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Cambridge
Scholars
Publishing

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This book first published 2025

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-0364-4315-3
ISBN (Ebook): 978-1-0364-4316-0

When digital transformation
is done right, it's like a caterpillar
turning into a butterfly,
but when done wrong,
all you have is a really fast caterpillar.

~ George Westerman

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PREFACE

The far-reaching benefits of smart plant nutrition and the creativity of choosing and implementing IoT techniques as an imperative in the transformation of a new generation of sustainable agricultural production are brought together in one scientific whole.

The monograph *Digitalization of Plant Nutrition Using IoT Techniques* represents a unique symbiosis of research and experiences from around the world in the application of IoT techniques in plant nutrition. The rapid increase in the number of the population worldwide conditions the need for increased and mass production of food that should equally satisfy the quality and safety criteria. In that context, this work represents a guide to digitization, as the fourth industrial revolution, as well as to agriculture based on IoT, which is much more efficient compared to conventional agriculture.

In the first chapter, an overview of the role and importance of plant nutrition is given. The physiological-biochemical role, symptoms of deficiency, and excess of macroelements and microelements are highlighted. Scientific knowledge about the availability and ratios of nutrient elements in the soil, the physiological needs of plants, as well as the action of individual agroecological factors, should be the basis for determining the doses and types of fertilizers. Therefore, the chemical analysis of the plant material is of great importance, which complements the agrochemical analysis of the soil, because in this way, the best view of the state of the crop or plantation is obtained. The results of the analysis of the plant material as well as the results of the agrochemical analysis of the soil are the basis for the precise determination of doses and types of fertilizers, increased income, and protection of the environment by adding plant nutrients in required quantities.

To obtain quick and precise results in agricultural production, new digital technologies are being introduced. The significance of the application of IoT techniques in agricultural production is highlighted. A review of the fundamental characteristics of IoT, as well as the advantages and disadvantages of this technology, is given. The basic communication models are highlighted because the main purpose of IoT technology is to enable people to communicate with different people and objects regardless of the time, place, network, or service they use. Technologies supporting IoT are described. Various communication protocols have been introduced due to the rapid growth of IoT devices and Wireless Sensor Networks (WSNs). Each protocol has its specifications depending on bandwidth, number of free channels, data transfer rate, battery life, cost, and other factors. IoT has also enabled smart agriculture. Smart agriculture is a high-tech method of clean and sustainable food cultivation.

The second chapter discusses the application of different types of IoT techniques for rapid determination of the content of macroelements and microelements in plant material in crop production, horticulture, orchards, and vineyard production. The agricultural process does not follow only sowing, watering, adding fertilizer, spraying pesticides, and collecting harvest from the field but also requires a lot of analytics in every phase of life. Only by replacing conventional with digital methods can the deficiency or excess of nutrients in plants be promptly detected, and this implies a quick and timely application of appropriate nutrients by producers, which means preventing production and economic losses. Agricultural IoT uses various sensor devices and sensing technologies to collect information on agricultural production, product circulation, and plant nutrition through wireless sensor networks, mobile communication wireless networks, and the Internet. These sensors monitor everything necessary for crop production, such as soil moisture, humidity, light, and temperature, determining the content of macro and microelements in the plant material and the soil, and automating the irrigation system. This system enables farmers to monitor conditions on the ground from anywhere. The obtained massive agricultural information is cleaned, integrated, and processed. Harvest, storage, transportation, and processing will be achieved through intelligent operation terminals, process monitoring, scientific decision-making, and real-time service in the entire industrial chain of agricultural product production. It is an important technical support for modern agriculture with high efficiency, precision, and environmental protection and is also necessary for agricultural informatization and intelligence.

IoT has the potential to maximize agricultural and food production by improving product quality, increasing crop productivity, helping to conserve resources, and helping farmers to better cost control. With the right investments in research and development, the agricultural industry will be able to reap the benefits of IoT technology.

This monograph is the key to the perfection of digitization and the power of IoT technology aimed at achieving greater benefits in agricultural production.

Filled with invaluable insights, practical advice, and extensive research, this monograph is a must-read and intended for readers who observe digitalization through scientific lenses, for those who already implement IoT techniques in practice, for students who want to be a step ahead in the study of this science, as well as for all readers and producers who want to expand the areas of their knowledge and to have ecological, sustainable and profitable production. This will improve the quality and quantity of the overall agricultural production.

