The Use of Anhydrous Ammonia as a Mineral Fertilizer and Its Reaction and Behavior in Soil

Musa Shavanov[1] and Ilyas Shigapov[2]
[1]*Chechen State University, Grozny, Russia*
[2]*Technological Institute, Branch of Ulyanovsk State Agricultural University, Dimitrovgrad, Russia*

Keywords: Nitrogen fertiliser, anhydrous ammonia, agriculture.

Abstract: Anhydrous ammonia (NH3) is the most concentrated nitrogen fertilizer containing 80-82% nitrogen and is widely used in many countries of the world as mineral fertilizer for agricultural crops. It is the third most abundantly produced toxic chemical in the world, which is extensively used as a fertilizer in agriculture. At present, the use of anhydrous ammonia in Russia is not so widely practiced, but demand is gradually increasing among farmers. There are several reasons why NH3 is used so widely in the world: firstly, because of its relatively easy application and ready availability; secondly, it is a starting material for the production of ammonia and thirdly, it is the least expensive source of nitrogen fertilizer. However, there are also disadvantages of applying anhydrous ammonia as fertilizer that limit its complete dominance in the market. It is a gas that is stored as a liquid under high pressure, requiring special equipment for its application and adequately educated workers. If handled wrong, it can cause rapid dehydration and severe burns as it combines with the moisture of the body. This article is a compilation of scientific data that has been evaluated from several perspectives of NH3 after it is applied to soil.

1 INTRODUCTION

The Anhydrous ammonia is one of the most common sources of nitrogen fertilizer, containing about 80-82% nitrogen. Usually, it has two states of aggregation: liquid and gas. The latter prevails under normal environmental conditions. For storage in large quantities, it is either liquefies under pressure (about 10 bar at 250C) or cooled (boiling point -330C), resulting in the formation of liquid ammonia. In this form, it is relatively easier to handle, of course, with special equipment designed to work with ammonia. Although anhydrous ammonia is extremely important for industry (it is widely used in medicine and the production of explosives), most of its production is used in agriculture. Ammonia is directly used as a fertilizer for crops, and it is also the starting material for the production of fertilizers such as ammonium nitrate, ammonium sulfate and others. When it enters the soil, it turns into a gas and forms ammonium hydroxide (NH4OH), the ions of which are absorbed by the soil (Pasman, 2015; Bityutsky, 2014).

It should be noted that ammonia is toxic. It is lighter than air, flammable and forms explosive mixtures with chlorine and sulfur dioxide gases, so untrained people should not be allowed to work with this substance. NH3 contains low water, therefore it aggressively absorbs moisture, whether from the soil, eyes, throat, lungs, or skin. Any contact with anhydrous ammonia with our body can cause tissue dehydration, caustic burns, and frostbite. The danger of ammonia spills is often underestimated, but they have resulted in a significant number of deaths. For example, despite all safety measures, in 1973 in Potchefstroom (South Africa) at a fertilizer plant, a tank filled with anhydrous ammonia cracked and a hole was formed from which 38 metric tons of anhydrous ammonia were released into the atmosphere as a gas and partly in the form of a boiling liquid. A massive cloud formed and dissipated into the air. As a result, 18 people died, 4 of whom lived in the village within a radius of 200 meters, and 65 workers required medical care (Pasman, 2015). In April 2013, a fire and explosion of ammonium nitrate at a West Fertilizer Company plant in Texas killed 15 people and injured 260. The 2014 annual report from the American Association of Poison Control Centers (AAPCC) reported 2,083 single cases of exposure to ammonia (Waheed, 2017).

