21st International Conference Man and Working Environment
SEMSIE
Safety Engineering & Management – Science, Industry, Education

ORIGINAL SCIENTIFIC PAPER

DOI: 10.46793/SEMSIE25.061G

TATJANA GOLUBOVIĆ[1]
ANA BIJELIĆ[1]
ANĐELA JOVANOVIĆ[2]
ALEKSANDAR LAZAREVIĆ[3]
ANA-MARIJA VALLAND[4]

[1]University of Niš,
Faculty of Occupational Safety, Serbia
[2]Elixir Prahovo, Serbia
[3]University of Niš,
Faculty of Technology, Leskovac, Serbia
[4]DREHM Pharma GmbH, Austria

[1]tatjana.golubovic@znrfak.ni.ac.rs
[1]ana.bijelic@znrfak.ni.ac.rs
[2]ajovanovic555@gmail.com
[3]acalazarevic92@hotmail.com
[4]valland.am7@gmail.com

OCCUPATIONAL EXPOSURE TO FERTILIZERS AND ASSOCIATED HEALTH EFFECTS

Abstract: *Fertilizers are generally used to provide nutrients to crops, through increasing yields and soil fertility. They are mainly categorized into two groups, organic and inorganic. Inorganic fertilizers are synthetic nutrient-rich products used to supply essential minerals to plants, such as nitrogen, phosphorus, and potassium. Organic fertilizers are obtained naturally from either plant (compost and biosolids) or animal sources (manure, slurry, etc.). Although the use of fertilizers in the agricultural sector is inevitable for achieving high-yield crop production, their production and application can present health and safety hazards. Some professions are especially significant in terms of exposure to fertilizers, primarily those associated with agriculture and related industries. They include agricultural workers, those who work in fertilizer plants and researchers. Individuals living in the same residential area are also exposed to these substances. Agricultural workers face potential exposure during planting, fertilizing, and harvesting, as well as through equipment maintenance and cleaning. Fertilizer plant workers may be exposed to dust and fumes during production, packaging, and storage. Transportation and handling of fertilizers, whether in bulk or packaged form, also present risks of exposure. Occupational exposure to fertilizers, particularly during manufacturing and agricultural application, can lead to various health issues. These range from respiratory problems and skin irritation to more serious conditions like kidney and liver damage, and even neurological effects.*

Keywords: fertilizers, occupational exposure, health effects

ORCID iDs:	Tatjana Golubović	https://orcid.org/0000-0001-6725-752X
	Ana Bijelić	https://orcid.org/0000-0002-8073-1641
	Anđela Jovanović	N/A
	Aleksandar Lazarević	https://orcid.org/0000-0002-8784-3769
	Ana-Marija Valland	N/A

INTRODUCTION

The issue of global food production becomes increasingly important as the global population expands and the availability and productivity of arable land, crucial for food production, decline. Fertilizers, both inorganic and organic, play an essential part in modern agriculture by significantly increasing crop yields, thus ensuring crucial human nutrition, global food security, crop quantity and quality, and sustainable soil management. Fertilizers can be applied in several ways, broadly categorized as soil application (broadcasting and banding), foliar application, and fertigation. Each method offers specific advantages depending on the crop, soil conditions, and nutrient requirements. About 90% of fertilizers are applied as solids, in granulated or powdered form. The most widely used solid inorganic fertilizers are urea, diammonium phosphate and potassium chloride (Rashid, 2022). Liquid fertilizers contain anhydrous ammonia, aqueous solutions of ammonia, aqueous solutions of ammonium nitrate or urea. Advantages of liquid fertilizer are its faster reaction and simple coverage of the treated area. While fertilizers are crucial for boosting crop yields in agriculture, their manufacture and use pose environmental and health risks. Farmers, fertilizer manufacturers, and those involved in the storage, transportation, and application of fertilizers are all at risk of exposure to fertilizers and other agrochemicals. Exposure to fertilizers can occur through various routes, including inhalation, skin contact, and ingestion, and can lead to both acute and chronic health effects. Anhydrous ammonia is an efficient and widely used source of nitrogen fertilizer. Any contact with anhydrous ammonia can cause tissue dehydration, caustic burns, and frostbite. Exposure to high concentrations of liquid or vapour causes severe burns to the skin, eyes, upper airways and gastrointestinal tract. There may be permanent effects including visual impairment, and chronic pulmonary disease such as obstruction of small and large airways, bronchiectasis