—Authors

CHAPTER I

CONVENTIONAL PLANT NUTRITION AND THE IMPORTANCE OF USING IOT IN PRECISION PLANT NUTRITION

1. Introduction

Since ancient times, special attention has been paid to plant nutrition, which studies how plants adopt, transport, and use mineral elements for physiological processes. This science is closely related to all areas of plant physiology, especially plant growth and development, which depends on the assimilation of mineral elements. Hence, the knowledge of this area is of special importance for the development of agricultural crops and for achieving optimal quality and quantity of yields. Plant nutrition is one of the oldest sciences within plant physiology. It records a long history as questions regarding the uptake of elements by plants, as well as their growth and development, were asked as early as 2000 years ago (Stojanova, 2018).

In modern agricultural production, high and stable yields as well as the quality of fruits (fruits, horticultural fruits, grapevines) depend on the biological properties of the variety, favorable climatic and soil conditions, but also on the correct and controlled nutrition of the plants.

The use of fertilizers (mineral or organic) improves the physical, chemical, and biological properties of the soil. Fertilizers contain many nutrients that have an impact on a large number of physiological-biochemical processes, the metabolism of substances, oxidation-reduction processes, photosynthesis, as well as respiration.

Through these processes, they influence the overall growth and development of the vegetative and generative organs of the plants, as well as obtaining a larger quantity and better quality fruits.

A very significant factor for the normal development and fruiting of crop plants is the optimal presence of many macroelements and microelements in the soil. Each nutrient element has a certain influence on the life activity of individual plant organs, and plants have different needs in the different phenophases of their development.

Plant nutrition can be carried out through the soil (basic nutrition) and the leaves (foliar nutrition or supplemental nutrition).

The determination of the doses and types of fertilizers, the time of application, as well as the method of use, should be based on scientific knowledge about the representation and relationships of nutrient elements in the soil, the needs of plants, the economy of production, as well as the intensity and the way of influence of the individual agroecological factors (Stojanova, 2020).

Hence, regular agrochemical analyses of the soil are of great importance, through which data are obtained on the fertility of the soil with available amounts of nutrients, as well as foliar analyses of the leaves, which are needed to determine the content of the elements adopted by the plant (Stojanova, 2017).

Traditional analyses of soil and plant material are longer and slower, which is why special attention is paid to the digitalization of methods for analyzing the content of nutrient elements in soil and plant material, as well as methods for monitoring the general growth, development, and fruiting of plants.

The uncontrolled use, that is, the introduction of large amounts of mineral fertilizers, causes long-term negative consequences, on the soil, the environment, but also on the plants.

All traditional approaches have been changed and overlapped by advanced technologies, such as the IoT and UAVs (Khan et al., 2021).

Precision agriculture, whose design incorporates IoT techniques for urban agriculture and precision agronomy in smart cities, is one of the most common uses of IoT technologies in agriculture. Smart cities are typically built on software-defined networks (SDN) and cyber-physical systems. The adoption of IoT (Internet of Things) in agriculture is revolutionizing the industry, paving the way for precision monitoring and data-driven farming. IoT and automation can be applied in the field of agriculture enormously to improve every aspect of it (Verma et al., 2022).

IoT technology utilizes advanced sensors and analytics to monitor and collect data related to soil and plant conditions, animal health, energy and water utilization, and much more. This data can then be analyzed to identify variances in the environment and pinpoint areas where efficiency and production can be improved. AIoT can also be used to monitor and analyze supply chains for sustainability purposes (Muthu, 2022).

