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Nitrification inhibitor and management of liquid hog manure: the effect on soil mineral nitrogen dynamics and wheat yield

Inibidor de nitrificação e manejos de dejeto líquido de suíno: efeito na dinâmica do nitrogênio mineral e produtividade do trigo

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Highlights

Management of liquid hog manure as a nitrogen source in wheat.
Dicyandiamide reduces the emergence of anionic forms of mineral nitrogen.
Replacement of mineral fertilizer with liquid hog manure + dicyandiamide injection.

Abstract

Management is of fundamental importance in increasing the efficiency of liquid hog manure (LHM) when used as a source of nitrogen (N) and minimizing its impact on the environment. This paper evaluates the effect of surface application and injection of LHM and the use of dicyandiamide (DCD) on the dynamics of mineral N in the soil and on the components of yield in wheat crops. An experiment was conducted at the Federal University of Santa Maria, Frederico Westphalen Campus, Rio Grande do Sul state, Brazil, involving the following treatments: T0 - Control; T1 - surface application of LHM (Sup); T2 - subsurface injection of LHM (Inj); T3 - surface application of LHM + DCD (Sup+DCD); T4 - subsurface injection of LHM + DCD (Inj+DCD), and T5 - application of N, phosphorus (P), and potassium (K) in mineral form (NPK) in 2014 and 2015. The mineral N recovered with the injection of LHM was superior to surface application, and DSD reduced the speed with which anionic forms of mineral N appear. There was a greater increase in the number of ears of wheat with LHM injection. In 2014, the number of grains per ear was higher with the injection of LHM + DCD, whereas in 2015 all the treatments were higher than the control. There was

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no difference in 1,000-grain weight between treatments with LHM. Hectoliter weight was higher with the injection of LHM + DCD and the yields observed in this treatment were also higher, not differing from mineral fertilization. It is concluded that LHM injection provides lower losses of N and DCD and reduces the speed with which anionic forms of mineral N appear. In addition, the final yield of wheat grains does not differ when comparing LHM + DCD with mineral fertilization.

Key words: DCD. Dicyandiamide. Injection of waste. Triticum Aestivum L.

Resumo

O manejo do dejeto líquido de suínos (DLS) é de fundamental importância para aumentar sua eficiência como fonte de nitrogênio (N) e minimizar impacto sobre o ambiente. O objetivo deste trabalho foi avaliar o efeito da aplicação em superfície e da injeção de DLS e o uso da dicianodiamida (DCD) sobre a dinâmica de N mineral no solo e nos componentes de produtividade na cultura do trigo. Para isso, um experimento foi conduzido na Universidade Federal de Santa Maria, Campus de Frederico Westphalen, RS com os seguintes tratamentos: T0 - Testemunha, T1 - aplicação em superfície do DLS (Sup), T2 - injeção em subsuperfície do DLS (Inj), T3 - aplicação em superfície do DLS + DCD (Sup+DCD), T4 - injeção em subsuperfície do DLS + DCD (Inj+DCD) e T5 - aplicação de N, fósforo (P) e potássio (K) na forma mineral (NPK) nos anos de 2014 e 2015. O N mineral recuperado com a injeção do DLS foi superior à aplicação superficial e, a DCD reduziu a velocidade com que surgem formas aniônicas de N mineral. Houve maior incremento no número de espigas com a injeção de DLS. No ano 1, o número de grãos por espiga foi superior com a injeção de DLS + DCD, e no ano 2 todos os tratamentos foram superiores à testemunha. Não houve diferença na massa de mil grãos entre os tratamentos com DLS. A massa de hectolitro foi superior com a injeção do DLS + DCD e as produtividades observadas nesse tratamento também foram superiores, não diferindo da adubação mineral. Conclui-se que a injeção de DLS proporciona menores perdas de N mineral, a DCD reduz a velocidade com que surgem formas aniônicas de N mineral e que a injeção do DLS + DCD não difere da adubação mineral quanto à produtividade de grãos.

Palavras-chave: DCD. Dicianodiamida. Injeção de dejetos. Triticum aestivum L.

Introduction

The use of liquid hog manure (LHM) as a nitrogen (N) source in wheat crops offers a promising alternative to reduce the high production costs associated with this crop, rendering it economically feasible. Liquid hog manure contains N in various forms with varying degrees of availability (Ceretta et al., 2010). Approximately 50% of the total N content in LHM exists in the ammoniacal form (Nunes et al., 2023). The application of LHM, typically preceding crop establishment, necessitates effective synchronization between N availability and the crop's demand, representing a critical aspect of its management (Angers et al., 2010; Marinho et al., 2021).

In wheat cultivation, nitrogen stands out as the nutrient that most contributes to increased productivity (Souza et al., 2021) because it governs the formation of tillers and plays an indispensable role in the initiation of nodes during early growth stages (Ecco et al., 2020). However, the timing of LHM application, which often precedes wheat sowing, may restrict N availability to plants during crucial phases of crop development (Pegoraro et al., 2021).

Apart from the challenge of aligning N supply in LHM with the requirements of wheat crops, this element is susceptible to various forms of loss, including surface runoff, ammonia (NH_3) volatilization (Aita et al., 2014), nitrate ($N\text{-}NO_3^-$) leaching subsequent to ammonium ($N\text{-}NH_4^+$) nitrification (Dell et al., 2012), and emissions of nitrous oxide (N_2O) and nitrogen gas (N_2) during denitrification (Aita et al., 2015). Therefore, the development of strategies to mitigate N losses post-LHM application is imperative, both to preserve its fertilizing potential as an N source and to mitigate environmental pollution. Enhancing the agronomic efficiency of LHM usage thus necessitates the adoption of technologies that curtail N losses in the soil, augmenting its availability to crops.

