

Positive and negative impact of nitrogen fertilizer on soil properties and nutrient dynamic

Abstract

Our study was conducted over the period of two years and explored the impact of nitrogen fertilization and non-fertilization systems on soil health indicators and crop yield. Our study hypothesized that no fertilization coupled with cover cropping would enhance soil health, carbon content, and bulk density. This study found that excessive nitrogen fertilization had negative impact on soil health factors such as bulk density increment and carbon content decline through deeper profiles. In contrast, the no-fertilization system exhibited improved bulk density and better carbon distribution near the soil surface, suggesting that reducing or eliminating nitrogen can promote soil health and prevent long-term fertility decline. The study also highlighted the imbalanced carbon to nitrogen ratio resulting from high nitrogen fertilizer rate can negatively impact soil microbial activity and nutrient mineralization.

Our study raised the importance of sustainable soil management practices in agriculture. While nitrogen fertilization can enhance short-term crop yield, it can have detrimental effects on soil health and long-term sustainability. Our study suggests alternative approaches like cover cropping and integrated management improve soil health while maintaining adequate crop yield. Farmers can promote sustainable and productive agriculture systems while minimizing environmental impact.

Key word: Cover crops, Sustainable agriculture, nitrogen fertilizer, agriculture management

Introduction

Nitrogen is the primary component of plant proteins, chlorophyll, and nucleic acids that considered as an essential nutrient required for plant growth and development (Uchida., 2000). Nitrogen is abundant in the atmosphere, but it is not available to plants in this form because it needs to be converted into a usable form by soil microorganism. Nitrogen gas (N_2) must be converted into ammonium (NH_4^+) or nitrate (NO_3^-), which called nitrogen fixation or nitrification and is carried out by nitrogen-fixing bacteria that live in soil (Islam et al., 2015). This process needs oxygen and carried out by Nitrite bacteria such as Nitrosomonas and Nitrate bacteria like Nitrobacter. However nitrate can easily be lost through leaching and denitrification and causes environmental contamination. Thereby, it is important to maintain the soil's microbiome to ensure that the nitrogen remains available to plants, which is expensive and time consuming (Uchida., 2000).

Nitrogen fertilizers are used as an essential part of modern agriculture as they help to boost crop yield and maintain soil fertility. The use of fertilizers has increased over the years as it helps farmers to produce more food for increasing populations. However, the use of fertilizers has a potential downside as it can lead to soil and environmental degradation (Erisman et al., 2008). The impact of fertilizers on soil health is dependent on factors such as the nutrient content of the fertilizer, soil type, climate, and management practices (Skorupka et al., 2021). In this situation the role of nitrogen use efficiency (NUE) rise up to be considered to increase soil health and decrease nitrogen losses. Nanotechnology is also in producing better and beneficial products in agriculture sector by food availability and security by improving NUE (Mirbakhsh., 2023).

Several studies have reported that the application of fertilizer and nano-fertilizer can have both positive and negative effects on soil health and its quality (Amanullah et al., 2016; Wang et al., 2020; Liu et al., 2021; Stewart 2022). The use of fertilizer has been linked to changes in the physical, chemical, and biological properties of the soil. Nitrogen fertilizers, for example, can contribute to soil acidification and decrease in soil organic matter content, which can lead to reduced soil fertility and productivity. Excessive use of phosphorus fertilizers can lead to soil eutrophication, which results in the overgrowth of algae and aquatic plants that depletes oxygen levels in water bodies. It can also lead to soil pollution through the accumulation of heavy metals (Chandini et al., 2019). On the other hand, appropriate use of fertilizers can help to maintain soil

fertility and promote healthy plant growth. For instance, the application of potassium-rich fertilizers can improve soil structure, reduce soil erosion and increase crop stress tolerance. It can also lead to soil pollution through the accumulation of heavy metals (L et al., 2016). Inappropriate application of fertilizer can affect soil health indicators, microorganisms, diversity that play an essential part in soil fertility and nutrient cycling (Dinca et al., 2022). Environmental changes and stressors such as salinization has a great impact on soil health that limit crop growth/yield, causes land degradation, and negatively impact plants' vital process (Mirbakhsh and Sedeh, 2022).