2. Plant Nutrition

Fertilization is an agrotechnical measure whose main goal is to increase soil productivity and achieve high and stable yields (Vukadinović and Bertić, 2013). Observing the importance of fertilization, i.e. supplying plants with the necessary nutrients, dates back to the 19th century. The basic principle of fertilization is the application of the necessary nutrient and its adequate dose, at the right time and in the right place at the right price. For food production, man has turned part of the spontaneous biosphere into an agrosphere, which has ecosystems adapted to intensive agricultural production. Because of agricultural production, it has become important to maintain balance in agroecosystems, which can be maintained by applying appropriate agrotechnical measures – the very concept of maintaining balance hints at the complexity of fertilization. The importance of fertilization is recognized at all levels of plant production, including in legislation, where the difference between conventional, integral, and ecological agriculture is highlighted, which differ, among other things, in the type of fertilizer applied and the crop protection system, which can be biological, biotechnical, chemical, physical, etc. Fertilization affects the height, quality, and stability of yields, soil fertility, environmental pollution, nutrient cycling, profitability, and sustainability of production. For fertilization to be successful and fulfill its basic goal – to provide crops with biogenic elements, it is very important to know the amount of nutrients available to the plant as well as the need of the plant species for a certain element. In this way, a high-quality assessment of the fertilizer dose is possible with an acceptable risk of ecological burden on the environment. The basic function of the roots in plants is to absorb water, and therefore, mineral substances dissolved in water, i.e. plant nutrients. Plants can also absorb water and nutrients through the leaves, which play an important role in the trophic capacity of plants due to the process of photosynthesis (performed by other green parts of plants) and transpiration (loss of water in the form of steam). According to numerous studies, no significant difference was observed in the uptake of mineral elements by leaves or roots, and the differences that appear are the result of different anatomical structures of leaves and roots (Marchner, 2013). The movement of elements in the plant adopted through the leaves is significantly different from the adoption of the same through the roots and depends on their mobility. The mobility of the elements adopted through the leaf has practical significance for the application of foliar fertilization. According to Jug (2015), foliar application of fertilizer is the fastest way to supply plants with nutrients, but not necessarily the best, because it provides the most effective way to eliminate the deficit of certain elements, but contains many technical and biological-physiological specificities.

To determine the intensity of fertilization, it is necessary to know the economic elements and economic conditions in the environment. Fertilization must be coordinated in such a way as to ensure the needs of the crops or other crops for which it is carried out, and at the same time, the soil's ability to mobilize certain amounts of plant nutrients should be assessed, along with an assessment of the economic profitability of fertilizer application in a particular system of plant cultivation. A proper approach to determining fertilization requires knowledge of soil characteristics: pH value, humus content, and content of available phosphorus and potassium for the plant. However, all other data on chemical, physical, and microbiological characteristics (if available) can be used to correct the calculated required amounts of fertilizer. On every farm, it is necessary to keep records of the achieved yields, applied fertilizers, the way of dealing with plant residues, tillage procedures, sowing and care of crops, and other relevant data. Each of the mentioned elements play a big role in determining the level of fertilization (Mesić and Bogunović, 2018).

Fertilization plays an important role in agriculture because it improves soil fertility. Fertilization must be coordinated in such a way as to ensure the needs of the crops (or other crops for which it is applied), and at the same time, it must judge the soil's ability to mobilize a certain amount of plant nutrients on its own, with an assessment of the economic profitability of fertilizer application in a particular plant cultivation system.

According to economic principles, the increase in doses of fertilizers is justified as long as agricultural production is profitable. Rational food production implies that the amount of fertilizers used corresponds to the needs of the plants, the condition of the plantations or crops, the fertility of the soil, as well as the appropriate climatic conditions. The chemical analyses of the soil determine the amount of nutrients that the plants can absorb from the soil, and the analyses of the plant material determine how many nutrients the plants need to achieve a certain yield.

Determining fertilization is not a simple procedure, because determining the amount and ratio of nutrients that should be applied to the soil varies depending on the type of crop, the phenophase of plant development, the dynamics of nutrients in the soil, and others, biotic and abiotic factors (Stojanova, 2018).

The purpose of plant nutrition is to ensure optimal plant nutrition during the entire vegetation period. This is possible only by applying laboratory diagnostic methods, and the occurrence of various physiological disorders and diseases can also be prevented.

Applying the proper amount of fertilizer can help plants produce good yields in better quantities, to meet the needs of a world that is constantly rising in need of food and food production. To develop and increase the quality and quantity of crops, fertilizers must contain sufficient nutrients, which are composed of micronutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K) (Rahman et al., 2020).

2.1. Division of The Elements

Plant tissues contain about 70 biogenic elements of which 17 (C, H, O, N, P, S, K, Ca, Mg, Fe, B, Mn, Zn, Cu, Mo, Ni, and Cl) belong to the group of essential elements. In addition to this group, there are two more groups: useful elements (Na, Co, Si, Al, and Se) and other (toxic) elements (Pb, Hg, Cd, Cr, and As). This classification of the elements is based on the role of the elements in the plant and is due to precise experiments with plant species that were watered with nutrient solutions, but certain elements were excluded from use. Then, the symptoms of the deficiency of those elements in the nutrition of the plants were monitored.