and interstitial lung disease. In the respiratory tract, anhydrous ammonia can cause laryngeal edema, pneumonitis and pulmonary edema. Airway obstruction and respiratory insufficiency may be fatal (ILO, 2010). Inorganic phosphates are widely used and essential fertilizers in agriculture. Severe burns, including those to the skin, upper airways, and gastrointestinal tract, as well as pulmonary inflammation, can result from exposure to inorganic phosphates. These injuries are often accompanied by a systemic inflammatory response, potential for infection, and a risk of long-term complications like scarring and respiratory issues. Inorganic phosphates, when systemically absorbed, can cause multi-organ toxicity, affecting the liver (hepatotoxicity), kidneys (renal damage), gastrointestinal system, and cardiovascular system. This toxicity can manifest as a range of symptoms, from mild discomfort to severe organ failure (Tagkas, 2024).

METHODS OF FERTILIZER APPLICATION

Fertilizers, containing essential macronutrients like nitrogen, phosphorus, and potassium, are vital for plant growth. While beneficial for crop yields, over-application of fertilizers can have negative environmental consequences. Different fertilizer application methods offer various advantages for crop production, impacting nutrient availability, efficiency, and environmental impact. Methods like broadcasting, banding, foliar application, and fertigation have unique benefits and drawbacks (Barłog, 2023).

Broadcasting. Broadcasting fertilizer, which involves spreading it evenly across the soil surface, has both advantages and disadvantages. It is a quick and cost-effective method for covering large areas. However, it can lead to lower fertilizer use efficiency and potential nutrient losses compared to other methods (Barłog, 2023).

Banding. Fertilizer is applied in concentrated bands, either near the seeds during planting or alongside existing crop rows. Banding fertilizer offers several advantages over broadcasting. This method helps to concentrate nutrients where plants can access them most effectively. This targeted approach minimizes the amount of fertilizer that can be lost by fixation to soil particles, leaching, or volatilization. Banding can also be more environmentally friendly, as it reduces the potential for nutrient runoff and pollution (Barłog, 2023).

Foliar application. Foliar application, or spraying nutrients directly onto plant leaves, offers both advantages and disadvantages compared to traditional soil-based fertilization. While it allows for rapid nutrient absorption and can be particularly useful for correcting deficiencies, it's not always a complete replacement for soil fertilization and can be more expensive and weather-dependent (Barłog, 2023).

Fertigation. Fertigation is the process of applying liquid or soluble fertilizers through an irrigation system. It combines irrigation and fertilization, delivering nutrients directly to the plant's root zone along with the water. Fertigation can synchronize nutrient supply and crop nutrient requirement, which enhances water-use efficiency, nutrient-use efficiency, and yield, while also reducing nutrient losses via leaching, ammonia volatilization, denitrification and weed pressure (ILO, 2010).

OCCUPATIONAL EXPOSURE TO FERTILIZERS AND CONSEQUENTIAL HEALTH EFFECTS

There are many different careers in the fertilizer industry, including fertilizer production jobs, application jobs, agricultural specialists, and researchers who innovate new methods to apply fertilizer or develop more effective fertilizers.

Exposure to fertilizers can occur through various routes, including inhalation, skin contact, and ingestion, and can lead to both acute and chronic health effects.

Around 22% of ammonia emissions from agriculture come from fertiliser, and 75% from livestock systems (https://www.yara.co.uk).

Anhydrous ammonia is an efficient and widely used source of nitrogen fertilizer. Anhydrous ammonia is stored and transported as a liquid in pressurized containers (Figure 1). If it is released from the pressurized tank, anhydrous ammonia will instantly transform to a gaseous state and can result in respiratory toxicity.