Shavanov, M. and Shigapov, I.
The Use of Anhydrous Ammonia as a Mineral Fertilizer and Its Reaction and Behavior in Soil.
DOI: 10.5220/0011555000003524
In *Proceedings of the 1st International Conference on Methods, Models, Technologies for Sustainable Development (MMTGE 2022) - Agroclimatic Projects and Carbon Neutrality*, pages 79-83
ISBN: 978-989-758-608-8

2 CHEMICAL AND BIOLOGICAL REACTION OF ANHYDROUS AMMONIA IN SOIL

Anhydrous ammonia should be applied to an appropriate depth to avoid losses due to volatilization of ammonia. It is retained in the soil by various chemical and physical reactions, the most common of which are reactions with free hydrogen ions (pH function) and with water. Anhydrous ammonia dissolves well in water and, when applied to the soil, reacts with soil moisture. The following reaction occurs with the formation of ammonium ions:

$$NH_3 + H_2O \longrightarrow NH_4^+ + OH^-$$

NH3 in the form of gas is highly reactive and ionizes to ammonium ions (NH4+) in the presence of water. Ammonium ions are positively charged and are attracted to negatively charged surfaces such as clay particles and organic matter that leads to the reduction of ammonium loss from the soil. The leaching of nitrogen from the soil occurs after ammonium is converted to nitrate (NO3-) by the nitrification process, which allows it to move with soil moisture. Anhydrous ammonia is considered physiologically alkaline, the application of which causes temporary alkalization of the soil. In the first few days after the introduction of anhydrous ammonia, the pH level in the soil rises (may temporarily rise above nine at the point of maximum concentration), but later the acidity of the soil solution stabilizes and increases. This acidification is caused by the conversion of NH4+ to NO3- by the action of nitrifying bacteria and the displacement of exchange-absorbed cations by the released hydrogen ion. The following reactions of biological nitrification of ammonium in the soil:

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 \longrightarrow 2NO_3^-$$

Eventually, such a reaction leads to a decline of the soil pH to the initial level or below. The application of anhydrous ammonia results in the formation of inorganic nitrogen under the soil surface, because most of it dissipates upward rather than downward after application. Anhydrous ammonia spreads in a diameter of approximately 5 to 13 cm depending on soil texture, cation exchange capacity and soil moisture. The loss of gaseous ammonia depends on the depth of its application and the soil moisture. The lack and excess of moisture contribute to the volatilization of ammonia into the atmosphere. In such cases, to minimize nitrogen losses, anhydrous ammonia is applied to a depth of at least 15 cm with additional equipment that covers the slot made by the knife of the equipment. The level of soil moisture directly affects the depth of anhydrous ammonia application. So, for example, soil with a moisture content of about 16% leads to minimal loss of ammonia, regardless of the depth of application, while on wetter or drier soils, a deeper application of gaseous ammonia is practiced. Studies have shown that soil with a moisture level of 2% leads to an immediate (less than 2 hours) loss of gas, while soil with a moisture content of about 23% has a gradual loss of soil nitrogen during the first 1-2 days (Harber, 2016; Sawyer, 2019; Vitosh, M. L.).

3 WORLD PRODUCTION OF ANHYDROUS AMMONIA

Scalar Food crops are necessary nowadays to quell the famine of the increasing population. The demand for food crops has been increasing substantially with the increasing human population pressure. Thus, there is an increase in the production of food crops globally, which naturally depletes soil nutrients. Farmers rely on fertilizers to keep their soils productive and produce quality crops (Zhichkin, 2021; Zhichkin, 2021a). Ammonia is an important source for the production of mineral fertilizers, as well as the most concentrated nitrogen fertilizer, which is applied to the soil with special equipment. About 80-90% percent of the world's ammonia production is used in agriculture for fertilizer production and also as a direct application. The concentration of mineral nitrogen in the places where anhydrous ammonia is applied can reach 250 mg/kg on loam granulometric composition soils (Miroshnichenko, 2015). The global NH3 market has shown stable growth in recent years, with the Asia-Pacific region (China and India), as well as Russia and America, being the largest production countries (Table 1). Over the next 4 years, a 4% increase in world production of ammonia is expected. Such an increase is mainly expected in Africa, Eastern Europe and South Asia, while in East Asia, on the contrary, the amount of ammonia produced will decrease due to factories closures. One of the factors that keep the constant demand for nitrogen fertilizers is the huge cultivated areas of corn, which accounts for about 10% of all cultivated areas in the world. For example, according to the US Department of Agriculture, 37.1 million hectares of corn were planted in America alone in 2019, which is 3% more compared to 2018 (USGS 2020).