For a mineral element to belong to the category of essential elements, it must meet one of the criteria of necessity. These criteria were proposed by Arnon and Stout in 1939:

1. The element should be **needed throughout the entire life cycle of plants** because, in its absence or deficiency, there will be no normal growth and development of plants;
2. The element should be **irreplaceable**, if it is not in sufficient quantity, deficiency symptoms appear. The symptoms disappear if the plants are re-introduced with that element;
3. The element should have a **direct role in plant metabolism**, that is, it should **be needed for the performance of specific physiological functions**. If an element is only an antagonist of

another element that has an adverse effect or is toxic, it is not essential for plant nutrition. So, for example, in the case of excessive concentration of copper, aluminum as its antagonist prevents the absorption of copper and the appearance of its side effects on plants. Therefore, in such conditions, the presence of the copper element is essential. However, if copper is not present in a toxic concentration, aluminum has no effect;

4. An element must be required by more than two plant species to be essential.

All listed 17 biogenic elements that satisfy these criteria. The deficiency of the necessary element can be removed only through the application of mineral fertilizers.

Useful elements (Na, Co, Si, Al, and Se) are those elements without which the plant can complete the vegetative cycle, but sometimes those elements can have a stimulating effect on the growth and development processes. Useful elements in some cases can partially replace the function of some necessary elements. It can be illustrated by the following examples: K-Na, K-Rb, Sr-Ca. So for example, sodium can replace potassium in some non-specific functions in certain plants. When there is not enough potassium then the presence of sodium is useful because in this way potassium is saved for specific needs. Silicon is a useful element for many plants of the *Gramineae* family because it gives strength to the cell wall. Aluminum affects the color of some flowers, such as hydrangea flowers, and this has implications for pollination by insects. In the presence of aluminum, the harmful effects of high doses of copper are reduced, so in those cases, aluminum is useful (Stojanova, 2018).

The other elements are those elements that do not affect plants at low concentrations but are toxic in excess (Pb, Hg, Cd, Cr, As).

Based on the representation in plant tissues, the necessary elements can be divided into two groups (Osman, 2013):

1. Macrobiogenic elements: N, P, K, Ca, Mg, H, O, S, and C are required in large quantities (> 1000 mg/kg dry matter);
2. Microbiogenic elements: Fe, Mn, Cu, B, Zn, Co, and Mo are required < 100 mg/kg dry matter.

The difference between macro and microbiogenic elements is only in their concentration, i.e. representation in plants, while the physiological significance in both groups is equal. Soil pH levels also affect the absorption of nutrients by plants. All of these minerals are available for plants in the range of pH 5.5–6.5.

Table 1-1. Nutrients, forms of uptake, and some functions in plants (Ashoka et al., 2023; Stojanova, 2018).

Nutrient element	Form of adoption	Function in the plant
Carbon (C)	CO_2 , CO_3^{2-}, HCO_3^-	Forms the backbone of organic molecules and is the source of energy
Oxygen (O)	H_2O, O_2	Necessary for respiration and structure of organic compounds
Hydrogen (H)	H_2O, H^+	Essential for building organic compounds and maintaining the plant's water status
Nitrogen (N)	NH_4^+, NO_3^-	Essential for protein synthesis and plant growth, forms part of chlorophyll
Phosphorus (P)	HPO_4^{2-}, $H_2PO_4^-$	The key for energy transfer and storage, aids in root development, flowering, and fruiting
Potassium (K)	K^+	Involved in protein synthesis, regulates water flow in cells, promotes strong roots
Calcium (Ca)	Ca^{2+}	Contributes to cell wall formation and growth, aids in nutrient transport
Magnesium (Mg)	Mg^{2+}	Component of chlorophyll, crucial for photosynthesis
Sulphur (S)	SO_3^{2-}, SO_4^{2-}	Component of some amino acids and vitamins promotes root growth
Iron (Fe)	$Fe^{2+,3+}$	Critical for chlorophyll synthesis and function
Manganese (Mn)	$Mn^{2+,3+}$	Involved in photosynthesis, aids in nitrogen metabolism