Figure 1. A*nhydrous ammonia application (http://blog.caseih.com/equipment-technology/upgrade-your-fall-fertilizer-applications)*

Except anhydrous ammonia, mineral nitrogen fertilizers which directly contain ammonium (ammonium sulfate, ammonium sulfate nitrate, ammonium nitrate, calcium ammonium nitrate) or are converted to ammonium in the soil subsequent to spreading (urea), are subject to potential ammonia losses. The significant sources of ammonia emissions from agriculture include manure handling and storage, as well as the application of manure and slurry.

Ammonia emissions have a negative impact on human health; hence, it is important to reduce the volatilization of ammonia (Wyer, 2022).

Acute inhalation exposure to high levels of ammonia in humans can provoke irritation and significant burns in

the lungs, mouth, and eyes. Airway obstruction and respiratory insufficiency may be fatal. Short-term or accidental exposures to high concentrations of ammonia gases are quite rare due to occupational exposure limits and health and safety protocols in many workplaces. Chronic exposure to airborne ammonia can raise the risk of respiratory irritation, cough, wheezing, tightness in the chest, and impaired lung function in humans (Figure 2).

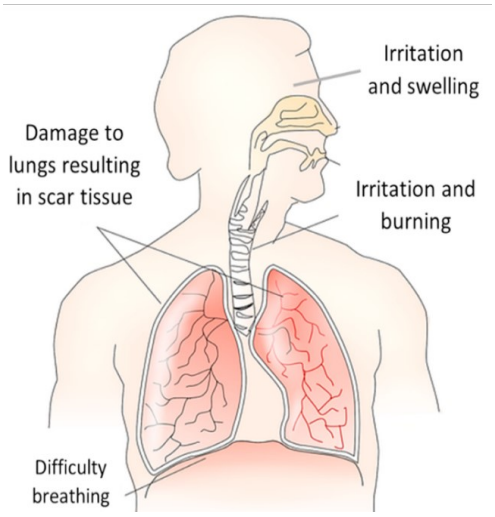

Figure 2. *The direct effects of ammonia on the respiratory tract (Wyer et al., 2022.)*

However, besides being toxic, gaseous ammonia is a precursor of secondary inorganic aerosols. It can react with NO_X or SO_2 to yield secondary fine particles ($PM_{2.5}$) comprising sulfates and nitrates. Although direct exposure to ammonia can be a possible risk for human health, when assessed as a precursor to $PM_{2.5}$, it has a considerable impact on human health. According to the World Health Organisation, $PM_{2.5}$ are particles which are small enough to penetrate deeply into the lung, causing irritation and corrosion of the alveolar wall, and consequently impairment of lung function (Lelieveld, 2015). As stated by the World Health Organization, more than 90% of the world's population is exposed to $PM_{2.5}$ concentrations that exceed the recommended guideline of 10 $\mu g/m^3$. Inhalable particulate matter (PM) has significant negative health impacts, primarily affecting the respiratory and cardiovascular systems. These effects include increased respiratory symptoms, exacerbation of asthma, higher rates of respiratory and cardiovascular hospital admissions, and increased mortality from respiratory, cardiovascular, and lung cancer. Adverse health effects can be exacerbated in vulnerable populations, including those with pre-existing lung or heart diseases, elderly people, pregnant women, and children (Table 1). When it comes to children, exposure to PM affects lung development, including reversible deficits in lung function as well as chronically reduced lung growth rate and a deficit in long-term lung function (World Health Organisation, 2013).

Table 1. *Influence of PM on the respiratory system*

Impact of PM on the respiratory system
Increases mortality
Increases the incidence of malignant tumors
Increases the incidence of chronic respiratory disease exacerbations
Increase or worsen overall respiratory symptoms
Reduce lung function growth in children
Causes temporary loss of lung function in normal people
Increases airway inflammation and increases airway hyperresponsiveness
Reduces pulmonary diffusing capacity in lung function

Dermal exposure to ammonia solutions or pressurized liquefied gas can lead to skin irritation and, depending on concentration, alkali burns. Liquefied ammonia, in particular, can also cause cryogenic burns due to the low temperature of the substance.