Management practices can affect soil properties (Ashworth et al., 2018) and used as an alternative to decrease human needs to fertilizer. The sustainability of soil resources can be maintained by promoting soil health through improved management practices (Norris et al., 2020). The choice of suitable cropping practices for increasing soil organic matter content should focus on several factors such as GHG emissions mitigation, nitrogen capture improvement, and temporal yield stability, and reducing environmental contamination (Knapp and van der Heijden, 2018). For example; well-managed arable land conversion to cover crops has been resulted in accumulation of SOC, due to their low nutrient requirements and subsequent turnover of aboveground biomass (Ledo et al., 2020; Chen et al., 2022) or no-tillage system reduces soil acidification, but increased organic matter and Ca, Mg, and K concentrations compared to conventional tillage (Tarkalson et al., 2006).

This study aimed to compare impact of fertilization and non-fertilization system under two cropping practices of corn with fertilization in rotation and corn-cover cropping without fertilization in some of soil health indicators. We hypothesized that no fertilization coupled with cover cropping will enhance soil health indicators and crop yield compared to conventional tillage annual crop-fallow.

Comment [DAL1]: Long Introduction! Please give an essential information!

Material and methods

Field experiment

The experiment was conducted at a Research Farm (Mashhad University, Mashhad Branch), located at 38° 88' N and 63° 72' E with an altitude of 1 m above sea level, during 2020-2022 crop year to test our alternative hypothesis. Plots are 10 m wide and 48.5 m long and Each plot is

individually drained with plastic agricultural tile lines (0.1 m diameter) installed in the longitudinal center of the plots at a depth of 0.9 m. Soil samples with 0.9 m depth were collected in May-April 2023 before tillage, planting, and fertilization. Measurements were made for intact and repacked soil cores. The experimental design includes 6 treatments in completely randomized block design that have been applied since 2005. The subset of three treatments chosen for corn cultivation that contains corn (CC) with tillage and fertilization. Three subsets of corn (*Zea mays* L.) in rotation with legume Persian clover (*Trifolium resupinatum*) was chosen as corn-cover cropping with no fertilization (Figure 1). Within our two experimental years, plots were burned on 8 Apr. 2022 and 13 Apr. 2023. The N sources for corn treatments were urea-ammonium nitrate 28% (w/w) N (UAN) side-dressed at corn growth stage V5 at rates of 157 and 135 kg N ha⁻¹ yr⁻¹ for CC and CS, respectively, and liquid swine manure (C/N ratio: 2:1, 80% [w/w] of N as NH₄⁺) injected into CC at a rate of 255 ± 24 kg N ha⁻¹ yr⁻¹ in either the spring (SM) or the fall (FM). For cover cropping white clover (*Trifolium repens*) were added to corn in different plots (Figure 1 b). Tillage operations were chisel in the fall and chisel plus disk in the spring. Soil samplings occurred within the week of corn planting in early May (11 May 2019 and 3 May 2020) and again at corn growth stage R1 in late July (25 July 2019 or 27 July 2020). Soils were tested each fall for general fertility using recommended protocols, and results indicated soil P, K, and pH were non-limiting.

Soil sampling and analysis

Four soil collections were done to monitor fractions of soil organic carbon (SOC) and total N (TN). Soil samplings occurred during the week of corn planting in May (11 May 2022 and 3 May 2023) and again at corn growth stage R1 in late July (25 July 2022 or 27 July 2023). The top 0.15 m of soil was sampled by auger hand probe (2.5-cm diam.) with at least 12 cores

