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APPLICATION OF ANHYDROUS AMMONIA AS NITROGEN FERTILIZER, ITS INFLUENCE ON SOIL PROPERTIES AND YIELD OF AGRICULTURAL CROPS

Nikolai CHEKAEV, Tatyana VLASOVA

Penza State Agrarian University, 30 Botanicheskaya Street, 440014, Penza, Russia

Corresponding author email: chekaev1975@mail.ru

Abstract

The article presents the scientific results of anhydrous ammonia on the acid-base properties of leached chernozem carried out in the training and production center of Penza State Agrarian University (Russia). After adding anhydrous ammonia, an increase in pH values is observed. During the growing season, an increase in acidity is observed as nitrification of ammonium nitrogen into nitrate. This is especially manifested when ammonia is introduced in doses of 150 and 200 kg/ha. In variants using anhydrous ammonia in doses of 150 and 200 kg/ha, the amount of absorbed bases decreased by 1.4-2.2 meq/100 g of soil. The greatest decrease was observed in variants with doses of 200 kg/ha in physical weight. The introduction of anhydrous ammonia in doses of 100 to 200 kg/ha in physical weight increased the content of nitrate nitrogen in the soil from the beginning of the growing season to the time of harvesting and provided spring wheat plants with available nitrogen. When conducting plant diagnostics on options using anhydrous ammonia, signs of nitrogen starvation of spring wheat plants were not observed.

Key words*: anhydrous ammonia, acidity, nitrate nitrogen, grain yield, spring wheat.*

INTRODUCTION

One of the most effective ways of intensifying crop production is to improve the supply of plants with nitrogen, since it is this element that most often limits yield. Currently, one of the indispensable attributes of highly profitable farming using intensive technologies is the use of anhydrous ammonia.

At the same time, its limited use in a number of countries indicates that the use of this liquid nitrogen fertilizer not only has advantages, but is also accompanied by certain difficulties (Smiciklas et al., 2008; Kovács et al., 2015).

Anhydrous ammonia (NH_3) - the most concentrated ballastless fertilizer, contains 82% nitrogen. Get it by liquefying gaseous ammonia under high pressure. This is a colorless liquid with a characteristic pungent odor, one of the most dangerous chemicals used in agriculture.

The agronomic advantage of anhydrous ammonia over solid nitrogen fertilizers is the fact that the diffusion of nitrogen from the granule depends on soil conditions and most often occurs in the vertical direction, while ammonia turns into gas at atmospheric pressure, diffusing in the soil over a greater distance in all directions , which allows one to more evenly distribute nitrogen in the soil layer and, accordingly, increase the coefficient of its assimilation by plants (Bundy et al., 2011; Zhang et al., 2015).

MATERIALS AND METHODS

In order to study the effect of anhydrous ammonia on the properties of leached chernozem and grain yield of spring wheat, studies were conducted on the experimental field of the training and production center of Penza state Agrarian University (Mokshansky district, Penza, Russia) in 2017-2019 according to the following scheme:

1. Without fertilizers (control);
2. Anhydrous ammonia (NH_3) - 100 kg/ha in physical weight (F.W.) when applied to a depth of 10 cm;
3. NH_3 - 100 kg/ha F.W. to a depth of 15 cm;
4. NH_3 - 150 kg/ha F.W.to a depth of 15 cm;
5. NH_3 - 200 kg/ha F.W.to a depth of 15 cm;
6. NH_3 - 100 kg/ha F.W.to a depth of 20 cm;
7. NH_3- 150 kg/ha F.W.to a depth of 20 cm;
8. NH_3 - 200 kg/ha F.W.to a depth of 200 cm.

Experiments were carried out on leached chernozem medium humus loamy.

The plot area is 1230 m^2. The plot allocation is randomized. Three iterations. The total area of

the experiment is 29,520 m^2 (2,952 ha). The predecessor is the winter wheat.
Before the introduction of anhydrous ammonia, disking was carried out to a depth of 12-14 cm and soil samples were taken for the initial values.
Anhydrous ammonia was introduced according to the research scheme. For application, the integrated Case IH 5300 aggregate with a working width of 8.4 m was used.
When conducting soil and plant analyzes, the following research methods were used:
- nitrate nitrogen in the soil by potentiometric method;
- pH of saline suspension by potentiometric method;
- hydrolytic acidity of the soil according to the Kappen;
- the amount of absorbed bases according to the Kappen-Gilkowitz method.
- crop accounting by the weighing method according to the experimental options in 3-fold repetition from 1.0 m^2.
- crudeprotein content in wheat grain by the Kjeldahl method;
- wetgluten content in wheat grain - by manual method;
- gluten quality on the IDK-3M device.

