BIOCHAR AND LIQUID DAIRY MANURE NITROGEN DYNAMICS

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ABSTRACT

Biochar has gained attention as a soil amendment due to its high carbon content, porous structure, and ability to retain water and nutrients. Previous research has shown that biochar can adsorb nitrogen (N) compounds and reduce nutrient losses from agricultural systems. However, the contribution of biochar-retained N to plant-available N pools has not been well quantified. This study examined the effects of biochar co-application with liquid dairy manure on soil N dynamics and corn productivity in a Wisconsin sandy-soil corn production system. Field research was conducted at the Hancock Agricultural Research Station in Wisconsin using a randomized complete block design with four replications. Treatments included a control, liquid dairy manure applied at 10,000 gallons acre^{-1}, manure combined with biochar at rates of 2.5 and 5 tons acre^{-1}, and multiple urea-N rates ranging from 60 to 220 lb N acre^{-1}. Results from year one indicated that manure amended with biochar produced yields that were not significantly different from the 100 lb N acre^{-1} urea treatment. Additionally, manure-biochar treatments retained greater amounts of soil nitrate following the growing season compared to manure-only applications, suggesting improved N retention within the soil profile. These findings suggest that biochar may enhance N conservation when co-applied with liquid dairy manure, potentially improving nutrient use efficiency while maintaining crop productivity in sandy soils.

INTRODUCTION

Wisconsin is one of the leading dairy-producing states in the United States, generating large volumes of liquid dairy manure that must be managed effectively to maximize crop productivity while minimizing environmental impacts. Liquid dairy manure supplies substantial quantities of essential nutrients and organic matter and can reduce reliance on synthetic fertilizers when managed appropriately. However, only a fraction of manure N becomes plant-available during the year of application (Laboski and Peters, 2012) because manure contains both inorganic and organic N forms, with the latter requiring mineralization before becoming available for crop uptake.

Improving the recovery of manure-derived N has become increasingly important because excess N may be lost through nitrate leaching, surface runoff, ammonia volatilization, and gaseous emissions (Aguirre-Villegas et al., 2017). These concerns are particularly relevant in Wisconsin's Central Sands region, where irrigated agricultural systems are frequently managed on coarse-textured soils with limited nutrient-retention capacity. Under these conditions, nitrate can move below the rooting zone and potentially contaminate groundwater resources.

Biochar has emerged as a potential tool for improving nutrient-use efficiency in these vulnerable systems. Produced through the pyrolysis of organic feedstocks, biochar possesses a highly porous structure and large surface area that can influence nutrient retention, soil water storage, and soil chemical properties (Blanco-Canqui, 2017). Previous studies have demonstrated reductions in nitrate leaching and improvements in crop performance following biochar application under certain conditions (Laird et al., 2010; Verheijen et al., 2011), although responses are often inconsistent and dependent on soil characteristics, biochar properties, and management practices.

Despite growing interest in combining biochar with livestock manure, limited information exists regarding the fertilizer value of manure-biochar mixtures under Wisconsin production conditions. In particular, questions remain regarding whether biochar can alter manure N availability sufficiently to improve crop performance. Therefore, the objective of this study was to evaluate the effects of co-applying biochar and liquid dairy manure on corn productivity and soil N dynamics in an irrigated Plainfield sand and to compare treatment performance against conventional synthetic N fertilizer.

MATERIALS AND METHODS

The study was conducted during 2025 and 2026 at the University of Wisconsin Hancock Agricultural Research Station on a Plainfield sand (Typic Udipsamments). Treatments were arranged in a randomized complete block design with four replications.

Treatments included:

- Control (20 lb starter N acre^{-1})

- Liquid dairy manure (10,000 gal acre^{-1})
- Liquid dairy manure + 2.5 tons biochar acre^{-1}
- Liquid dairy manure + 5.0 tons biochar acre^{-1}
- Synthetic fertilizer N rates of 60, 100, 140, 180, and 220 lb N acre^{-1}

Biochar was incorporated before planting in 2025, while manure was applied annually to relevant treatments. Soil samples were collected at depths of 0-1, 1-2, and 2-3 ft at pre-plant, mid-season (V5~V6 growth stage) and post-harvest to evaluate nitrate dynamics, and corn grain yield was measured at harvest. Yield responses were compared with the synthetic fertilizer response curve to estimate fertilizer N equivalence.