Table 1: World production of ammonia (million tones) (USGS 2020).

	2018	2019
USA	13,1	14
Algeria	1,6	2,4
Australia	1,3	1,3
Belarus	1,05	1,1
Brazil	1	1
Canada	3,83	3,8
China	41	40
Egypt	3,7	4,1
Germany	2,6	2,6
India	11,4	12
Indonesia	5	5
Iran	3,4	3,4
Holland	2,4	2,4
Oman	1,7	1,7
Pakistan	3,1	3,1
Poland	2,17	2,2
Qatar	3,1	3,1
Russia	14,9	15
Saudi Arabia	4	4,3
Trinidad and Tobago	4	4
Ukraine	1,62	1,6
Uzbekistan	1,2	1,2
Vietnam	1,1	1,1
Other countries	15,8	15
Total	**144**	**150**

4 EFFECT OF ANHYDROUS AMMONIA ON SOIL MICROBIAL POPULATION

In the second half of the XX century, some authors expressed concerns about the deterioration of a number of soil indicators such as humus content, soil structure and microbial cenosis when anhydrous ammonia is applied (Papendick, 1966; Parr, 1969). According to other authors, the quality of crop yield did not differ when this fertilizer was applied, but, on the contrary, even improved. However, it must always be taken into account that the use of mineral fertilizers in excessive quantities can reduce the quality of agricultural products, as well as negatively affect the environment. Цюпка (1989) for 4 years studied the effect of the regular use of liquid ammonia and ammonium nitrate on the fertility of the chernozem soil and the production of agricultural crops in the Belgorod region. In areas with liquid ammonia, the content of ammonia nitrogen increased by 1.4 times, and nitrate nitrogen sometimes up to 4.3 times compared with the application of ammonium nitrate, which led to a slight decrease in the quality of crop yield and soil fertility. Also, the reproduction of some groups of microorganisms was observed while other microorganisms decreased in number. Microorganisms involved in the transformation of ammonia nitrogen and in the decomposition of organic matter are bred more intensively. These are nitrifying and denitrifying bacteria, actinomycetes, spore-forming bacteria, cellulose decomposers and oligotrophs (Tsyupka, 1989).

Conducted studies in the late 90s and early 2000s showed that the use of anhydrous ammonia can favorably affect soil microorganisms and nitrifying bacteria, and also result in nitrogen retention in the soil, reduced nitrate leaching and increased yields of various crops (Biederbeck, 1996; Motavalli, 2008). This can be proved by the applied horticultural studies by Harber A. (2016), in which the positive effect of anhydrous ammonia on soil microorganisms is observed, as well as the reduction of leaching into groundwater through interaction with clay particles and soil moisture. Мирошниченко (2015), in turn, argue that the use of anhydrous ammonia did not cause significant changes in the microstructure and microflora of the soil. This study mentions that during the first days after fertilization, microorganisms that assimilate mineral and organic forms of nitrogen are depressed, as a result of which their number is halved. However, after three weeks the activity of microorganisms recommences.

Today, ammonia is widely used in leading countries of the world, some of which prefer anhydrous ammonia as a fertilizer. For example, the USA is the largest producer and consumer. In 2008 anhydrous ammonia accounted for 35% of all nitrogen fertilizers applied in the USA (Fujinuma, 2011) and during 2019, 16 companies were producing ammonia at 35 plants in 16 US states. About 60% of the total ammonia production is concentrated in the states of Louisiana, Oklahoma and Texas due to their large gas reserves, which is the main raw material for the synthesis of ammonia. About 88% of domestic ammonia consumption is used as fertilizer, including direct-applied anhydrous ammonia, and for the production of urea, ammonium nitrate, ammonium phosphate and other nitrogen compounds (Apodaca, 2020).