Copper (Cu)	Cu^{2+}	An integral part of certain enzymes assists in photosynthesis
Zinc (Zn)	Zn^{2+}	Plays a role in growth hormone synthesis and enzyme systems
Molybdenum (Mo)	MoO_4^{2-}	Needed for nitrogen fixation and nitrate reduction
Bor (B)	BO_3^{3-}	Required for cell wall formation and growth, pollen tube growth
Chlorine (Cl)	Cl^-	Involved in osmosis and ionic balance, also necessary in photosynthesis

Plants require a proper mix of nutrients to reside, grow, and reproduce. It represents symptoms of being unhealthy when plants are malnourished. Two sources and micronutrients of plant resources fall into macronutrients. In relatively higher quantities, macronutrients are the elements needed (Table 1-1). These include nitrogen, sodium, arsenic, calcium, magnesium, and phosphorus; Plants require micronutrients in small amounts such as carbon, boron, manganese, zinc, copper, chlorine, and molybdenum. Macronutrients as well as microelements typically separate roots from the earth to get additional requirements plant roots need to obtain nutrients from the soils. Third, the soil must be proper enough to permit the roots to absorb nutrients and sustain them. Correcting ineffective methods of irrigation also reduces the symptoms of deficient nutrients. Fixing ineffective irrigation methods also eliminates symptoms of nutrient deficiencies. The temperature of the soil must decrease within a given range to ensure absorption (Swati, 2022).

When soil nutrient deficiencies occur, they pose a significant risk to plant growth and yield. Deficiency of necessary nutrients can lead to stunted growth, decreased yield, and increased susceptibility to diseases. For instance, nitrogen deficiency can lead to chlorosis, a condition where leaves turn yellow due to a lack of chlorophyll, thereby affecting photosynthesis and overall plant health (Havlin et al., 2005). Nutrient imbalances have environmental implications, particularly through nutrient run-off and pollution. Overuse of fertilizers can lead to excess nutrients that plants cannot absorb, resulting in run-off into nearby water bodies. This causes eutrophication, a process where the nutrient-rich run-off leads to excessive growth of algae, consequently depleting oxygen levels and harming aquatic life (Ashoka et al., 2023).

2.1.1. Physiological Role of Nutrients

Plants use macro and microelements for their growth, development, and fruiting, which are necessary to carry out complex biochemical and physiological processes. In the nutrition of plants, these elements should be represented in an optimal amount, otherwise, disorders occur that negatively affect development and fruiting. Separately, each nutrient element has a certain specific influence on the life activity of the plant. Macro and micronutrient requirements are variable in different phenophases of plant development (Stojanova, 2023).

Nitrogen (N) – is the most important mineral for plants and its deficiency is crucial for plant vitality. Nitrogen is involved in the building of the amino and nucleic acids, it is important for the biochemistry of coenzymes, for the photosynthetic pigments, and for the polyamines (Maathuis, 2009). The chloroplast proteins contain almost 75% of the nitrogen that exists in the leaves of plants (Cetner et al., 2017). In the chloroplasts, nitrogen is associated with the light-harvesting apparatus, photosystem I (PSI), photosystem II (PSII), electron transport chain, peripheral proteins, and ATF synthase. It affects the resistance of plants to stress factors (the increased amount of nitrogen affects the reduction of resistance of plants to low and high temperatures, droughts, and diseases) (Stojanova, 2018).

Phosphorus (P) – is another crucial microelement for plant growth. It is involved in the composition of ATP, DNA, and RNA; in the phospholipids constituting the cell membranes; in the sugar-phosphate intermediates; and lastly, in photosynthesis and breathing. It participates in the construction of phospholipids, nucleic acids, nucleotides (AMP, ADP, ATP, GTP, UTP), coenzymes (FMN, FAD, NAD, NADP), etc. (Stojanova, 2023). This element is included in almost all metabolic processes. It plays an important role in the assimilation of carbon and nitrogen, in energy processes and lipid metabolism (Aleksandrov, 2022).

Potassium (K) – is a very important macronutrient for plants and it is involved in plant development and overall productivity. The potassium ion is important for photosynthesis, osmoregulation, enzyme activation, protein synthesis, and ion homeostasis. The early visual symptom of potassium deficiency is chlorosis, which then develops into necrosis. The potassium ions are not involved directly in photosynthetic metabolism; however, K-deficiency strongly affects photosynthesis as a whole due to lack of potassium leading to a decrease in the ATP synthesis and reduction of the CO_2 assimilation (Hafsi et al., 2014). Additionally, K deficiency leads to a reduction of the photosynthetic process as a result of the low chlorophyll content (Duli et al., 2001). In addition, potassium plays a crucial role in the resistance of plants to pests and diseases (Amtmann et al., 2008).