collected at random positions throughout each experimental plot. Each core was separated into 0- to 5- and 5- to 15-cm depth increments, composited within each depth and sieved in field-moist condition to pass an 8-mm mesh within 24 h after collection. Sieved soils were thoroughly mixed, air dried, and stored at room temperature for physical fractionation. Air-dried soil subsamples were finely ground using a Dyno-Crush 2 Grinder (Customs Laboratory Equipments, Inc., Orange City, FL), passed through a 2-mm sieve and stored at room temperature in 20-mL polyethylene vials for chemical fractionation as well as determination of SOC and TN. Any identifiable plant material in this subsample was removed before grinding. Bulk density was determined in separate, undisturbed soil cores (5 cm i.d. and 2.5 cm length) collected with a double-Cylinder, hammer-driven core sampler from three sampling positions at 0- to 5- and 5- to 15-cm depth increments from each experimental plot. For the deeper soil depth increments (15–30, 30–50, 50–75, and 75–100 cm) bulk density was determined from subsamples of the cores collected by the tractor probe. Total soil profile (0–100 cm) SOC and TN storage were estimated as the sum of storages in each layer following correction with bulk density values for equivalent layer mass.

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Data Processing

The fractions of SOC and TN (g kg^{-1} soil) were recorded in each individual depth increment. Following Ellert et al. (2002), the equivalent soil mass correction were performed before calculation of cumulative TOC and TN mass storage (Mg ha^{-1}) in the complete soil profile (0–90 cm) to adjust the layer and get correction. Finally, mass (M) of SOC and TN was calculated in each individual soil depth (0–5, 5–15, 15–30, 30–60, 60–90) cm as follows:

$$M = pb \times Co \times (To + Tadj) \times 10\,000 \text{ m}^2 \text{ ha}^{-1} \times 0.001 \text{ kg g}^{-1} \text{ [Batjes., 1996]}$$

Where ρ_b is bulk density, C_o is SOC or TN concentration, and T_o is the thickness of a layer.

All variables were assessed for homogeneity of variance and normality by Cook's distance, Bartlett, and Shapiro–Wilk tests, and Tukey. Multivariate analysis of variance (MANOVA in PROC GLM) was run to test for no overall treatment, year, sampling time, and depth effects by Wilk's Lambda test, these main, fixed effects and their interactions, the full model also included block and block by treatment (error) as random effects using R version 4.0 (R core Team 2020).

RESULTS AND DISCUSSION

Bulk density

Soil bulk density and nitrogen fertilization are both important factors in agriculture and soil management also nitrogen application indirectly affect soil bulk density. Soil acidification due to ammonium-based fertilizer contribute to pH alternation by producing nitrate form by soil microorganism, which potentially leading to increased soil bulk density (Zeng et al., 2016; Sun et al., 2015). Moreover, excessive reliance on fertilization without organic matter management can lead to a decline in organic matter content, which can result in soil compaction, porosity reduction and bulk density increment over time (Nawaz et al., 2013).

Our results recorded the negative impact of fertilization on soil bulk density that increased through soil profile and it is clearly shown in shallowest profiles (Figure 2a-b). The interaction of soil bulk density and soil depth is shown in figure 2 c. No fertilization decreased and improved soil bulk density in the most top soil layers (0-30 cm) (Figure 2c). Our results are aligned with the hypothesis of the negative impact of excessive application of nitrogen fertilizer and soil health (Wang et al., 2018; Zhang et al., 2015; Snyder et al., 2009). Excessive fertilization can lead to vigorous plant growth and increase biomass production, which make excessive plant residues and organic matter accumulation that increase bulk density and negatively impact soil structures (Niu et al., 2022).

Soil Carbon

The impact of nitrogen fertilizer is like a two-edge sword and can vary depending on various factors such as management practices, soil condition, and environmental factors.

Nitrogen fertilizer can enhance crop growth and productivity leading to higher residues, which can increase soil carbon content over time (Wang et al., 2014). Organic carbon decomposition can stimulate microbial activity resulting in more efficient decomposition of organic matter and CO₂ releasing into the soil. Moreover, nitrogen fertilizers can promote root development and proliferation leading to increase root biomass that positively influence soil carbon level. On the other side, excessive nitrogen fertilization can accelerate decomposition which can lead to microbial activity and rapid breakdown of organic matter over long time (Hussain et al., 2016). Nitrous oxide emission under improper condition can indirectly impact on soil carbon by reducing ecosystem carbon sequestration potential (Foley et al., 2011). Our results showed greater amount of soil carbon under Fertilization during two years of experiment (Figure 3a). However, carbon content decreased through soil profiles and the lower amount of carbon was recorded in (30-60 cm) (Figure 3b). The results of interaction plot of carbon content, soil depths, and different treatments recorded the greatest difference between the treatments in the shallowest layer (0-15 cm) (Figure 3c).

