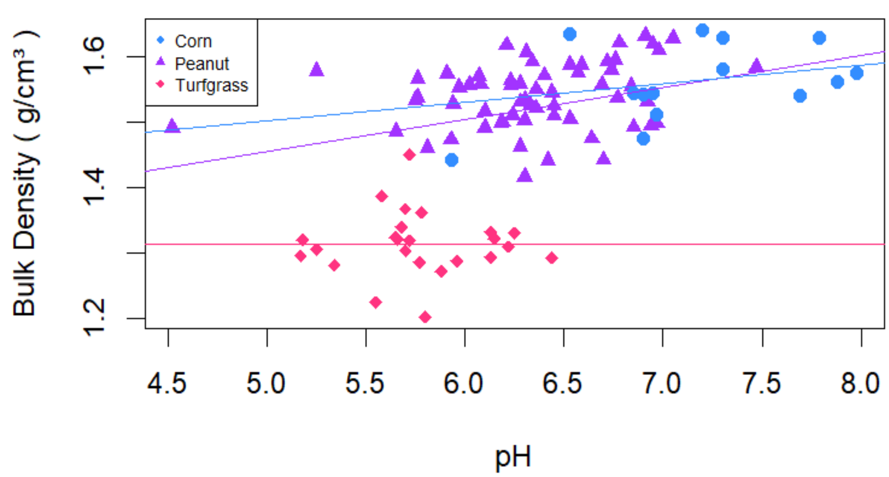

Figure 2. Scatterplot comparing pH and bulk density across the three sampling sites: Citra (corn, blue circles), Chiefland (peanut, purple triangles), and Gainesville (turfgrass, red diamonds).

Bulk Density and pH Analysis of Variance

As can be seen in Table 1, ANOVA results for bulk density and pH at Citra (corn) showed no significant difference by treatment, and at Gainesville (turfgrass) only showed a significant difference for pH ($p < 0.05$). These results indicate that fertilizer treatments applied at Citra didn't have significant effects on the pH or bulk density of the soil, and treatments applied at Gainesville only had a significant effect on the pH. Low variation in pH values in Citra may explain why there was little variation found in bulk density as well.

Table 1. ANOVA results for bulk density and pH at Citra (corn) and Gainesville (turfgrass).

Variance by field			df	Sum of Squares	Mean of Squares	*F*	*p*
Corn							
	Bulk density	Trt	1	0.002	0.002	0.777	0.382
		Residuals	58	0.146	0.003		
	pH	Trt	1	0.033	0.033	0.143	0.707
		Residuals	58	13.278	0.229		
Turfgrass							
	Bulk density	Trt	1	0.004	0.004	1.687	0.207
		Residuals	22	0.052	0.002		
	pH	Trt	1	0.442	0.442	4.442	0.0467
		Residuals	22	2.190	0.0995		

Note. Number of samples = 84. Trt = treatment. df = degrees of freedom.

Paired T-test Results for pH and Row Location

Differences between root area and inter-row space were determined using a paired t-test. The results for the corn and peanut fields showed a significant difference in pH ($p < 0.001$) and bulk density ($p = <0.01$) by row location (Table 2). This reflects past studies, however it remains unclear whether the differences observed in either variable are correlated with one another.

Table 2. Paired t-test results for Citra (corn) and Chiefland (peanut).

Variance by location to root zone	df	MD	t	95% CI		*p*
				LL	*UL*	

Corn & Peanut						
pH	36	0.34	3.65	0.150	0.525	<0.001
Bulk density	36	0.03	2.73	0.007	0.045	<0.01

Note. Number of samples = 74. MD = mean difference; CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

These results highlight the influence of spatial variation in an agricultural field, and why attention to detail in research and production is important. Soil structure can vary widely from the inter-row area to the root zone. When evaluating physical factors such as bulk density in soils, a small difference in distance could affect treatment outcomes or test results. Collecting samples from the same location relative to crop rows can reduce sources of variability in bulk density and pH studies, which is important to consider when writing protocols for future research. Reduced variability in sampling practices allows for more consistent results.

Conclusion

This study presents how altered pH can potentially affect soil bulk density, and how crop row location does affect both pH and bulk density. Changes to soil pH may have an influence on the physical properties of silt and clay soils (Jalabert et al., 2010), but more research would need to take place in sandier soils to see what results occur. This study shows that bulk density and pH can display a positive relationship in sandy soils, but sample sizes were small and may not accurately portray the results in larger cropping systems.

Regarding the spatial variation of soil properties between root and inter-row areas, a significant result was found in this study. In the peanut and silage corn fields, both pH and bulk density varied between the root and inter-row areas of crop rows. This reflects the results of past studies where location in the crop row area influenced pH values (Magdić et al., 2022), showing the importance of recognizing small spatial differences in agricultural decisions and protocol writing for agricultural research. Taking precise soil samples closer to the crop versus farther into the row will produce more specific results that better represent the plant’s needs, improving overall efficiency for producers sampling for fertilizer recommendations.

Nonetheless, physical and chemical relationships in sandy soils can be overlooked, and require further research to establish confident conclusions. The types and sources of treatments in this study varied greatly, but it still shows how pH-altering fertilizers impact soil structure and how their effects vary at small spatial scales. Soil compaction has been and will continue to present issues in agriculture moving forward, and the impacts of different practices on soil structure will continue to be a conversation as producers must continue to learn ways to produce efficiently.

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