Consequently, the injection of LHM into the soil and the application of nitrification inhibitors, such as dicyandiamide (DCD), have emerged as evaluated technologies. Soil injection of LHM reduces N losses due to NH_3 volatilization (Gonzatto et al., 2016), whereas DCD application slows the nitrification of ammoniacal N, leading to a reduction in N-NO3- leaching within the soil profile, up to 77% (Vallejo et al., 2005), and reducing N_2O emissions by up to 66% (Aita et al., 2014).

The reduction in nitrification rate achieved through LHM injection and the use of DCD is presumed to favor N uptake by the crop (Gonzatto et al., 2016). However, limited research has been conducted to investigate the impact of these strategies on N supply dynamics and wheat yield components. Thus, this paper examines the influence of surface application and injection of LHM, as well as the utilization of dicyandiamide (DCD), on the dynamics of mineral N within the soil and yield parameters in wheat crops.

Material and Methods

The study was conducted during the years 2014 and 2015 within an experimental area proximate to the Frederico Westphalen campus of the Federal University of Santa Maria, located in the state of Rio Grande do Sul, Brazil. The soil in this region is characterized as a typical Aluminoferric Red Latosol, as defined by the Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA] (2013). This soil had been under agricultural cultivation for a period of 12 years, under the no-till system. At the beginning of the experiment, the soil exhibited the following physical and chemical attributes, assessed within the 0.00-0.10 m layer: pH (H_2O) = 5.00; organic matter (OM) = 2.98 g dm^{-3}; phosphorus (P) (Melich) = 7 mg dm^{-3}; potassium (K) = 93.68 mg dm^{-3}; density of 1.35 g dm^{-3}; 154.6 g kg^{-1} sand; 77.3 g kg^{-1} silt; and 768.3 g kg^{-1} clay. The climate in this region is classified as subtropical humid, denoted as a cfa type according to the Köppen-Geiger classification (Heldwein et al., 2009). Figure 1 illustrates the rainfall and mean temperature data, sourced from the Instituto Nacional de Meteorologia [INMET] (2015) automatic station, situated at a distance of 1,000 m from the experimental area.

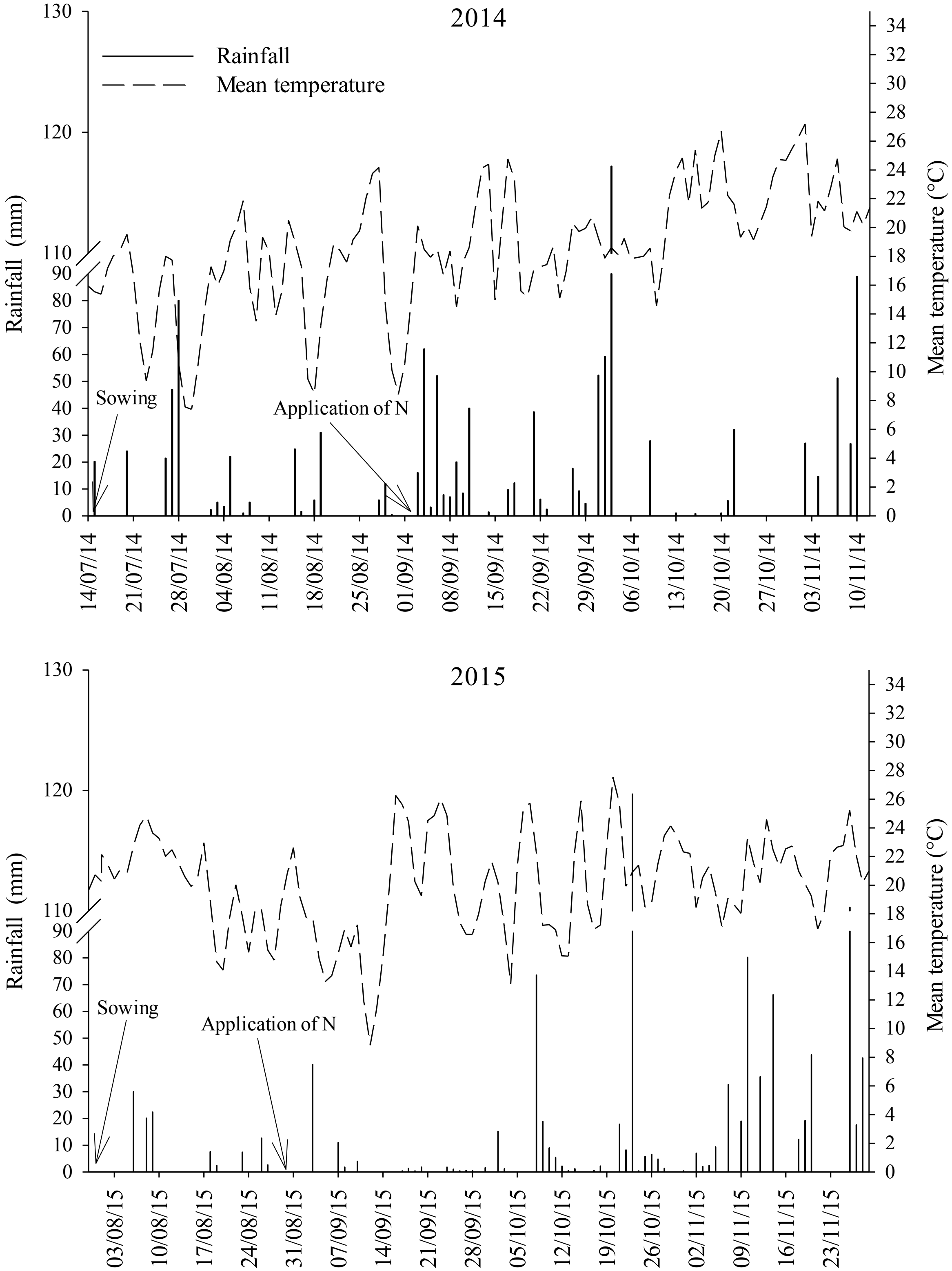


Figure 1. Rainfall and average daily air temperature during the experiments.
Source: INMET (2015).

