

Review Article

The Role of Chemistry in the Development of Agriculture

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Abstract

This article analyzes the role of chemistry in agriculture in detail and particularly emphasizes the importance of chemical fertilizers in increasing crop productivity. The article extensively explains the chemical composition, structural properties, and behavior of fertilizers in the soil-plant system. At the same time, the classification of fertilizers - simple and complex fertilizers, as well as the main macroelements - nitrogen, phosphorus, and potassium fertilizers- is analyzed in separate sections, showing their functions in plant development and application characteristics. In addition, the article provides a scientific explanation of fertilizer production technologies, their effects on soil fertility, and the physiological processes of plants. Plant protection products are also examined, explaining the role of pesticides, herbicides, and other protective agents in maintaining productivity and combating diseases. Consequently, the application of chemistry in agriculture is shown to be one of the key factors for sustainable and efficient production.

Keywords: chemical preparations, agriculture, nutrients, macrofertilizers, microfertilizers, mineral fertilizers

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1. Introduction

As the science of chemistry develops, its influence is constantly felt in the multifaceted processes of human life. It is very difficult to imagine life without the application of chemical science's achievements. In particular, the role of chemistry in the development of agriculture is crucial. Thus, the production of various mineral fertilizers significantly increases the productivity of plants. Some chemical preparations are successfully used against plant pests [1], [2].

2. Characteristics and Classification of Fertilizers

When the soil lacks nutrients essential for plant nutrition and growth, mainly nitrogen, phosphorus, and potassium, these elements are added to the soil artificially in the form of mineral fertilizers. The use of mineral fertilizers helps increase productivity.

Plants contain more than 70 different chemical elements. However, among these elements, 16 are considered essential for the normal growth and development of plants. Some of these elements are obtained through photosynthesis, while others are absorbed from the soil. Elements necessary for the normal development of plants are called nutrients. There are three main nutrients: nitrogen, phosphorus, and potassium [3].

Fertilizers are substances that contain nutrients. Mineral fertilizers are compounds, mainly salts, that contain nutrients for plants.

Elements required by plants in large quantities (C, O, H, N, P, K, Ca, Mg, Fe, S) are defined as macroelements, and fertilizers containing these elements are referred to as macrofertilizers (or conventional fertilizers).

Elements required by plants in small amounts (B, Cu, Co, Mn, Zn, Mo, etc.) are defined as microelements, and fertilizers containing these elements are known as microfertilizers. [4].

Of the macronutrients, plants need three elements in greater quantities, such as nitrogen, phosphorus, and potassium. These are called essential nutrients.

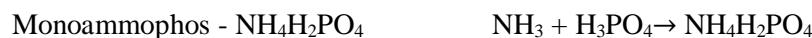
The classification of mineral fertilizers can also be expressed as follows (Table 1) [5], [6]:

Table 1. Classification of mineral fertilizers

According to their main nutrients	According to their composition	According to their origin	According to their aggregate state
Nitrogen fertilizers	Simple fertilizers	Mineral fertilizers (fertilizers mentioned above)	Solid fertilizers (salts, phosphates)
Phosphorus fertilizers	Compound / complex fertilizers	Organic fertilizers (manure, poultry droppings, etc.)	Liquid fertilizers (liquid NH ₃ , ammonia water)
Potassium fertilizers	Mixed fertilizers		

Fertilizers that contain only one nutrient are called simple fertilizers. For example: KCl, NaNO₃, NH₄NO₃, Ca(H₂PO₄)₂, CaHPO₄·H₂O, (NH₄)₂SO₄, and CO(NH₂)₂.

Fertilizers that contain two or three nutrients are called compound fertilizers. For example: KNO₃, (NH₄)₂HPO₄, and NH₄H₂PO₄.



Mixed fertilizers contain different types, such as simple, complex fertilizers, or both:

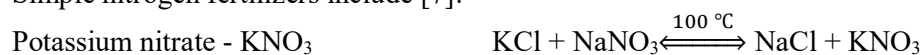


Nitrophoska is a mixture of three salts: (NH₄)₂HPO₄ + NH₄NO₃ + KCl

3. Nitrogen Fertilizers

Nitrogen fertilizers are fertilizers that contain the nutrient element nitrogen. A lack of nitrogen in plants makes it difficult to form green mass, plants develop poorly, and their leaves turn yellow. Nitrogen plays a special role in plant nutrition. It is included in the composition of chlorophyll and proteins. Plants absorb nitrogen mainly in the form of ammonium NH₄⁺ and nitrate NO₃⁻ ions.