C:N

The impact of nitrogen fertilization on soil carbon to nitrogen (C: N) ratio can vary depending on several factors. It is important to consider that the impact on C: N is influenced by various factors and specific outcomes may depend on soil type, climate, crop management practices, and initial soil condition. Increased nitrogen content from nitrogen fertilizer can decrease the C: N ratio. Moreover, adequate nitrogen supply stimulates microbial activity, accelerating organic matter decomposition and potentially reducing the C: N.

On the other side, to mention to the negative impact; excessive nitrogen fertilization without nutrient management can lead to imbalanced nutrient ratio, limiting microbial activity and potential increase C: N. In some case, nitrogen fertilization can promote the preservation of organic matter resulting in higher C: N.

Our results recorded more variation of the results in no-fertilization (figure 4a) and higher carbon to nitrogen ratio was recorded under fertilization (figure 4b). Obviously, under nitrogen fertilization, the carbon to nitrogen ratio typically increases, which means the higher proportion of carbon relative to nitrogen is available in the soil or plant matter. Nitrogen uptake by the plants accelerate in comparison to carbon assimilation and as a result the carbon content in plant tissues become relatively higher compared to nitrogen content. Nitrogen mineralization is the other reason that can stimulate microbial activity in the soil, which leading to increased decomposition of organic material resulting in decrease in carbon content relative to nitrogen due to carbon dioxide emission. The other possible reason could be nitrogen immobilization that is caused by microbes which can rapidly consume and immobilize the added nitrogen because microbes require carbon for their growth and energy needs and they may scavenge carbon from soil organic matter.

Mineralization.

Conclusion

The impact of fertilizers on soil health and the environment is dependent on its concentration, type, and mode of application. Excessive use of fertilizers can lead to soil degradation, loss of biodiversity, and environmental pollution (Bisht and Chauhan, 2020). Sustainable management practices like soil testing, integrated nutrient management, conservation tillage, and crop rotation can help to mitigate the adverse effects of fertilizers on soil health (Farmaha et al., 2021). To mitigate the potential negative impacts of fertilization and maximize the positive effects of management practices on soil health, it is important to follow the best and less expensive management strategies. It is essential to adopt sustainable nutrient management methods to promote healthy soil, ensure environmental sustainability, and enhance food security. Cover

cropping is one of the management practices, which can improve soil health through erosion, nutrient cycling, weed suppression (Balota et al., 2014). It increases soil carbon content, promote bulk density, and enrich soil with nutrient and could be considered as an alternative for nitrogen fertilizer.

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Figure 1. The subset of treatment chose for corn cultivation that contains corn (*Zea mays* L.) (CC) with tilling and fertilization (a). Subsets of corn in rotation with legume Persian clover (*Trifoliumresupinatum* L.) was chosen as corn-cover cropping with no fertilization (b).