RESULTS AND DISCUSSIONS

The experiments have shown, before sowing spring wheat, the pH of the soil in the experimental plots varied between 5.01-5.85 units and was characterized as weakly acidic and close to neutral, while an increase in pH was observed in variants with the introduction of anhydrous ammonia (Table 1).
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Table 1. Soil pH (KCl) (units) in a layer of 0-25 cm, depending upon the dose of anhydrous ammonia (average for 2018-2019)

Variant	Before implemen-tation (October)	Sample Duration				Deviations from the initial values
		Before sowing (first decade of May)	Exit to the handset (third decade of June)	At the time of harvesting (second decade of August)	One month after harvesting (second decade of September)	
1. Without fertilizers (control)	5.02	5.01	4.99	4.95	4.92	-0.10
2. NH_3 100 kg/ha 10 cm	5.02	5.22	5.15	5.05	5.00	-0.02
3. NH_3 100 kg/ha 15 cm	5.07	5.48	5.10	5.03	5.03	-0.03
4. NH_3 150 kg/ha 15 cm	5.22	5.62	5.52	5.38	4.98	-0.23
5. NH_3 200 kg/ha 15 cm	5.20	5.64	5.54	5.42	4.92	-0.28
6. $NH_3$100 kg/ha 20 cm	5.07	5.22	5.13	5.07	4.87	-0.19
7. $NH_3$150 kg/ha 20 cm	5.13	5.49	5.22	5.15	4.95	-0.18
8. NH_3 200 kg/ha 20 cm	5.30	5.85	5.35	5.32	4.92	-0.38

The increase in pH depending on the dose of anhydrous ammonia was 0.2-0.55 units pH. The dynamics of increasing the pH of the soil is associated with the use of anhydrous ammonia and the alkalization of the soil solution and soil with the formed ammonium hydroxide.
The greatest changes were in the case where 200 kg/ha of ammonia was added to a depth of 20 cm. In the subsequent determination, the pH of the soil decreased by 0.07-0.5 units for all variants of the experiment pH.
At the time of harvesting, there was a further trend towards a decrease in pH both on options without fertilizers (control) and with the use of different doses of anhydrous ammonia (Melbourne et al., 2014).
The largest decrease in pH was observed in the variants using anhydrous ammonia at doses of 150 and 200 kg/ha, deviations from the initial values range from 0.18 to 0.38. This tendency to lower soil pH is associated with mineralization and nitrification processes. Ammonium forms of nitrogen gradually turn into nitrate forms with acidification of the soil solution and soil.
Hydrolytic acidity prior to the introduction of anhydrous ammonia according to the test variants was in the range of 2.65-5.03 meq/100 g of soil. During the growing season, minor

changes occurred depending on the options of the experiment. In variants without fertilizers and with the use of anhydrous ammonia to a depth of 10 cm, an increase in hydrolytic acidity by 0.19-0.22 meq/100 g of soil is observed (Table 2).

Table 2. Hydrolytic acidity in the soil layer 0-25 cm, depending upon the application dose of anhydrous ammonia, meq/100 g of soil (average values for 2018-2019)

Variant	Before implementation (October)	At the time of harvesting (second decade of August)	Deviations from the initial values
1. Without fertilizers (control)	4.55	4.77	0.22
2. NH_3 100 kg/ha 10 cm	4.41	4.60	0.19
3. NH_3 100 kg/ha 15 cm	4.76	4.45	-0.31
4. NH_3 150 kg/ha 15 cm	5.03	4.68	-0.35
5. NH_3 200 kg/ha 15 cm	2.65	2.49	-0.17
6. $NH_3$100 kg/ha 20 cm	4.22	4.17	-0.05
7. $NH_3$150 kg/ha 20 cm	3.59	3.38	-0.21
8. NH_3 200 kg/ha 20 cm	3.16	2.76	-0.40

In the variants with the introduction of anhydrous ammonia to a depth of 15 and 20 cm at the end of spring wheat vegetation, a decrease in the hydrolytic acidity index by 0.05-0.4 meq/100 g of soil was observed. This can be explained by the fact that when there is a lack of moisture in the soil, the nitrification process is slow and all the ammonia introduced has not yet completely converted to nitrate nitrogen.

The amount of absorbed bases before applying anhydrous ammonia was in the range of 34.3-38.9 meq/100 g of soil. During the growing season of cultivated crops, insignificant changes in the amount of absorbed bases occurred. On options for the experiment with the use of anhydrous ammonia, there was a tendency to decrease this indicator by 0.8-2.2 meq/100 g of soil. In the variant without fertilizers, the amount of absorbed bases decreased by 0.8 meq/100 g of soil (Table 3).

The greatest decrease in the amount of absorbed bases was observed for variants with doses of 150 and 200 kg/ha with values of 1.4-2.2 meq/100 g of soil. This tendency to reduce the amount of absorbed bases is due to the fact that when anhydrous ammonia is introduced from the soil absorption complex, calcium and magnesium are displaced into the soil solution and used by plants during the growing season.