Calcium (Ca) – it is a secondary macronutrient. Calcium in plants affects membranes because calcium ions maintain their stability by connecting the phosphate and carboxyl groups of phospholipids and proteins on the surface of the membrane (deficiency of calcium leads to the degradation of membranes increasing their permeability and uncontrolled exit of ions from the cell); the stabilization and hardening of the cell wall (formation of calcium pectate in the cell wall); neutralization of excess organic acids in the metabolism (hardly soluble calcium salts are created which are deposited in the cell wall or separate cells); increasing the activity of membrane-bound enzymes (Stojanova, 2023).

Magnesium (Mg) – this element has a very important role in almost all physiological processes in the plant such as photosynthesis, biosynthesis of proteins, metabolism of nucleic acids, water regime of plants, growth and development, quality and quantity of yields. It is necessary for nucleic acids (it is a cofactor of enzymes that catalyze hydrolysis and the creation of ester bonds that are important for the processes of transcription, translation, and replication of nucleic acids); affects nitrogen metabolism; affects the water regime (Stojanova, 2023).

Iron (Fe) – it is part of the enzymes catalase, cytochrome oxidase, peroxidase, and nitrate reductase and in them, it has an important oxidoreduction role as a result of its ability to pass from ferro to ferri form. It has an important role in nitrogen metabolism, and respiration, and is also a redox catalyst in the reduction of nitrates and nitrites. It can create chelates important for physiological biochemical processes in plants (Stojanova, 2020).

Manganese (Mn) – it has the role of a biocatalyst, it stimulates growth, and the creation of chlorophyll A and B, and it especially affects the creation of carotenoids. It plays a role in the photolysis of water to hydrogen and oxygen. It participates in the metabolism, as well as in the assimilation of carbohydrates in plants. It is an activator of over 35 enzymes; participates in the control of auxin content; indirectly or directly affects lipid and nitrogen metabolism; and affects the absorption of iron, calcium, and magnesium (antagonistic effect).

Copper (Cu) – plants take up copper as a Cu^{2+} cation or in the form of Cu-chelates. The adoption process is active. The physiological function of copper is due to its polyvalence. Copper is a structural component of many enzymes: cytochrome oxidases; ascorbic acid oxidases (regulates the ascorbate/dehydroxyascorbate redox system); phenol oxidases; hydroxylases (transforms phenylalanine into alanine); oxygenases; galactosidase (participates in the processes of oxidation and decomposition of carbohydrates). It affects the metabolism of nitrogenous compounds so that with the increase in the amount of nitrogen, the amounts of proteins and the content of nucleic acids also increase. Its presence activates the redox potential and affects the migration of iron, both in the soil and in the plant.

Boron (B) – the role of boron in plants is: to maintain the stability of membranes and cell walls; influence meristem activity and hormone balance; indirect or direct participation in the metabolism of nucleic acids (biosynthesis of amino acids and proteins), synthesis of carbohydrates, phenols and synthesis of lignin, influence on respiration, action on the activity of amylases, ribonucleases, catalases, phosphatases, nitrate reductases, ascorbic acid oxidases; impact on carbohydrate transport (accelerates and facilitates transport because it builds complexes with carbohydrates).

Zinc (Zn) – it enters into the composition of various ferments and through them indirectly affects a series of processes in the plant. Zinc affects the biosynthesis and transformation of proteins, and with its deficiency, a decreased turnover of proteins is observed. It has an important role in the physiological processes of respiration, turnover of proteins, and carbohydrates, biosynthesis of chlorophyll, creation of phosphatides, and vitamin C. It affects the formation of sucrose, starch, phospholipids, and organic acids, as well as the physical and chemical properties of the colloids of living plasma. In the presence of a sufficient amount of zinc, plants have increased resistance to heat and drought, and the growth of the root system accelerates, where carbohydrates are retained in autumn, which explains the resistance of plants to low winter temperatures.

Cobalt (Co) – this element is found in small amounts in the soil. Dissolves adopt it as a divalent cation. Its action in the plant is related to polyvalency. It usually participates in oxidation processes, increases the turnover of peroxidase, and enters the composition of vitamin B12. It is mostly present in the top leaves.