Since the end of the 20th - the beginning of the 21st century, in some post-Soviet countries (Ukraine, Russia, Belarus) this form of nitrogen fertilizer has not been widely used. For example, Ukrainian agricultural producers use only 12% of the total produced 200-250 thousand tons of anhydrous ammonia. In the USSR anhydrous ammonia was used as the main nitrogen fertilizer, but in the 21st century, its use in the post-Soviet countries has become problematic. On the one hand, it can be explained by the high toxicity of anhydrous ammonia, which, if not handled correctly, can lead to a fatal outcome. On the other hand, it is due to the need for trained personnel to work with NH3 and special equipment for both transport and storage, and for its application to the soil (Miroshnichenko, 2015). Today, the application of anhydrous ammonia in agriculture is steadily expanding. In Russia, NH3 is still used in small quantities, but the increasing application in Belarus and Ukraine leads to high interest among Russian farmers (Kuguchina, 2020).

5 SUITABLE CROPS FOR ANHYDROUS AMMONIA APPLICATION

Anhydrous ammonia as a fertilizer is suitable for various crops. It is applied for cereals, industrial crops, vegetables, sugar beets. It is applied either in late autumn or in early spring three weeks before sowing, to avoid seed burns and weak shoots. Since anhydrous ammonia is applied to moist soil, the optimal application time for dry regions is spring. Usually, it is recommended to apply at a distance of 10-12 mm from the plants or in the middle of the row. Otherwise, the plants may get burned. According to Steen T.N. (1979), anhydrous ammonia is effective for growing potatoes, sugar beet and cabbage (Steen, 1979). Thus, the application of 200 kg/ha of anhydrous ammonia contributed to a higher yield of the first-grade cabbage compared to 200 kg/ha of calcium nitrate. In New Zealand, for example, field experiments were conducted to evaluate the yield of lettuce, radish and spinach using fertilizers such as urea, ammonia sulfate and anhydrous ammonia. The latter produced a higher dry weight of radish compared to urea and control. Due to the application of fertilizers in the low-temperature months of June and July, the plot with anhydrous ammonia received a higher yield, since anhydrous ammonia stimulated plant growth and accelerated the recovery of nitrogen from the soil (Thomas, 1973). Чекаев Н.П. 2020 in his studies in the Penza region showed that the application of anhydrous ammonia at a rate of 100 to 200 kg/ha to a depth of 10-20 cm increases the grain yield of spring wheat cultivars Granny and Triso by 0.48-1.72 t/ha or by 24.4-86.3% compared to the control. The yield of corn increased by 3.55 t/ha when anhydrous ammonia was applied in autumn at a rate of 150 kg/ha alongside the use of diammofoska at a rate of 300 kg/ha compared with the "control" option and by 1.53 t/ha when applied (NH3) in the spring at a rate of 80 kg/ha before sowing corn compared to the "control". The yield of sugar from sugar beet root crops increased by 35.5% compared to the variant without the use of ammonia. Also, field studies in the Bryansk region on the Lady Clair potato cultivar showed an increase in yield compared to the experimental options where ammonium nitrate and azophos fertilizers were applied (Chekaev, 2020; Torikov, 2020).

6 CONCLUSIONS

Anhydrous ammonia is the most concentrated nitrogen fertilizer containing 80-82% nitrogen and is widely used in many countries of the world as mineral fertilizer. Despite significant limitations in the use of this product and many statements about the deterioration of a number of soil indicators after its application, today it is mandatory used for high-tech agriculture in the developed countries of Europe, as well as in the USA and Canada. Based on the analysis of various scientific data on the evaluation of the effectiveness of the use of anhydrous ammonia, no significant changes were found in the stability of the soil microstructure as a result of the use of this product. The only limiting factor to the spread of NH3 application is the significant requirements for handling NH3 and the associated limitations. Agricultural producers need to hire companies that professionally provide a range of services for transportation and fertilization, or create their own service of professionals within the company, which is quite difficult.

REFERENCES

Bityutsky, N. P. 2014. *Mineral nutrition of plants.* Publishing House of St. Petersburg State University.

Kuguchina, I., Antonov, A. 2020. *Anhydrous ammonia is a new trend in nitrogen fertilizers.* https://www.argusmedia.com/.