Reserves of nitrate nitrogen in the soil layer 0-40 cm before the introduction of ammonia were in the range of 21.0-27.2 kg/ha. In the spring, when determining the reserves of nitrate nitrogen in the soil according to the experimental options, its content varied depending on the application dose and ranged from 46.0 to 113.5 kg/ha (Table 4).

Table 3. The amount of absorbed bases in the soil layer 0-25 cm depending on anhydrous ammonia application dose, meq/100 g of soil (average indicators for 2018-2019)

Variant	Before implementation (October)	At the time of harvesting (second decade of August)	Deviations from the initial values
1. Without fertilizers (control)	35.1	34.3	-0.8
2.NH_3 100 kg/ha 10 cm	34.3	33.1	-1.2
3. NH_3 100 kg/ha 15 cm	36.2	34.6	-1.6
4. NH_3 150 kg/ha 15 cm	37.6	36.3	-1.4
5. NH_3 200 kg/ha 15 cm	36.7	34.5	-2.2
6. $NH_3$100 kg/ha 20 cm	35.0	34.3	-0.7
7. $NH_3$150 kg/ha 20 cm	36.8	34.8	-2.0
8. NH_3 200 kg/ha 20 cm	38.9	36.7	-2.2

Table 4. The content of nitrate nitrogen in the soil layer of 0-40 cm, depending on the dose of anhydrous ammonia, kg/ha (average for 2018-2019)

Variant	Before implementation (October)	Sample duration			Deviations from the initial values
		Before sowing (first decade of May)	Exit to the handset (third decade of June)	At the time of harvesting (second decade of August)	
1. Without fertilizers (control)	26.6	21.5	14.1	11.6	-
2. NH_3 100 kg/ha 10 cm	23.8	46.0	24.2	15.5	3.9
3. NH_3 100 kg/ha 15 cm	22.0	55.8	34.4	27.1	15.5
4. NH_3 150 kg/ha 15 cm	24.4	88.6	35.0	38.1	26.5
5. NH_3 200 kg/ha 15 cm	21.0	113.5	77.5	73.0	61.4
6. $NH_3$100 kg/ha 20 cm	24.4	58.4	24.8	18.8	7.2
7. $NH_3$150 kg/ha 20 cm	23.2	86.6	31.5	30.6	19.0
8. NH_3 200 kg/ha 20 cm	27.2	113.0	45.8	54.6	43.0

Compared with the control variant, the nitrate content in the soil layer of 0-40 cm increased by 23.5-92.0 kg/ha. An increase in the content of nitrate nitrogen is associated with nitrification and the transition of ammonium forms to nitrate ones. The nitrification process under these conditions is faster than on the version without fertilizers (Zhou et al., 2014).

In the middle of the growing season, the same trend is observed. The highest nitrate nitrogen content was observed in variants with doses of 200 kg/ha in F.W. 45.8 kg/ha when applied to a depth of 20 cm and 77.5 kg/ha when applied to a depth of 15 cm. In the variant without fertilizers, the content of nitrate nitrogen decreased to 14.1 kg/ha, which is associated with an increase in plant nutrition with this element in the middle of the growing season (Diane et al., 2011). When comparing the data on the content of nitrate nitrogen in the soil with the previous determination period, it is seen that there was a decrease in the stock of nitrate nitrogen for all variants of the experiment.

At the time of harvesting, the content of nitrate nitrogen in all experiment variants decreased. The highest nitrate nitrogen content was in the variants with 200 kg/ha of ammonia and amounted to 73.0 kg/ha when applied to a depth of 15 cm. In the variants with different doses of ammonia, the nitrate content in the soil at the time of harvesting was higher compared to the control on 3.9-61.4 kg/ha. In the control variant, the nitrate nitrogen content decreased to 11.6 kg/ha. The largest deviation of the nitrate nitrogen content in the soil in the 0-40 cm layer from the control at the time of harvesting was found in the options for using anhydrous ammonia at a dose of 200 kg/ha to a depth of 15 and 20 cm, the deviations were 43.0 and 61.4 kg/ha, relatively.

The spring wheat grain yield was experimentally influenced by the weather conditions of the vegetation periods of 2018 and 2019. Weather conditions during the summer growing season of 2018 were characterized as arid. During the growing season of spring wheat from May to August, 116 mm of precipitation fell. When comparing with the data of perennial values, in the growing season of 2018, 54% of precipitation fell from the average long-term values, which subsequently affected the size of the crop yield. The weather conditions in 2019 were characterized, as in 2018, as arid. During the growing season of spring wheat, 153 mm of precipitation fell, which was lower than the long-term average by 62 mm or 29%. The month of June was the most arid. The air temperature in June ranged from +5.8°C to +33.4°C, and the amount of precipitation was 22 mm. During this month, 8 days with precipitation were observed, and only once 11 mm of precipitation fell, the remaining precipitation was less than 5 mm and was unproductive.