RESULTS AND DISCUSSION

Grain Yield Response and N Fertilizer Equivalence

All manure-based treatments improved crop performance relative to the low-N control. Yield comparisons with the synthetic fertilizer response curve suggested that manure and manure-biochar treatments were generally lower in comparison to fertilizer N. In the first year, no statistical difference was found between the manured treatments (Fig. 1). In addition, biochar treatment performance was similar to approximately 100 lb N acre^{-1} applied as urea (Fig. 1). However, in the second-year yields were statistically different between the manured treatments, while responses generally corresponded to 100-140 lb N acre^{-1} applied as urea (Fig. 2).

The fertilizer N equivalence of the manure treatments in year 1 was estimated at 78, 85, and 100 lb N acre^{-1} for manure alone, manure + 2.5 tons biochar, and manure + 5 tons biochar, respectively. These values corresponded to first-year N availability coefficients of 43%, 47%, and 55%, respectively. In year 2, the fertilizer N equivalence was estimated at 104, 101, and 96 lb N acre^{-1} for manure alone, manure + 2.5 tons biochar, and manure + 5 tons biochar, respectively. These values corresponded to first year N availability coefficients of 57%, 55%, and 53%.

Year-to-year differences in fertilizer equivalence likely reflect environmental influences on N mineralization, N losses, and crop uptake. Although the higher fertilizer N equivalence observed for the biochar-amended treatments in year 1 is consistent with the hypothesis that biochar improved retention of manure-derived N, this effect was not maintained in year 2. In addition, relative to year 1, year 2 showed higher availability coefficients. This could mean that in year 2, conditions were more favorable for mineralization across treatments as also reflected by generally higher yields in year 2 (Fig. 2). In other words, the contrasting responses between years indicate that weather and other environmental factors likely played a substantial role in determining N availability and may have outweighed any biochar effects in this study.