Molybdenum (Mo) – it participates in the transport of electrons and redox processes. It is part of many enzymes. It is a cofactor of peroxidases and phenoloxidases; stimulates phosphorylation (incorporates phosphorus into organic compounds and inhibits acid phosphatase); has a role in nitrate reduction in biological nitrogen fixation; affects the growth and development and resistance of plants to stress factors (Stojanova, 2020).

2.1.2. General Symptoms in Deficiency and Excess of Nutrient Elements

Nutrient deficiency occurs when an essential nutrient is not available in sufficient quantity to meet the requirements of a growing plant and the plant is toxic when excess nutrients are given to the plant (Figure 1-1).

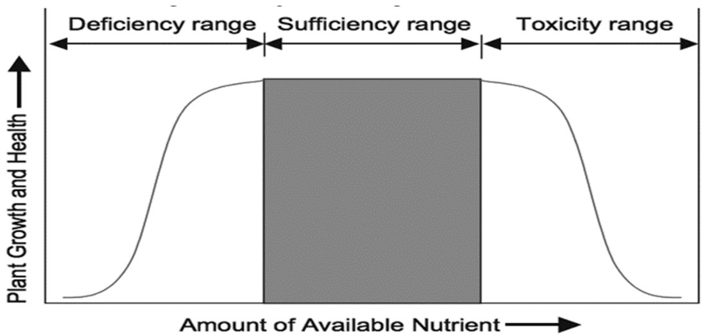

Fig. 1-1. Relationship between plant growth, health, and the number of available nutrients (Kar and Willert, 2021).

The general symptoms of deficiency and excess of nutrients required for plant nutrition are as follows (Stojanova, 2018; Stojanova, 2023):

Macroelements

Nitrogen (N):	**Deficiency symptoms:** Reduced growth of the top parts of the plant and root; the plant develops spindle-shaped; in the early stages of development the leaves are pale yellow-green, and later they turn yellow, and in some cases, they may turn orange or red; the deficiency is first noticed on the lower leaves, and the chlorosis spreads from the top to the basal part of the leaf.

Symptoms of excess: The leaves are dark green, the plant is susceptible to diseases, insect attacks, and drought stress, and lodging occurs in cereals.

Phosphorus (P):

Deficiency symptoms: Reduced growth of the top parts of the plant and root; the plant develops spindle-shaped; in the early stages of development the leaves are blue-green, and sometimes they can have a dark green color; in stages of development, the leaves become purple, and sometimes the edges of the leaves turn brown; the leaves fall very early, especially the older ones.

Symptoms of excess: an excess of phosphorus is manifested by a deficiency of Zn, Fe, or Mn. In case of an excess of phosphorus, standard symptoms of Ca deficiency occur.

Potassium (K):

Deficiency symptoms: Leaf tips turn light brown; necrosis appears along the edges of the leaves; in some plant species, light brown spots develop on the leaf, which are more numerous on the edges; the deficiency is first noticed on the lower leaves. There is a reduced quantity and quality of production.

Symptoms of excess: Plants show typical symptoms of Mg and possibly Ca deficiency as a result of cation imbalance.

Calcium (Ca):

Deficiency symptoms: Symptoms of calcium deficiency mainly appear on young leaves; the leaves are wrinkled and the ends are bent up; necrotic tissues appear in certain places and the leaf dies. The quality of the fruits decreases with the possibility of their rotting.

Symptoms of excess: plant leaves show typical symptoms of Mg deficiency, and in many cases, K deficiency may also occur, depending on the concentration of these two elements in the plant.

Magnesium (Mg):	**Deficiency symptoms:** A pale color appears on the leaves: pale yellowish color appears between the leaf veins, and the phenomenon is known as magnesium chlorosis; in the leaf, there are also necrotic fields that are surrounded by a green part of the leaf; The leaf spot is often observed, and when the spots accumulate tissue necrosis occurs, causing the leaf to wither; changes are characteristic of old leaves.
	Symptoms of excess: K or Ca deficiency symptoms may occur if the Mg content of the plant is very high (> 1.0%).
Sulfur (S):	**Deficiency symptoms:** Young leaves have a pale yellow-green color, which is very similar to nitrogen deficiency; the growth of clusters is reduced.
	Symptoms of excess: Premature drying of the leaves may occur.