A randomized-block experimental design with four replications was employed. The treatments were distributed as follows: T0 - Control; T1 - surface application of LHM (Sup); T2 - sub-surface injection of LHM (Inj); T3 - surface application of LHM + DCD (Sup+DCD); T4 - sub-surface injection of LHM + DCD (Inj+DCD); and T5 - application of N, P, and K in mineral form (NPK). Liquid hog manure was applied as a single dose before the sowing of wheat, and the treatments were allocated in plots of 36 m^2 (6 × 6 m).

The LHM, sourced from animals in the finishing phase, was collected from anaerobic manure, transported to the experimental site, and stored in 1,000-L polypropylene containers. One week prior to application, LHM samples were drawn from each container to determine dry matter, total N, and ammoniacal N contents, following the methodology proposed by Tedesco et al. (1995). Table 1 describes the LHM composition.

Table 1
Main characteristics of LHM and amounts of dry matter (DM) and nitrogen (N) applied in wheat

		Waste composition			Amount added		
Year	Rate	DM$^{(1)}$	N Tot$^{(2)}$	Amo N$^{(2)}$	DM	Total N	Amo N
	m^3 ha^{-1}	--------------kg m^{-3}------------------			---------------------kg ha^{-1}-----------------		
2014	75	16.6	2.1	1.4	1245.0	157.005	105.0
2015	40	14.7	3.4	2.2	588.0	137.60	88.0

Total N: Total N; Amo N: Ammoniacal N; (1) dry base, (2) wet base.

The dose of LHM applied was based on the recommendations for organic fertilization as proposed by the Comissão de Química e Fertilidade do Solo [CQFS] (2004), without considering the residual effect for subsequent crops. The nitrification inhibitor DCD was applied in its pure form at a rate of 10.0 kg ha^{-1}, mixed with LHM immediately prior to soil application.

Liquid hog manure was applied to the soil surface using sprinklers, while sub-surface injection was carried out using tractor-based equipment equipped with a 4,000-L metal tank. A hydraulic piston inserted a guillotine-type blade into the soil at the rear of the equipment. The furrowing rods, with a thickness of 2.0 cm, were spaced 35 cm apart, and the injection depth ranged from 8 to 11 cm.

The application of LHM occurred on 07/14/2014 and 07/29/2015, preceding wheat sowing. In 2014, a rate of 75 m^3 ha^{-1} was applied, and in 2015, a rate of 40 m^3 ha^{-1} was used. The genetically modified TBio Sinuelo wheat cultivar was sown using a tractor-based seeder one day after LHM application. The furrows were spaced at 0.17 m, resulting in a final plant population estimated at 400 plants m^{-2}. For the NPK treatment, the following quantities were applied at sowing: 15 kg N ha^{-1} in the form of urea (2014 and 2015), 52.5 kg P_2O_5 ha^{-1} (2014), and 75 kg P_2O_5 ha^{-1} (2015) in the form of triple superphosphate; and 60 kg K_2O ha^{-1} (2014 and 2015) in the form of potassium chloride. Additional N (only in the NPK treatment), in the form of urea, was applied as a topdressing on 09/02/2014 (90 kg of N ha^{-1}) and 08/28/2015 (95 kg of N ha^{-1}), respectively, in the first and second years, during the tillering stage of the crop. Wheat was harvested on 11/12/2014 and 11/29/2015.

To evaluate mineral N, including ammoniacal (N-NH_4^+) and nitric (N-NO_3^-) forms in the soil after LHM application, four soil sub-samples were collected from each of the four treatment replications. This procedure was adopted due to the high degree of variability observed in soil mineral N content, especially following LHM application, as reported by Morvan et al. (1996). In treatments in which LHM was injected into the soil, soil samples were collected separately from the injected row and between the rows, resulting in two sets of four sub-samples per plot. Soil moisture and mineral N levels were determined using the methodology described by Tedesco et al. (1995). Soil density was assessed using the volumetric ring method, yielding a value of 1.35 g cm^{-3}.