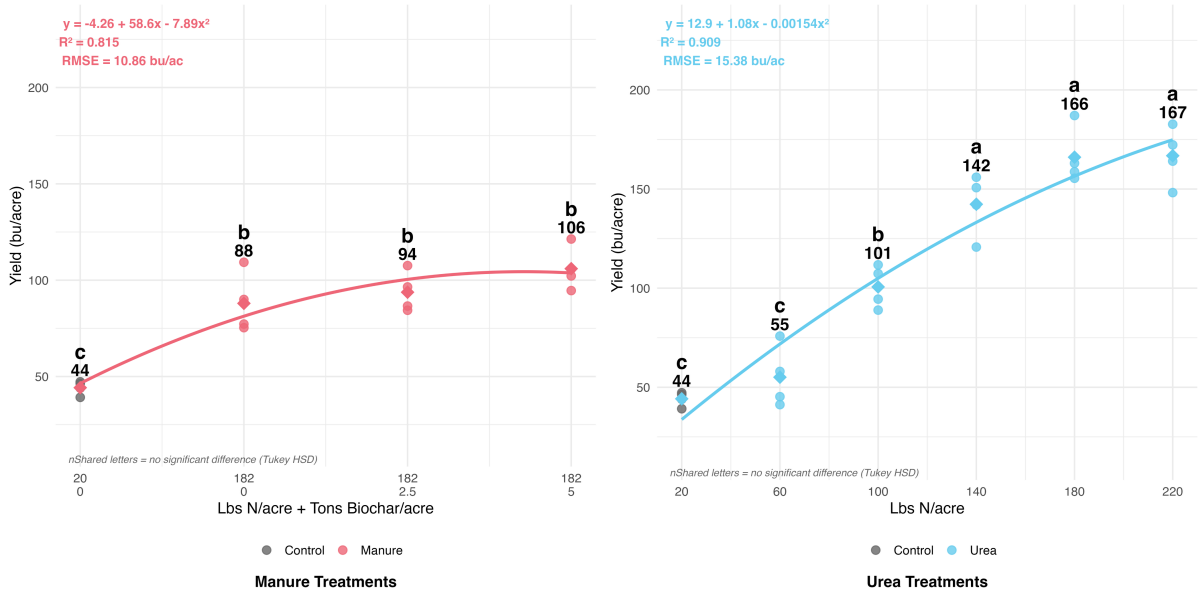


Figure 1. Corn grain yield response in 2025 to manure-biochar amendments (left) and urea fertilizer N rates (right) in a Wisconsin sandy soil. Manure treatments received liquid dairy manure at 182 lb N ac^{-1} either alone or amended with 2.5 or 5 ton biochar ac^{-1}, while urea treatments received 20, 60, 100, 140, 180, or 220 lb N ac^{-1}. Points represent individual plot observations, diamonds indicate treatment means, and curves show fitted quadratic regression models. Mean yields are displayed above each treatment. Treatments sharing the same letter are not significantly different according to Tukey's HSD test (α = 0.05).

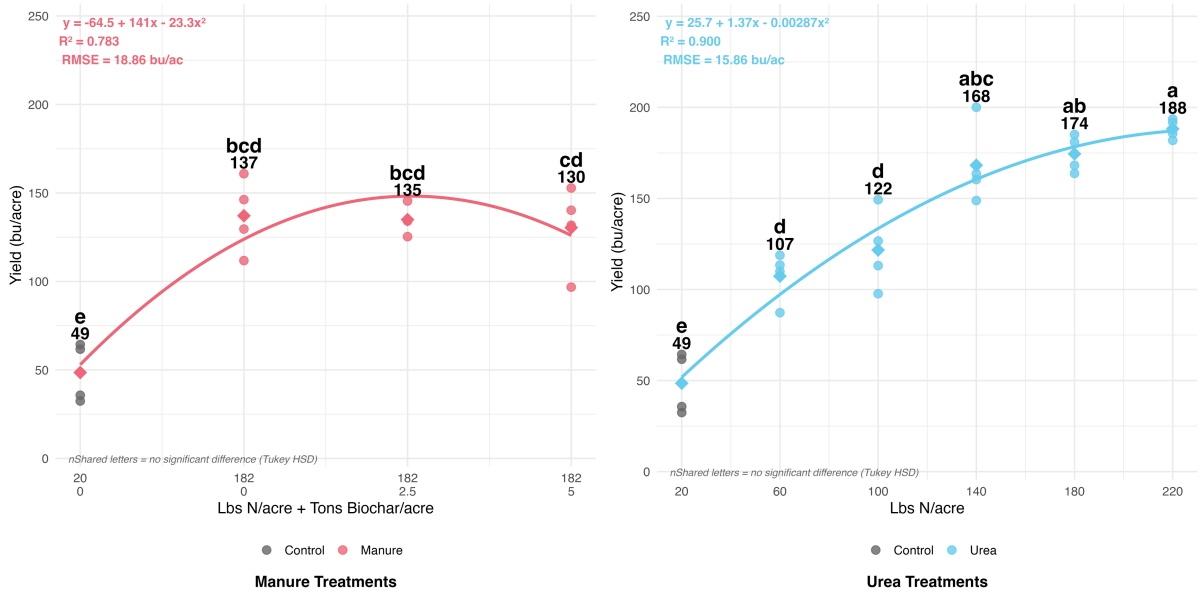


Figure 2. Corn grain yield response in 2026 to manure-biochar amendments (left) and urea fertilizer N rates (right) in a Wisconsin sandy soil. Manure treatments received liquid dairy manure at 182 lb N ac^{-1} either alone or amended with 2.5 or 5 ton biochar ac^{-1}, while urea treatments received 20, 60, 100, 140, 180, or 220 lb N ac^{-1}. Points represent individual plot observations, diamonds indicate treatment means, and curves show fitted quadratic regression models. Mean yields are displayed above

each treatment. Treatments sharing a common letter are not significantly different according to Tukey's HSD test (α = 0.05).

Soil Nitrogen Dynamics

Soil nitrate concentrations tended to decrease during the season (Fig. 3) with no significant difference between the manure and manure-biochar amended treatments. In comparison, a significant decrease did occur in nitrate in the urea treatments, except for treatments receiving 140 lb N ac^{-1} and 220 lb N ac^{-1} (Fig 3). This response suggests that biochar may influence N retention within the soil profile and potentially increase the availability of mineral N during the growing season.