Simple nitrogen fertilizers include [7]:



The salts obtained from this reaction are highly soluble in water. However, at 100°C, sodium chloride is less soluble than potassium nitrate. At this point, sodium chloride crystallizes in the solid solution, and the equilibrium in this reversible reaction shifts to the right [8], [9], [10].



In addition to those mentioned, simple nitrogen fertilizers include calcium salt (Ca(NO₃)₂), ammonium sulfate (NH₄)₂SO₄, liquid ammonia, and ammonia water. NaNO₃, KNO₃, NH₄NO₃, and (Ca(NO₃)₂) are called salts.

Calculation of the nutritional value of nitrogen fertilizers is expressed as the mass fraction of nitrogen in the same substance and shown as a percentage. The higher the mass fraction of nitrogen in a fertilizer, the more nutritious it is or the richer it is in nitrogen. For instance, the nutritional value of nitrogen in urea is calculated as follows:

$$\omega(\text{N}), \% = \frac{A_r(\text{N}) \cdot 2}{M_r[\text{CO}(\text{NH}_2)_2]} \cdot 100\% = \frac{28}{60} \cdot 100\% = 46,7\%$$

When excess nitrates are added to the soil, they accumulate in plants. Such plants harm human health when used as food.

Examples of complex fertilizers containing nitrogen include ammonium dihydroorthophosphate (ammophos) $\text{NH}_4\text{H}_2\text{PO}_4$, ammonium hydroorthophosphate (diammophos) $(\text{NH}_4)_2\text{HPO}_4$, potassium nitrate KNO_3 , etc.

In the soil, fertilizers are converted into a form that plants can absorb:

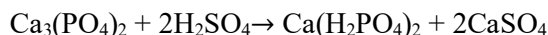


In addition to mineral nitrogen fertilizers, organic nitrogen fertilizers (manure, poultry droppings, etc.) are also used [11].

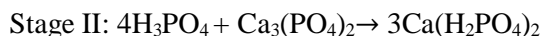
4. Phosphorus Fertilizers

Phosphorus plays a major role in the growth of flowers and fruits of plants. Phosphorus fertilizers are the following (the main raw material for the production of phosphorus fertilizers is phosphorite - $\text{Ca}_3(\text{PO}_4)_2$):

1. Phosphorite flour ($\text{Ca}_3(\text{PO}_4)_2$) is obtained by finely grinding phosphorites. Phosphorites are poorly soluble in water but well soluble in organic acids. This fertilizer is usually applied to acidic soils.
2. Simple superphosphate is obtained from the reaction of $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot 2\text{CaSO}_4$ phosphorite ($\text{Ca}_3(\text{PO}_4)_2$) or apatite with sulfuric acid:

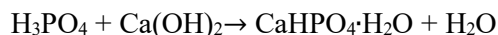


3. Double superphosphate $\text{Ca}(\text{H}_2\text{PO}_4)_2$ is obtained in two stages. At this time, CaSO_4 is formed as an intermediate product:



The CaSO_4 obtained in the first stage precipitates and is filtered and separated.

4. The precipitate $\text{CaHPO}_4 \cdot \text{H}_2\text{O}$ is obtained from the interaction of orthophosphoric acid with calcium hydroxide and calcium carbonate (limestone):



5. Bone meal consists mainly of $\text{Ca}_3(\text{PO}_4)_2$ and is obtained by grinding the bones of domestic animals [12].