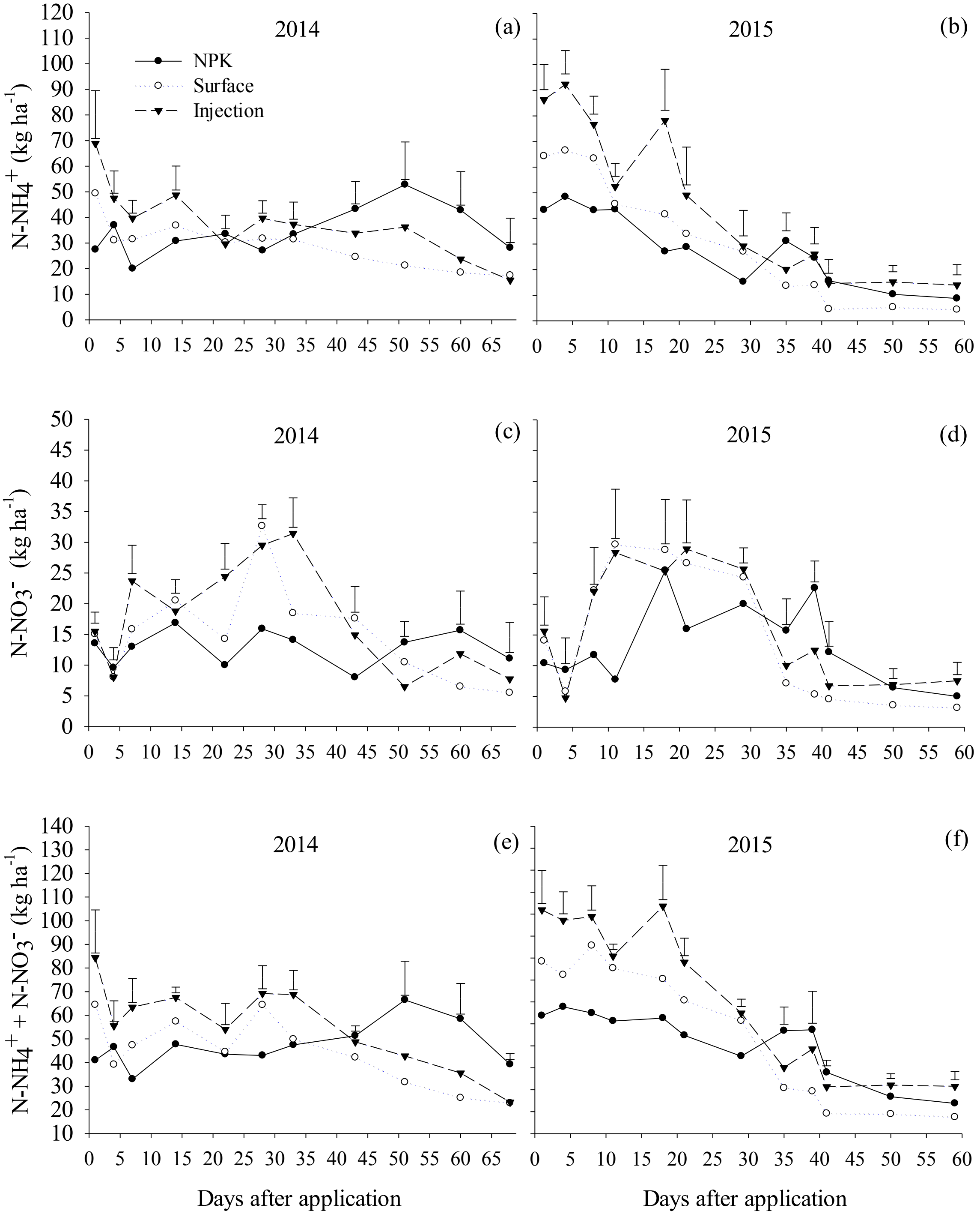
Soil sampling, conducted in the 0-10 cm soil layer, started one day after treatment application and continued on the 4th, 7th, 14th, 22nd, 28th, 33rd, 43rd, 51st, 60th, and 68th days in the first year (2014) and on the 4th, 8th, 11th, 18th, 21st, 29th, 35th, 39th, 41st, 50th, and 59th days in the second year (2015), following the transformations of N in the soil after the most significant rainfall events. The quantities of mineral N in the soil were expressed in kg ha^{-1} by subtracting the values obtained in the control treatment.

The following variables were evaluated during the wheat harvests: number of ears per square meter (NE, m^2); number of spikelets per ear (NSE); number of grains per ear (NGE); 1,000-grain weight (MMG); and grain yield (GY), in plants harvested in five linear meters and four rows. The number of ears per square meter and NSE were determined by counting these variables in the collected ears. Thousand-grain weight followed the methodology recommended by the Ministério da Agricultura, Pecuária e Abastecimento [MAPA] (2009), and GY was adjusted for 13% moisture content and extrapolated to kilograms per hectare.

The data were subjected to analysis of variance (ANOVA), and if significant differences between treatments were identified, the Scott-Knott test for mean separation, with a 5% probability of error, was conducted using Sisvar software (Ferreira, 2011).

Results and Discussion

The mineral N content in the 0-10 cm soil layer exhibited a noticeable increase compared to the control treatment due to the ammoniacal N applied through LHM (Figure 2). Specifically, the recovery of N-NH_4^+ following LHM injection one day post-application exceeded the values obtained with surface application by 19 kg ha^{-1} in both years. This difference persisted throughout the evaluation period (Figure 2ab). In contrast, concerning N-NO_3^-, similar levels were observed between surface and injection applications (Figure 2cd), and both methods surpassed mineral fertilization until the nitrogen topdressing application.



* The vertical bars indicate the least significant difference between the treatment means (Tukey 0.05)