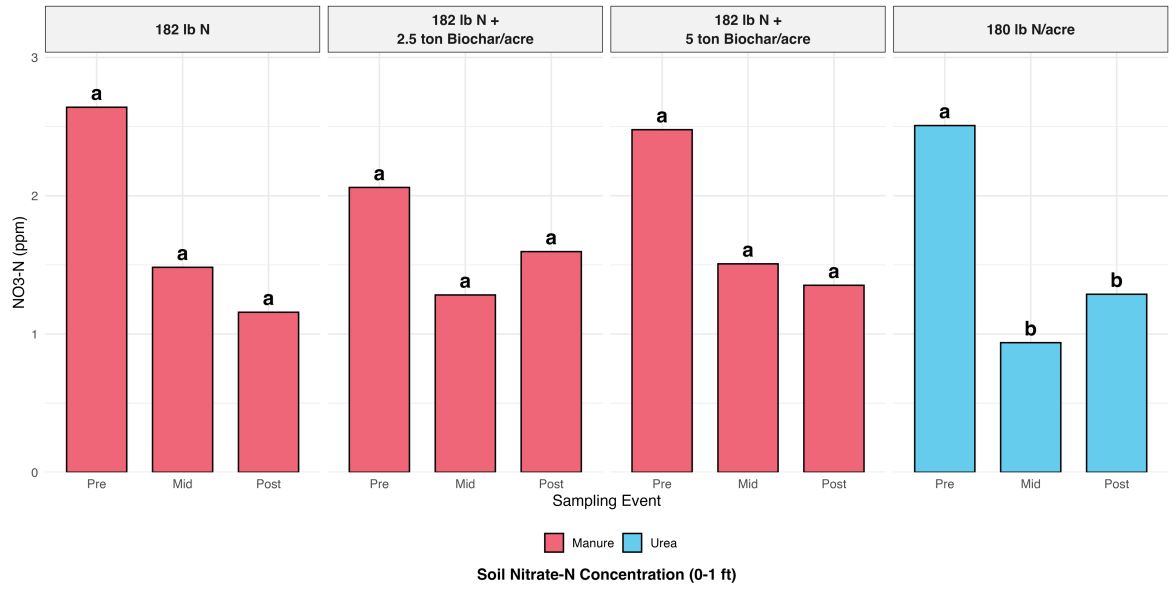


Figure 3. Soil nitrate-nitrogen (NO_3^--N) concentration in the 0- to 1-ft soil depth at pre-plant, mid-season (V5-V6), and post-harvest sampling events following application of liquid dairy manure alone or amended with 2.5 or 5 ton biochar ac^{-1}. The manure treatments received 182 lb N ac^{-1}. A urea treatment receiving 180 lb N ac^{-1} is shown for comparison as a fertilizer-N reference. Bars represent treatment means. Within each treatment, sampling events sharing the same letter are not significantly different according to Tukey's HSD test (α = 0.05).

Interpretation of these results is complicated by the organic nature of manure N. A large portion of manure N must first be mineralized before becoming available for plant uptake (Lazicki et al., 2020), and biochar may affect this process through changes in soil physical, chemical, or biological properties (Luo et al., 2025). Consequently, greater soil nitrate concentrations do not necessarily translate into greater crop N recovery or reduced N losses. Additional analyses of plant N uptake are ongoing, and results from a complementary column study evaluating N retention and transport will provide further insight into the mechanisms responsible for the observed treatment effects.

CONCLUSIONS

This study evaluated the effects of combining biochar with liquid dairy manure in an irrigated sandy soil used for corn production. Key findings include:

- Manure and manure-biochar treatments produced yields comparable to moderate synthetic fertilizer N rates (~100-140 lbs N $acre^{-1}$).
- Biochar additions did not increase yields beyond those obtained with manure alone.
- Soil nitrate concentrations mid- and post-season tended to be greater in manure and manure-biochar-amended treatments relative to commercial fertilizer, indicating potential effects on N retention and availability.
- Biochar increased fertilizer N equivalence in Year 1, but the absence of a similar response in Year 2 suggests that environmental conditions largely governed manure N availability.

Biochar demonstrated potential to improve manure N utilization; however, the variable response observed across years underscores the need for long-term research to evaluate how biochar interacts with environmental conditions to influence soil N availability, crop N recovery, and N loss over time.

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