Microelements

Iron (Fe):	**Deficiency symptoms:** Chlorosis appears between the veins in young leaves.
	Symptoms of excess: Appearance of small brown spots on the leaves, a typical symptom that occurs in some cereal plants.
Manganese (Mn):	**Deficiency symptoms:** Light green to yellow leaves with characteristic green venation appear; in some cases, light brown spots appear on the leaves, which then disappear; most often the symptoms appear first on the young leaves.
	Symptoms of excess: Older leaves have brown spots surrounded by chlorotic zones or circles.
Copper (Cu):	**Deficiency symptoms:** A pale green color appears in young leaves and mild chlorosis along the edges.
	Symptoms of excess: A deficiency of Fe occurs and the appearance of iron chlorosis on the leaf.

Boron (B):	**Deficiency symptoms:** The root system is poorly developed; the top leaves of the branches turn yellow; the nerves become purple, and necrosis appears on the edges of the leaves; reduced fertilization; characteristic is the appearance of short internodes, small and narrow leaves, the branches are rosette-like and dry quickly; the fruits are poorly developed and smaller; they develop internal or external corky spots or spots. **Symptoms of excess:** The tips of the leaves first turn yellow and later darken due to piled pine on the edges of the leaf and fall prematurely.
Zinc (Zn):	**Deficiency symptoms:** Chlorosis appears between the nervature followed by wilting of the chlorotic parts; low growth and the appearance of short internodes. **Symptoms of excess:** Excess zinc creates iron deficiency.
Molybdenum (Mo):	**Deficiency symptoms:** Leaves become chlorotic with curled edges; molybdenum deficiency in plants often causes nitrogen deficiency. **Symptoms of excess:** There are no known symptoms of excess molybdenum.

2.2. Parameters for Determining Doses of Fertilizers

To achieve full effects, i.e. increasing the quality and quantity of agricultural crop production, increasing the resistance of plants to low winter temperatures, droughts, and diseases, soil, and foliar fertilization should be carried out in optimal quantities, following the fertility of the soil, the quantity of bringing out nutrients, as well as with the yield and the varieties grown in certain climatic conditions (Stojanova, 2018).

Fertilizers play a pivotal role in modern agriculture. Fertilizers are crucial in agriculture for enhancing soil fertility and promoting food security for a growing global population. Fertilizers provide essential nutrients like nitrogen, phosphorus, and potassium, ensuring optimal and sustainable crop development and increased yields. By replenishing nutrient levels depleted during farming, fertilizers contribute significantly to global food production.

The importance of fertilizers lies in sustaining agricultural practices, supporting food security, and meeting the nutritional demands of a growing population. Fertilizers enable farmers to maximize the efficiency of their crops, ultimately playing a pivotal role in addressing global hunger and ensuring a stable food supply for communities worldwide. Nitrogen-based fertilizers, for instance, stimulate vegetative growth, phosphorus aids in root development, and potassium enhances overall plant health. Despite the benefits, the excessive or improper use of fertilizers can result in several disadvantages, posing threats to both the environment and human health. Indiscriminate use of fertilizers can lead to adverse environmental and economic consequences (Anjaneyulu et al., 2024).

Therefore, fertilization is an agrotechnical measure that, above all, increases the productivity of the soil in agricultural production.

Scientific and professional knowledge about the availability and relationships of nutrient elements in the soil, the physiological needs of plants, the economy of production, as well as the intensity and direction of action of individual agroecological factors, should be the basis for determining the doses and types of fertilizers, the chemical form of the nutrients, as well as the time and method of application of fertilization.

According to modern concepts, fertilization is formulated in the following way:

application of the necessary nutrients → appropriate dose → appropriate phenophase → appropriate place → appropriate price of the fertilizer

The purpose of fertilization can be seen through the following facts:

- supplementing the natural sources of nutrients in the soil to meet the needs of plants to achieve high and stable yields;
- replenishment of the lost and removed nutrients with yields;
- improvement of unfavorable soil properties.

To determine the necessary amounts of fertilizers, it is first of all necessary to know the individual plant species, as well as the state of the available nutrients in the soil.

Determination of the doses of fertilizers must be based on the results of the agrochemical analysis of the soil, chemical analysis of the plant material, as well as the visual symptoms of deficiency or excess of nutritional elements.