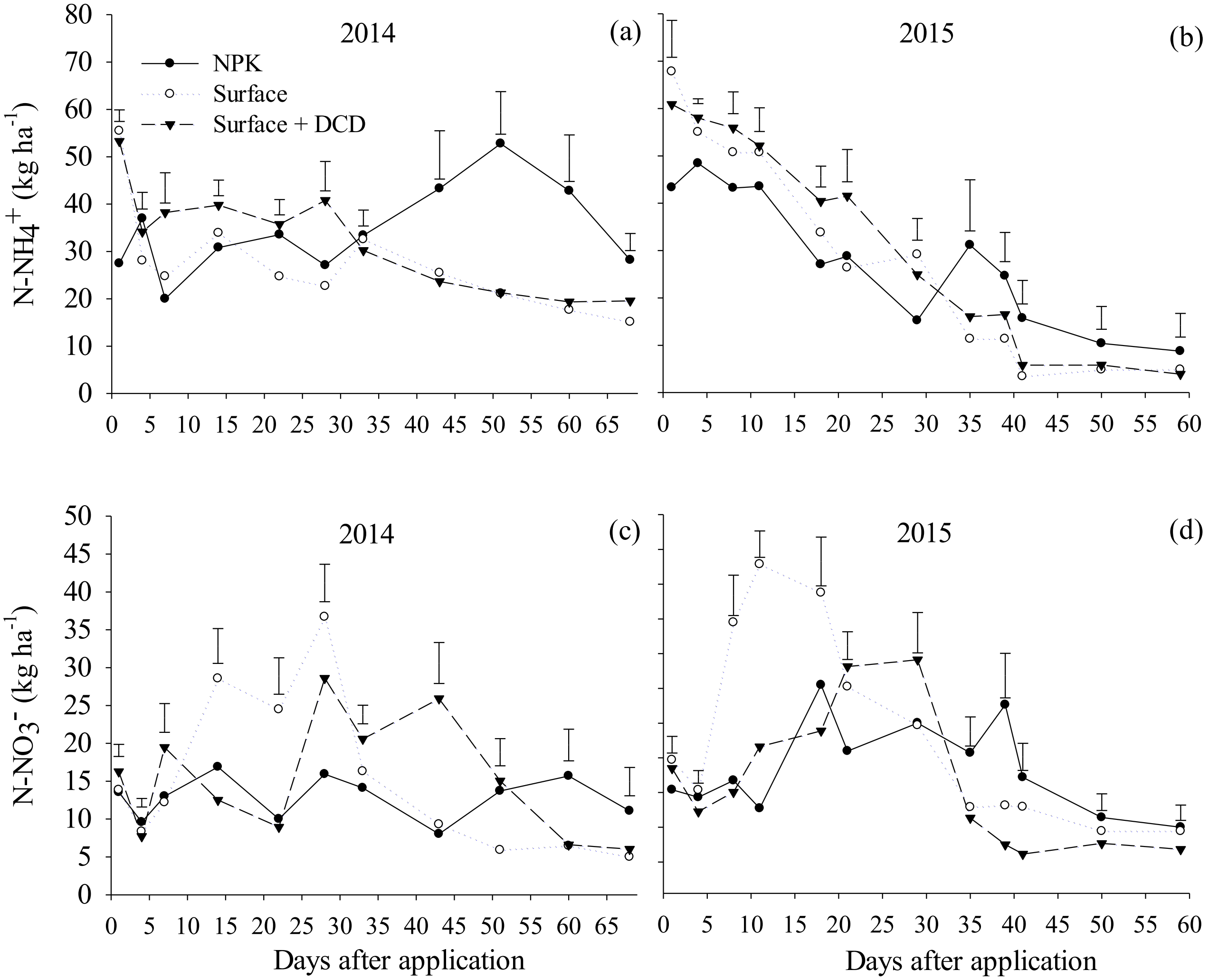
Figure 2. Mineral N content (NH_x^+, NO_x^-, and $NH_x^+ + NO_x^-$) of the soil during the experimental conduct as a result of the application of N, P, and K in mineral form (NPK), surface application of LHM (Surface), and sub-surface injection of LHM (Injection).

When considering the cumulative sum of N-NH_4^+ + N-NO_3^-, the values recovered with sub-surface injection exceeded those achieved with surface application (Figure 2ef). It was only after the application of topdressing that the values of N-NH_4^+ + N-NO_3^- in the mineral fertilization treatment surpassed those in the LHM injection treatment. The initial incomplete recovery of ammoniacal N applied via LHM is in line with the findings of Rochette et al. (2009). This phenomenon occurs due to N-NH_4^+ fixation in the soil's colloidal fraction and retention in straw, where a significant portion of the liquid fraction of applied LHM, containing the highest concentration of ammoniacal N, is concentrated.

Considering the anticipated reduction in N losses due to NH_3 volatilization with LHM injection, it was expected that the recovery with surface LHM application would be lower (Rochette et al., 2009). This expectation arises from the fact that, in addition to ammoniacal N, the high initial pH of LHM contributes to an increase in soil/LHM interface pH, potentially elevating NH3 emissions during the first 24 h following LHM application, particularly in surface applications. Moreover, high temperatures and pore obstruction resulting from particulate organic matter may have enhanced NH_3 volatilization (Meade et al., 2011). In contrast, LHM injection reduces NH_3 volatilization by reducing the concentration of N-NH_4^+ at the soil/atmosphere interface, facilitating greater infiltration and enhancing nitrification (Monaco et al., 2012).