5. Potassium Fertilizers

Potassium also plays a significant role in plant physiology. Thus, they accelerate the photosynthesis process, help accumulate carbohydrates, and strengthen the stems of cereal plants. Potassium fertilizers are also found in nature. Potassium fertilizers are:

- Sylvite mineral - KCl
- Sylvinit mineral - $\text{KCl} \cdot \text{NaCl}$

- Kainite mineral - $\text{KCl} \cdot \text{MgSO}_4 \cdot 3\text{H}_2\text{O}$
- Carnallite mineral - $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$

6. Nutritional Value of Fertilizers

In nitrogen fertilizers, the nutritional value of the fertilizer is expressed as the mass fraction of nitrogen in the nitrogenous compound considered as fertilizer ($\omega\% \text{N}$):

$$\text{CO}(\text{NH}_2)_2 \quad \omega_{\text{N}} = \frac{\text{Ar}(\text{N}) \cdot 2}{\text{Mr}(\text{CO}(\text{NH}_2)_2)} \cdot 100$$

In phosphorus fertilizers, the nutritional value of the fertilizer is calculated based on P_2O_5 , which corresponds to the phosphorus in the phosphorus compound considered as fertilizer:

$$\text{Ca}(\text{H}_2\text{PO}_4)_2 \quad \omega_{\text{P}_2\text{O}_5} = \frac{\text{Mr}(\text{P}_2\text{O}_5)}{\text{Mr}(\text{Ca}(\text{H}_2\text{PO}_4)_2)} \cdot 100$$

$$\text{CaHPO}_4 \cdot \text{H}_2\text{O} \quad \omega_{\text{P}_2\text{O}_5} = \frac{\text{Mr}(\text{P}_2\text{O}_5)}{\text{Mr}(\text{CaHPO}_4 \cdot \text{H}_2\text{O}) \cdot 2} \cdot 100$$

The reason for taking twice the molar mass of the fertilizer in the denominator of the second equation is that the P_2O_5 molecule in the figure contains 2 moles of P atoms. That is, 1 mole of P_2O_5 corresponds to 2 moles of $\text{CaHPO}_4 \cdot \text{H}_2\text{O}$.

In potash fertilizers, the nutritional value of the fertilizer is also calculated based on the K_2O , which corresponds to the potassium in the potash compound considered as the fertilizer:

$$\text{KCl} \quad \omega_{\text{K}_2\text{O}} = \frac{\text{Mr}(\text{K}_2\text{O})}{\text{Mr}(\text{KCl}) \cdot 2} \cdot 100$$

$$\text{K}_2\text{CO}_3 \quad \omega_{\text{K}_2\text{O}} = \frac{\text{Mr}(\text{K}_2\text{O})}{\text{Mr}(\text{K}_2\text{CO}_3)} \cdot 100$$

Here, the reason for taking twice the molar mass of the fertilizer in the denominator of the first equation is that the K_2O molecule in the formula contains 2 moles of K atoms. That is, 1 mole of K_2O corresponds to 2 moles of KCl.

7. Plant Protection Products

Currently, more than a thousand crop protection products are available, which can be classified in various ways [13].

According to the type of pest:

- Insecticides: used against insects.
- Acaricides: used against ticks.
- Ovicides: used to destroy the oocysts (eggs) of insect pests, including mites.
- Larvicides: used to kill insects in the larval stage.
- Nematocides: used to kill roundworms (nematodes).
- Rodenticides: used to protect plants from mammals and rodents.
- Fungicides: used to combat fungal infections.

- Bactericides: used to destroy bacterial pathogens.
- Herbicides: used to control weeds and grasses.
- Arboricides: used only to kill trees or shrubs.
- Algae: used to control algae.
- Virocides: used to protect plants from viral diseases.

According to chemical composition:

- Inorganic (containing sulfur, fluorine, copper, mercury)
- Organic (organic phosphorus and organic chlorine compounds, nitrophenols, etc.)
- Biogenic

According to toxicity:

- Low toxicity
- Moderate toxicity
- High toxicity

8. Conclusion

Plant protection products must be used with caution due to their potential toxicity. Improper use of crop protection products can cause serious environmental problems, including:

- *the emergence of persistent pest populations that will require more resources to control.*
- *potential to affect beneficial fauna and flora of ecosystems.*
- *the potential to interfere with biological and biogeochemical cycles in nature.*

Mineral fertilizers are applied when there is a lack of nutrients in the soil. Plant protection products are used to combat agricultural pests. It is crucial to follow the rules for applying mineral fertilizers and plant protection products to protect human and animal health and prevent environmental problems.

Therefore, mineral fertilizers and pesticides should be applied in controlled and recommended amounts to avoid ecological imbalance.

Author Contributions

Both authors contributed substantially to the study and approved the submitted version.

Conflict of Interest

The authors declare no conflicts of interest.

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