The results of studies to determine the yield of spring wheat grain showed that the autumn use of anhydrous ammonia increased the yield of spring wheat grain by 0.12-2.28 t/ha. The use of anhydrous in a dose of 100 kg/ha in F.W. when applied to a depth of 10 cm, the grain yield increased by 0.12 t/ha (6.3%). The greatest increase in spring wheat grain yield in the experiment was obtained with the option of introducing a dose of ammonia of 200 kg/ha to a depth of 20 cm. When applying doses of ammonia from 100 to 200 kg/ha in F.W. wheat grain productivity increased by 0.48-1.72 t/ha or by 24.4-86.3% compared to the version without fertilizers.

The weight of 1000 grains in the variants ranged from 35.8-38.9 g. The lowest weight of 1000 seeds was obtained in the variant without fertilizers, and the highest in the variant using anhydrous ammonia at a dose of 200 kg/ha to a depth of 20 cm (Table 5).

Table 5. The yield of grain of spring wheat, depending on the dose of anhydrous ammonia (average values for 2018-2019)

Variant	Grain yield			Mass of 1000 grains, g
	t/ha	deviations from control, t/ha	deviations from control, t/ha	
1. Without fertilizers (control)	1.99	-	-	35.8
2. NH_3 100 kg/ha 10 cm	2.11	0.12	6.3	37.2
3. NH_3 100 kg/ha 15 cm	2.47	0.48	24.4	37.6
4. NH_3 150 kg/ha 15 cm	2.82	0.83	41.9	36.8
5. NH_3 200 kg/ha 15 cm	3.71	1.72	86.3	38.2
6. $NH_3$100 kg/ha 20 cm	2.37	0.38	19.1	37.1
7. $NH_3$150 kg/ha 20 cm	3.50	1.51	75.7	37.5
8. NH_3 200 kg/ha 20 cm	4.27	2.28	114.7	38.9
HCP_{05}		0.11 ± 0.03		0.95 ± 0.06

Important quality indicators of spring wheat grain in the Russian Federation are the protein and gluten content.

Studies show that without the use of fertilizers, the protein and gluten content in wheat grain is reduced (Table 6). The protein content in the variant without the use of fertilizers on the Granny variety was 12.57%, and the gluten content is 17.5%, this grain is rated as grade 5.

Table 6. Grain quality of spring wheat depending on the doses of anhydrous ammonia

Variant	Crude protein, %	Gluten			
		%	Grade	IDK	Quality group
1. Without fertilizers (control)	12.57	17.5	5	80	2
2. NH_3 100 kg/ha 10 cm	13.71	23.0	4	77	1
3. NH_3 100 kg/ha 15 cm	14.05	23.0	4	79	1
4. NH_3 150 kg/ha 15 cm	14.32	25.5	3	72	1
5. NH_3 200 kg/ha 15 cm	14.45	29.0	2	87	2
6. $NH_3$100 kg/ha 20 cm	13.37	24.0	3	81	2
7. $NH_3$150 kg/ha 20 cm	13.54	27.0	3	72	1
8. NH_3 200 kg/ha 20 cm	13.71	27.5	3	77	1

The use of anhydrous ammonia in different doses increased the protein content to 13.37-14.45%, and gluten to 23.0-29.0%. When using anhydrous ammonia at a dose of 100 kg/ha to a depth of 10 and 15 cm in conditions of 2018, they received fourth-grade spring wheat grain of the first quality group. The introduction of ammonia in a dose of 150 kg/ha to a depth of 15 cm and from 100 to 200 kg/ha to a depth of 20 cm made it possible to obtain grain of the third class.

The most productive was the introduction of a dose of 200 kg/ha of anhydrous ammonia on leached chernozem to a depth of 15 cm, this made it possible to obtain grain of the second class of the second quality group with a content of: 14.45% protein, high quality gluten 29%.

CONCLUSIONS

The introduction of anhydrous ammonia in doses from 100 to 200 kg/ha in F.W. increased the content of nitrate nitrogen in the soil from the beginning of the growing season to the time of harvesting and provided spring wheat plants with available nitrogen.

When conducting plant diagnostics on variants using anhydrous ammonia, signs of nitrogen starvation of spring wheat plants were not observed.

In variants with a dose of ammonia of 200 kg/ha, an increased nitrate content is observed during the entire growing season of spring wheat, while nitrate nitrogen in the soil accumulated faster than was used by plants during nutrition.

The use of anhydrous ammonia in doses of 100, 150 and 200 kg/ha at different depths in spring wheat cultivation technologies increases grain yield depending on application doses by 24.4-114.7% and improves grain quality, increasing protein and gluten content.

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