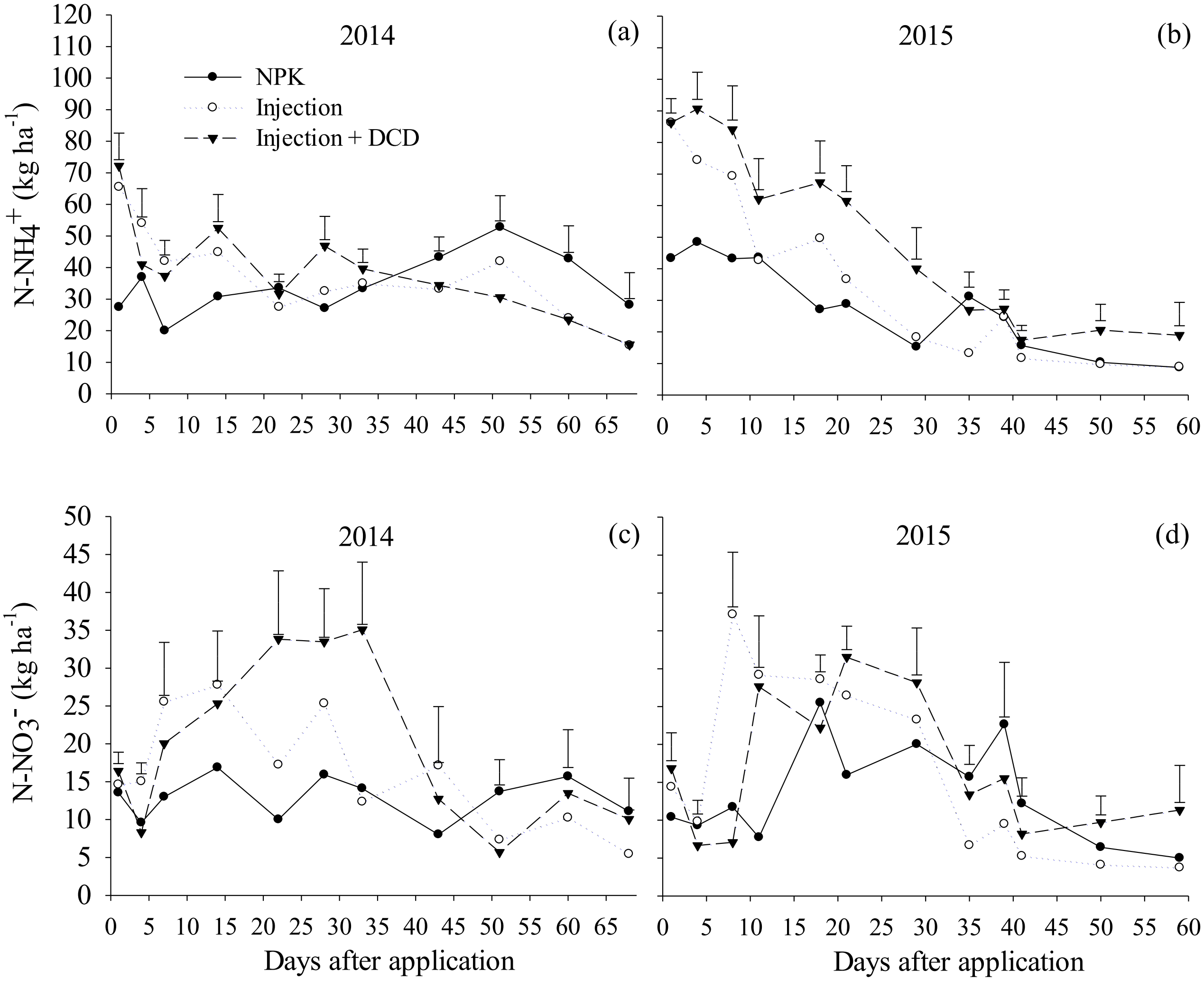
Similarly, when urea was applied as topdressing, a series of reactions may have led to the formation of N-NH_4^+, bicarbonate, and hydroxyl ions, elevating the pH surrounding the granules. During this process, a portion of N-NH_4^+ may convert to NH_3, which may have been lost to the atmosphere (Rochette et al., 2009). The increase in cation-exchange capacity (CEC) associated with the rise in organic matter content with LHM reduces N losses (Chantigny et al., 2014). Additionally, injection promotes the immobilization of inorganic N in LHM, with the effect becoming more pronounced after 30 days post-sowing (Morvan et al., 1996).

The impact of DCD on soil's ammoniacal N and nitric N content is evident from the comparison (Figures 3 and 4). In cases of surface LHM applications without DCD, the evaluation of mineral N content on the 14th (2014) and 18th (2015) days after application saw a decline in N-NH_4^+ content from 55.5 to 33.9 kg ha^{-1} in 2014 and from 67.8 to 33.8 kg ha^{-1} in 2015 (Figure 3ab). Meanwhile, the N-NO_3^- content increased by 14.7 kg ha^{-1} in 2014 and by 24 kg ha^{-1} in 2015 (Figure 3cd). In surface applications with DCD, the recovered N-NH_4^+ content decreased from 53.2 to 39.7 kg ha^{-1} in 2014 and from 60.9 to 40.4 kg ha^{-1} in 2015. Conversely, the N-NO_3^- content dropped by only 3.7 kg ha^{-1} in 2014 but increased by 5.4 kg ha^{-1} in 2015.



* The vertical bars indicate the least significant difference between the treatment means (Tukey 0.05)

Figure 3. Soil mineral N (NH_x^+ and NO_x) content during the experiment with application of N, P, and K in mineral form (NPK), surface application of LHM (Surface), and surface application of LHM + DCD (Surface + DCD).



* The vertical bars indicate the least significant difference between the treatment means (Tukey 0.05)

Figure 4. Mineral N content (NH_x^+ and NO_x^-) during the experiment with application of N, P, and K in mineral form (NPK), sub-surface injection of LHM (Injection), and sub-surface injection of LHM + DCD (Injection + DCD).

The observed discrepancy between the increase in N-NH_4^+ and N-NO_3^- content in treatments without DCD can be attributed to N immobilization processes stemming from LHM application (Giacomini et al., 2009). Differences between treatments with and without DCD highlight the inhibitory effect of DCD on the nitrification of ammoniacal N. Dicyandiamide temporarily blocks the active site of the ammonia monooxygenase enzyme, particularly in *Nitrosomones europea,* a bacterial species responsible for the conversion of N-NH_4^+ (Moir et al., 2007).