Miroshnichenko, N. N., Gladkikh, E. Yu., Revt'e, A. V., 2015. Effect of anhydrous ammonia on soil properties and productivity of field crops. *Plant nutrition.* 1.

Torikov, V. E., Sobolev, S. Yu., 2020. Yield and quality of potato tubers using anhydrous ammonia. *Journal "Bulletin of the Bryansk State Agricultural Academy"*. 3 (79). pp. 20-26.

Tsyupka, V. P., 1989. Application of liquid ammonia. *Journal "Chemization of Agriculture"*. 5.

Chekaev, N. P. 2020. Efficiency of using anhydrous ammonia as a fertilizer in the Penza region. *Journal "Agricultural Sciences"*. 2(10).

Apodaca, L. E., 2020. *Mineral Commodity Summaries 2020 USGS – science for a changing world.* U. S. Geological Survey, Reston, Virginia: 2020.

Biederbeck, V. O., Campell, C. A., Ukrainetz, H., Curtinl, D., Boumanl, O. T., 1996. Soil microbial and biochemical properties after ten years of fertilization with urea and anhydrous ammonia. *Canadian Journal of Soil Science*. 76(1). pp. 7-14.

Fujinuma, R., Venterea, R. T., Rosen, C. J., 2011. Broadcast Urea Reduces N2O but Increases NO Emissions Compared with Conentional and Shallow-Applied Anhydrous Ammonia in a Coarse-Textured Soil. *Journal of Environmental Quality.* 40(6). pp. 1806-1815.

Harber, A. 2016. *The Effects of Using Anhydrous Ammonia to Supply Nitrogen to Vegetable Crops.* Horticulture Innovation Australia Ltd.

Motavalli, P. P., Goyne, K. W., Udawatta, R. P., 2008. Environmental Impacts of Enhanced-Efficiency Nitrogen Fertilizers. *Crop Management*. 7(1).

Papendick, R. I., Parr. J. F., 1966. Retention of anhydrous ammonia by soil: Dispensing apparatus and resulting ammonia distribution [Electronic version]. *Soil Sci.* 102. pp. 193-201.

Parr, J. F., 1969. Retention of anhydrous ammonia by soil: Recovery of microbiological activity and effect of organic amendments [Electronic version]. *SoilSci.* 107. pp. 94-104.

Pasman, H., 2015. *Risk Analysis and Control for Industrial Processes-Gas, Oil and Chemicals*. Chapter 1– Industrial Processing Systems, Their Products and Hazards.

Sawyer, J. 2019. *Understanding Anhydrous Ammonia Application in Soil.* Iowa State University: Integrated Crop Management. https://crops.extension.iastate.edu/.

Steen, T. N., 1979. Anhydrous ammonia for winter cabbage. *Tidsskrift for Planteavl*. 83(3). p. 278-286.

Thomas, M. B., 1973. Anhydrous ammonIa in vegetable cropping: I. Vegetative response to various application rates. *New Zealand Journal of Experimental Agriculture*. 1(3), pp. 261-266.

USGS 2020. *Mineral commodity summaries 2020: U.S. Geological Survey.* p. 200.

Vitosh, M. L. *What happens to Anhydrous Ammonia in Soil.* Michigan State University: Crop and Soil Sciences Department.

Waheed, I., Fuller Audra, 2017. Anhydrous ammonia pulmonary toxicity: A significant farming hazard. *The Southwest Respiratory and Critical Care chronicles.* 5(19). pp. 41-44.

Zhichkin, K., Nosov, V., Zhichkina, L., 2021. The Express Method for Assessing the Degraded Lands Reclamation Costs. *Lecture Notes in Civil Engineering*. 130. pp. 483-492.

Zhichkin, K. A., Nosov, V. V., Zhichkina, L. N., Ramazanov, I. A., Kotyazhov, A. V., Abdulragimov, I. A., 2021a. The food security concept as the state support basis for agriculture. *Agronomy Research*. 19(2). pp. 629–637.