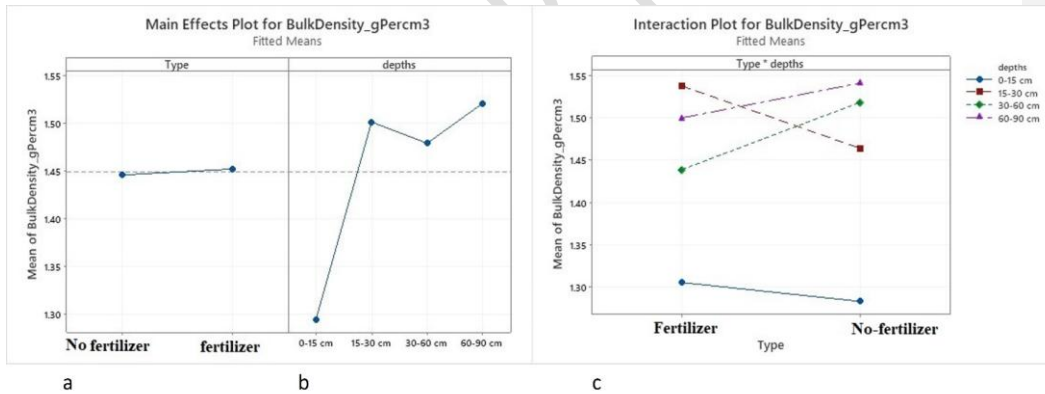


Figure 2. The impact of fertilization on bulk density according to the type of fertilization treatments (a). Change of bulk density through soil profile from top soil to deep soil (b). Interaction plot of soil bulk density, soil depth, and type of treatment (c).

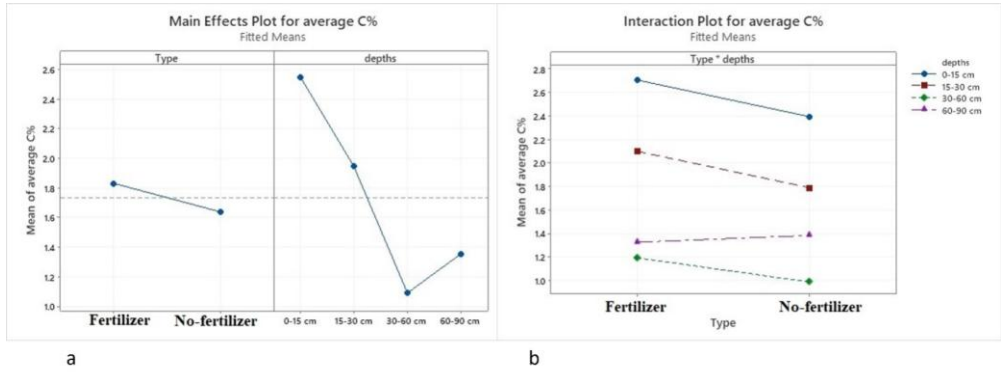


Figure 3. The impact of fertilization on soil carbon according to the type of fertilization treatments (a). Change of soil carbon through soil profile from top soil to deep soil (b). Interaction plot of soil carbon content, soil depth, and type of treatment (c).

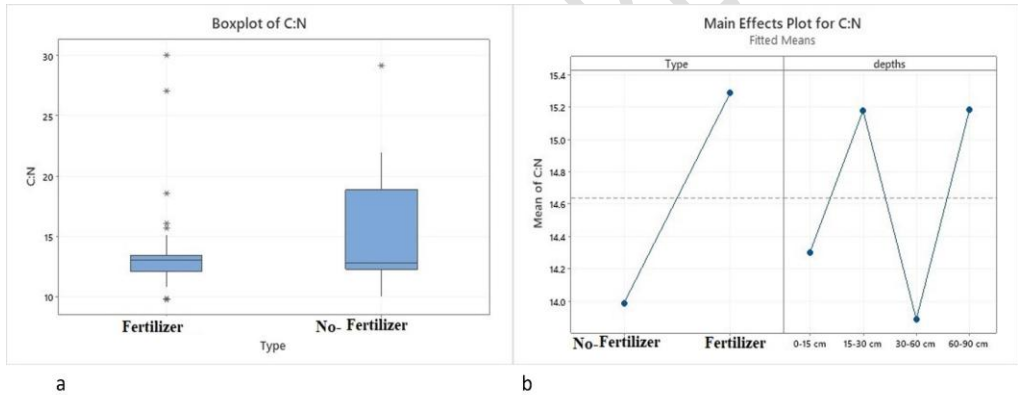


Figure 4. The impact of fertilization on soil C: N ratio according to the type of fertilization treatments in a box plot (a). Change of soil C: N through soil profile from top soil to deep soil, the lowest C: N is shown in 30-60 cm and the highest are shown in 15-30 cm and 60-90 cm (b).