The alteration in mineral N dynamics induced by DCD may have led to N losses due to volatilization, particularly in surface applications. This deduction is justified by the small variation in N-NO_3^- levels in relation to the absence of DCD (Figure 3d). The increase in pH, coupled with the rapid hydrolysis of urea, could have elevated N-NH_4^+ content, potentially leading to NH_3 losses (Zaman et al., 2009). Assessing the impact of DCD through N-NO_3^- content is difficult due to the high mobility of anionic forms and the influence of rainfall, which may have resulted in N-NO_3^- leaching within the soil profile.

With LHM injection, considering the same evaluation moments as surface applications, the N-NH_4^+ content decreased from 65.5 to 44.9 kg ha^{-1} and from 86.2 to 50 kg ha^{-1} (Figure 4ab), while the N-NO_3^- content increased by 13.2 and 14.2 kg ha^{-1}, in 2014 and 2015, respectively (Figure 4cd). When using LHM injection with DCD, the N-NH_4^+ content decreased from 72.2 to 52.4 kg ha^{-1} and from 86.3 to 67.3 kg ha^{-1}, with an increase in N-NO_3^- of 8.9 kg ha^{-1} in 2014 and 5.37 kg ha^{-1} in 2015 (Figure 4cd). Given the expectations of reduced NH_3 losses with LHM injection (Dell et al., 2012), the N-NH_4^+ content was expected to be higher than that of surface application. The observed increase in N recovery in 2015 may be attributed in part to the residual effects of the 2014 application.

When comparing N-NO_3^- recovery in treatments with and without DCD, the presence of the inhibitor consistently resulted in lower levels of N-NO_3^- recovery in the first few days post-application, regardless of the application method (Figures 3 and 4). In surface applications with DCD, N-NO3-content remained higher until 33 (2014) and 21 (2015) days post-sowing. With LHM injection, an inversion in N-NO_3^- recovery values with DCD was observed after 22 and 21 days post-sowing, in 2014 and 2015, respectively.

In the absence of DCD, rapid nitrification occurs, potentially leading to the accumulation of N-NO_3^- in the soil at a rate faster than plants and microorganisms can utilize. Consequently, when rainfall occurs, anionic forms of nitrogen (NO_2^- and NO_3^-) may leach from the soil, reducing the availability of N (Giacomini et al., 2013).

The most substantial increase in the number of ears per square meter, compared to the control, was observed with the injection of LHM (Figure 5a). Specifically, in 2014 and 2015, this increase amounted to 115 and 160 ears per m^2, respectively. In contrast, surface applications yielded smaller increments of 59 and 115 ears per m^2. This reduction, although not statistically significant compared to injection in 2015, likely reflects nitrogen losses associated with surface applications.