Ammonia can rapidly penetrate and damage the eyes, potentially causing temporary or permanent blindness. Even low concentrations of ammonia vapor can irritate the eyes.

Ingestion of ammonia solution causes rapid symptoms including pain in the mouth, throat and chest, excessive salivation and extensive alkali burns. In severe cases, perforation of the stomach or oesophagus may occur, resulting in issues such as cardiac injury and pneumonitis. Chronic oral exposure to ammonia has not been characterised in humans.

Farmers and agricultural workers may be exposed to ammonia during the application of fertilizers containing anhydrous or liquid ammonia, mineral nitrogen fertilizers, or manures high in ammonia (https://www.ncbi.nlm.nih.gov/books/NBK598711/). They are at an increased risk for inhalational exposure, due to high ammonia levels in the air. Ammonia emission attributed to volatilization from soils and plants due to the application of synthetic fertilizer and manure may rise with increasing global temperatures (Shen, 2020).

The nitrogenous fertilizer industry faces significant occupational and environmental health challenges due to ammonia exposure during production.

Bhat and Ramaswamy found that exposure to chemical fertilizers, specifically ammonia, urea, and diammonium phosphate (DAP), was associated with decreased lung function in fertilizer plant workers. Their study indicated that long-term exposure, particularly to diammonium phosphate, could potentially lead to restrictive lung disorders (Bhat, 1993).

Ramah and co-workers demonstrated that exposure to ammonia at higher amounts was related to an increased prevalence of respiratory symptoms and an acute depletion of lung functions among urea fertilizer factory workers (Ramah, 2007).

Based on research by Ballal et al., which included two urea fertilizer producing factories in Saudi Arabia, it was found that occupational exposure to ammonia is significantly related to an increase in respiratory symptoms and bronchial asthma. According to the authors, workers in factory A, who were exposed to higher levels of ammonia (2.0-130.4 mg/m^3), had a significantly increased risk of respiratory symptoms compared to workers in factory B, and the control group. The ammonia levels in factory B were below the threshold limit value -TLV (range 0.02-7.0 mg/m^3 of air). The authors recommend implementing engineering controls to reduce ammonia levels in Factory A, alongside occupational exposure monitoring. This includes measures like enclosing processes, improving ventilation, and using personal protective equipment. Monitoring aims to assess workers' exposure and ensure the effectiveness of implemented controls (Ballal, 1998).

The study conducted by Menadi and co-workers in order to evaluate the possible effects of chemical fertilizers (NPK 15.15.15) on occupational health included forty male participants, divided into two main groups. The first group consisted of 20 workers exposed to fertilizers in the fertilizer industry of Annaba (Algeria) for at least 6 years. The second (control) group included 20 participants with no history of exposure to any chemical fertilizer. Occupational exposure to NPK fertilizer dust in Annaba has been shown to cause significant alterations in biochemical parameters and oxidative stress status among workers. Specifically, studies have indicated increased levels of cholesterol and triglycerides, decreased erythrocyte count and hemoglobin concentration, and a significant decline in antioxidant enzyme activity (superoxide dismutase-SOD, glutathione peroxidase-GPx, and catalase- CAT). Additionally, there was an observed increase in malondialdehyde (MDA) levels, a marker of lipid peroxidation and oxidative damage. Authors concluded that, taken together, occupational exposure to chemical fertilizer can induce many adverse health effects, illustrated mainly by kidney and liver function impairments, and can also cause deleterious impacts on the biomarkers of oxidative stress status (Menadi, 2024).