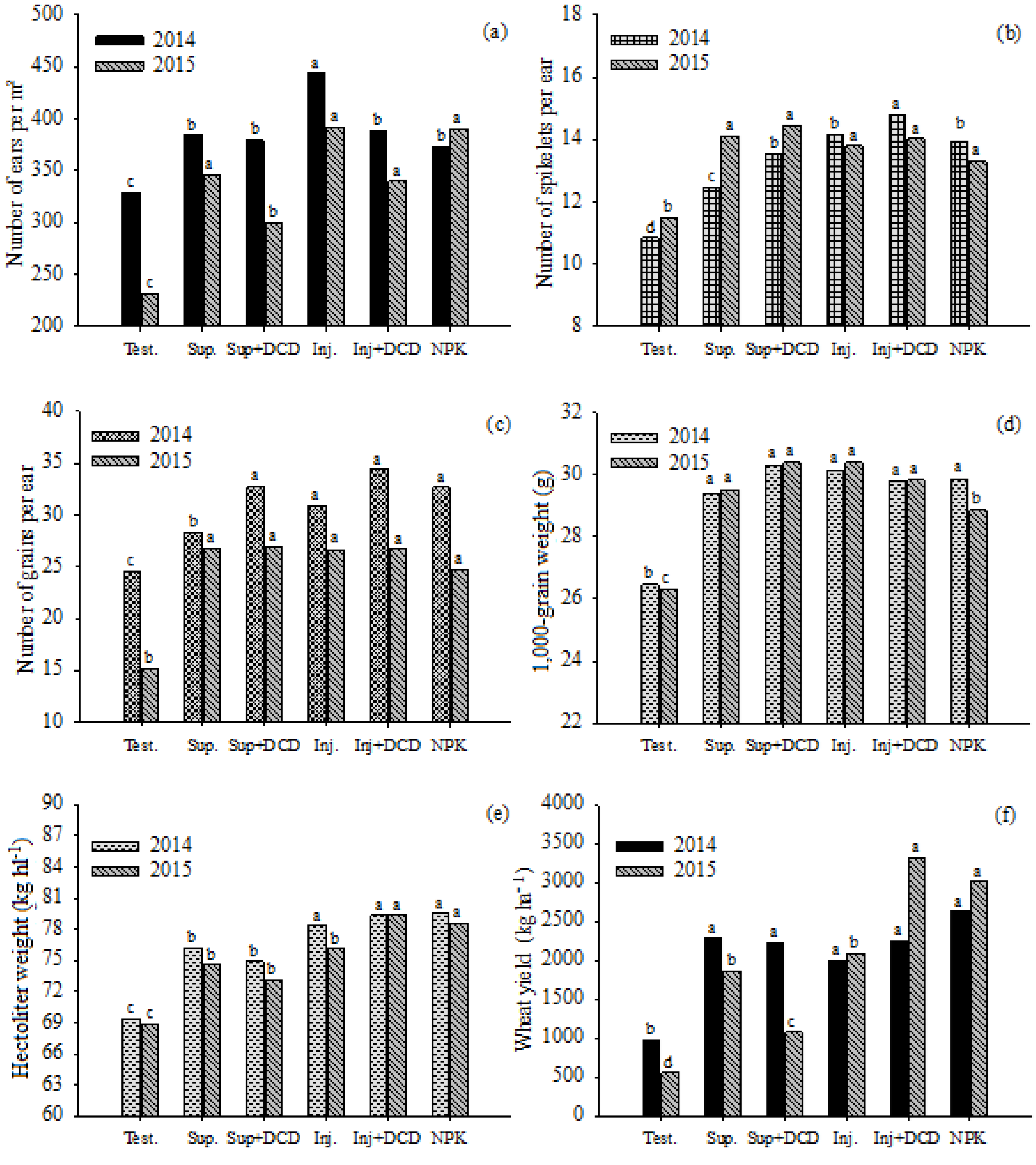


Figure 5. Number of ears per m² (a), spikelets per ear (b), grains per ear (c), 1,000-grain weight (d), hectoliter weight (e), and yield (f) of wheat as a result of liquid hog manure application mode, presence or absence of nitrification inhibitor, and mineral fertilization. Frederico Westphalen, Rio Grande do Sul state, 2014/2015 harvest. Where: Test = Control; Sup. = surface application; Sup.+DCD = surface application with dicyandiamide; Inj. = sub-surface application; Inj+DCD = sub-surface application with dicyandiamide; NPK = nitrogen, phosphorus, and potassium in mineral form. * Means followed by the same letter do not differ from each other by Tukey's test at the 5% probability level.

Competition among tillers, particularly under nitrogen limitation, determines the number of viable tillers and, consequently, the number of ears per unit area, ultimately impacting final grain yield (Mundstock & Bredemeier, 2001). In the treatment with LHM injection, the concomitant supply of $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$ during the induction, emergence, and development phases of the tillers likely increased the accumulation of structural N, leading to greater N availability for the tillers (Taiz & Zeiger, 2013). In 2014, there was no difference in the number of ears per square meter whether surface-applied DCD was used or not, whereas in 2015, there was a reduction in the number of tillers.

There was a reduction in the number of spikelets per ear when LHM was applied on the surface in 2014. Conversely, the highest values in 2014 were observed for the injection of LHM with DCD, whereas in 2015, no differences were found between application methods, with or without DCD, and values were higher than the control and similar to mineral fertilization (Figure 5b). In 2014, sustained high soil nitrogen levels due to LHM with DCD likely increased gibberellic acid content, leading to greater protein synthesis and increased flowering (Marchner, 1995).

Concerning the number of grains per ear, the injection of LHM with DCD produced the highest values in 2014, differing only from surface application and the control, which showed 28% and 13% fewer grains, respectively. In 2015, similar to the results for the number of spikelets per ear, no differences were observed between the application methods of LHM, with or without DCD, and the values surpassed the control, approximating mineral fertilization (Figure 5c). The residual effect of the prior application, combined with the N available in 2015, likely increased nitrogen content in the ears between anthesis and the onset of grain filling, playing a critical role during intense mitotic activity observed in newly fertilized ovules and thereby reducing ovule abortion at the beginning of grain filling (Sangoi, 2001).

No differences were observed in the 1,000-grain weight due to application mode or the addition of DCD to LHM (Figure 5d). Grain weight is typically associated with nitrogen availability during the grain-filling period. Therefore, when comparing grain mass obtained with LHM application, it was evident that it fulfilled the crop's nitrogen requirements and even surpassed that achieved with mineral fertilization in 2015.

In both years evaluated, hectoliter weight exceeded 78 kg hl^{-1} with the injection of LHM with DCD (Figure 5e). This treatment consistently yielded values greater than surface application and similar to mineral fertilization in these two years. The observed increase in hectoliter weight can be attributed to enhanced N availability in the soil, which promotes extended photosynthesis and increased production of photoassimilates, ultimately resulting in greater grain reserve accumulation (Dourado et al., 2004). Additionally, hectoliter weight holds substantial significance for trade as it serves as an indicator of quality and yield in flour extraction, influencing product pricing (Corrêa et al., 2006).

Regarding productivity, differences in values were only evident in 2014 when compared to the control, which yielded lower values than other treatments. In 2015, higher yield values were achieved with the injection of LHM with DCD, with no significant difference from mineral fertilization (Figure 5f). Processes associated with microbial immobilization of inorganic nitrogen and mineralization of organic N applied in 2014 may have impacted N release to the crop in the subsequent year, resulting in the observed increase (Giacomini et al., 2009). Lower results associated with surface application of LHM compared to injection in 2015 may be linked to a higher percentage of N loss. This may have favored the volatilization of NH3, which experiences losses of approximately 80% within the first 22 h following LHM application (Gonzatto et al., 2013).

Strategies employing LHM as a fertilizer offer environmental benefits, with DCD effectively blocking nitrification when mixed with LHM. Conversely, LHM injection efficiently maintained higher ammonium levels in the studied soil. In Brazil, there remains a scarcity of studies aimed at determining the efficiency of DCD in mitigating greenhouse gas emissions and reducing environmental impacts associated with excessive ammonia in the soil. The economic and environmental significance of LHM underscores the need for further research in this field within Brazil.

Conclusion

The soil's mineral N levels following the injection of liquid hog manure surpass those achieved through surface application.

The use of dicyandiamide results in a slower appearance of anionic forms of mineral N in the soil.

In terms of grain yield, there is no distinction between the injection of liquid hog manure with the incorporation of dicyandiamide and mineral fertilization.

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