A cross-sectional descriptive study was conducted in Ubon Ratchathani province, Thailand, in April 2016. Seventy-six chili farmers, directly contacting chemical fertilizers, participated in the study. Face-to-face interviews were performed to gather information about frequency and type of fertilizer used, participant characteristics, behaviours concerning chemical fertilizer use (the use of personal protective equipment and hand hygiene, symptoms occurring in work with chemical fertilizers). Descriptive statistics were used to describe information. All chili farmers used both chemical and organic fertilizers in chili farms. Most of them used chemical fertilizers 1-3 times monthly (80.3%). Urea fertilizer and NPK fertilizer (15.15.15) were generally used. Inappropriate behaviors related to chemical fertilizer use, such as handling chemical fertilizers without personal protective equipment, were found. About 26.3% of interviewees indicated the appearance of symptoms within 48 hours after using the fertilizer. Most common symptoms were coughing or sneezing (15.8%) and skin irritation or itching (14.5%). Based on the conducted research, the authors concluded that the prevalence of acute health effects related to chemical fertilizer exposure was relatively low. The study showed that the frequency of chemical fertilizer use (particularly more than three times per month), along with alcohol consumption and smoking habits, are significant risk factors for acute health effects associated with chemical fertilizer exposure. The study's authors recommended further research to investigate both acute and long-term health effects of fertilizer exposure and emphasized the need for farmers to adopt safer handling practices to minimize exposure (Nganchamung, 2017).

Exposure to nitrogen-based fertilizers can cause more severe skin reactions compared to other types of fertilizers. In a study of 132 farmers with contact dermatitis, 13% of cases were found to be caused by chemical irritants like fertilizers and pesticides. This highlights the significant role these substances play in causing skin problems for farmers (Kiec-Swierczynska, 2003).

In the work of Elmas et al., a case study of a 19-year-old strawberry picker is presented. He developed severe, itchy, and burning vesicular and bullous lesions on legs after working in a field where he had applied a nitrogen-based fertilizer. The lesions were limited to the areas of skin that contacted the leaves. It is important to note that the patient had no previous history of allergies or skin conditions. Histological examination showed epidermal damage and inflammation. The diagnosis was irritant contact dermatitis caused by nitrogen-based fertilizer. Authors point out that prioritizing the protection of workers from contact, especially with nitrogen fertilizers, is crucial for occupational safety and health in agriculture (Elmas, 2016).

Occupational exposure to nitrates primarily occurs through inhalation of dusts and dermal contact, especially in fertilizer and explosives industries. Workers in these fields, as well as farmers handling fertilizers, face potential risks (Tagkas, 2024; Martínez-Dalmau, 2021).

Ammonium nitrate fertilizer is a widely used high-nitrogen fertilizer, that provides plants with readily available nitrogen in both nitrate and ammonium forms (Ma, 2018). Short-term exposure to ammonium nitrate can lead to skin and eye irritation. Inhalation of this substance may cause irritation to the respiratory tract. Symptoms may include coughing, sore throat, and shortness of breath. At high temperatures, exposure to toxic nitrogen oxides (decomposition products) can quickly cause acute respiratory problems. Inhalation of large amounts of ammonium nitrate aerosol can lead to systemic acidosis and abnormal hemoglobin. High oral doses of nitrates can interfere with the ability of the

blood to carry oxygen, causing headache, fatigue, dizziness, and a blue color to the skin and lips (methemoglobinemia). Higher levels can cause trouble breathing, collapse and even death. When it comes to chronic exposure, small repeated oral doses of nitrates may cause weakness, depression, headache, and mental impairment (https://www.ncbi.nlm.nih.gov/books/NBK592476).

As previously mentioned, workers in the fertilizer industries and farmers handling fertilizers face potential risks due to occupational exposure to nitrates. In order to prevent or reduce those risks, protective measures are needed. They include enclosing operations, using local exhaust ventilation, and wearing appropriate personal protective equipment like gloves, clothing, and respirators.

CONCLUSION

Fertilizers play a crucial role in modern agriculture by significantly increasing crop yields and improving overall agricultural productivity. While fertilizers are essential for boosting crop yields and ensuring food security, their production and use introduce significant environmental and health risks. Farmers, fertilizer manufacturers, and those involved in the handling and application of these products are all susceptible to exposure. Occupational exposure to fertilizers can pose various health risks, including respiratory problems, skin and eye irritation, and potential long-term effects like cancer or endocrine disruption. Protective measures such as using personal protective equipment, proper ventilation, and safe handling practices are crucial to mitigate these risks.

ACKNOWLEDGEMENTS

This paper is supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia pursuant to agreement № 451-03-137/2025-03/200148 g13 with the University of Niš, Faculty of Occupational Safety.

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