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Short Title: Regulation of mineral nutrition of agricultural crops in precision farming

RESEARCH ARTICLE

Regulation of mineral nutrition of agricultural crops in precision farming

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Abstract

The article demonstrates the effectiveness of precision farming in the regulation of plant mineral nutrition, using corn as an example. Variable rate fertilizer application should be based on soil agrochemical analysis data from fields, yield planning, and forecasting. Essential indicators for planning include the content of organic matter, pH, nitrogen, phosphorus, potassium, individual meso and microelements, and cation exchange capacity. It has been proven that in the conditions of the Left–Bank Forest–Steppe on areas with Chernic chernozems on loess like loams with a high potassium content, it is possible to apply reduced rates of potassium containing fertilizers or omit them entirely, thus conserving resources and achieving the goal of precision farming equalize grain yield across the field.

Keywords: Yield, Fertilizers, Precision farming, Soil, Fertility, Organic matter, Corn, Zea mays, Potassium

Introduction

Currently, ensuring food security in agricultural production requires a modern approach to sustainable agriculture through the improvement and more efficient use of precision farming technologies (Chen et al., 2011; Hryhoriv et al., 2023). These include positioning systems and various sensors used to gather information about the environment, plants, and soil to make informed management decisions. This allows for the assessment and control of soil fertility variations through the powerful use of Geographic Information System (GIS) technologies and advanced cultivation techniques. Remote sensing data are used to assess the normalized vegetation index, which can indicate the condition of plants in the field and predict future yields.

Nutrient management of soil is now carried out in modern farms based on agrochemical analysis, planning, and yield forecasting (Barczak et al., 2019; Karpenko et al., 2020). Each farm has areas at different landscape positions, meaning there are elevation changes, closed depressions, and runoff slopes, resulting in soils forming in reliefs with properties and indicators that differ from typical soils. When soil samples are taken for analysis, yield, pH, organic matter content, NPK, and other meso and microelement maps are created. It should be emphasized that nutrient management recommendations are often "general" since they do not account for the significant dynamics of fertilizer requirements, which depend on seasonal and field conditions, as well as time (Hryhoriv et al., 2021; Karpenko et al., 2021).

For planning purposes, agronomists need to maintain field histories and input data into relevant programs, such as field area, predecessors, previously applied fertilizers, previous yields, residue management (whether residues were removed from the field or left), drought or flooding risks, soil indicators (mainly soil reaction, granulometric composition, organic matter content, salinity), and problematic areas in the field with gleying. By modelling, it is possible to assess risk levels for desired programmed crop yields. During wartime, a farmer may opt for a lower achievable yield due to the country's economic situation and military actions, adjusting the cultivation technology according to the available budget and trends in the global and Ukrainian markets (Zakharchenko et al., 2024). Since domestic market prices are unstable, fertilizer costs, their purchase, delivery, application, possible yield increases, and profitability calculations based on past years' experience are assessed to determine whether a particular crop will be profitable in the current year.

The availability of modern equipment suitable for precision farming is essential for its implementation. Special seeders for differential sowing are required, as well as verified and certified seeds purchased from trusted distributors. All these factors minimize losses (Kholodiuk et al., 2024).

It is known that fertilizer application must follow basic principles, including: the selection of the fertilizer (form); the selection of the correct application rate; the selection of the optimal timing of application; and the selection of the application method (Food 2020). The use of nutrients on a particular plot increases agricultural crop yields by improving nutrient uptake and response (Jiang et al., 2024). Optimizing sowing times and planting density is aimed at optimizing plant uptake of nutrients available in the soil and those applied as fertilizers (Ciampitti et al., 2011, 2013; Kharchenko et al., 2019). For instance, (Postma et al. 2021) reported nitrogen depletion in the soil profile down to 2 meters at high plant densities compared to low plant densities, with a greater depletion at depths of 1 meter –2 meters than at 0 meter –1 meter. At high corn plant density, root competition for soil nutrients intensifies. In their study conducted in New Mexico (USA), (Djaman et al. 2024) demonstrated that nitrogen fertilizer application to increase corn productivity, as well as the profitability and sustainability of the system on New Mexico's sandy soils, should be adjusted according to plant density.

Since nitrogen fertilizer production results in significant emissions and water losses or evaporation beyond the fields, reducing fertilizer requirements without yield reduction is of paramount importance (Ishaya & Rasmussen, 2024). Additionally, the high cost of phosphorus and potassium fertilizers, along with delivery complications, presents new challenges to farmers, requiring adjustments to fertilizer application rates.

Killeen et al. 2024 found that mid–growing season is ideal for obtaining UAV or satellite images, which, through the NDVI index, allow for yield forecasting. It should be noted that the United States has firmly established itself as a pioneer in the widespread adoption of precision farming, playing a significant and confident role in promoting this practice globally (Barbosa et al., 2024). It has been proven that yield monitoring systems can be useful for some crops, such as sorghum, wheat, soybeans, and corn (McFadden et al., 2024), though they cannot be widely applied to all crops. Predictive models enable producers to make informed decisions on resource allocation and crop management practices, using input variables such as weather data, soil characteristics, plant growth parameters, and historical yield data.

Materials and Methods

The analysis of the effectiveness of precision farming elements in the context of applying mineral fertilizers was conducted based on a single field, typical of the Forest Steppe zone in terms of relief and parent materials, latitude: 50.70428, longitude: 34.83233, located in the Lebedyn community of the Sumy district. Most of the field's area is research field soil Chernic chernozem (leached), deep, low humus, sandy medium loamy. A small part of the field, which slopes towards the ravine network, is characterized by Chernic chernozem, deep, moderately eroded, sandy light loamy.

In 2023, the DKS 373 corn hybrid from Monsanto with an FAO of 280 was planted in the field, characterized by resistance to extreme growing conditions, high tolerance to diseases, and good responsiveness to monoculture cultivation.

The predecessor crop was corn. Autumn tillage included residue shredding using a CASE Sellford 600. Potassium chloride was applied late in autumn using an Amazon spreader. Ammonium phosphate was applied in February. Gascon deep tillers were used in the spring to remove the compacted layer caused by the constant movement of precision farming machinery across the field. Herbicides were applied using a Case 3330 sprayer: 1st treatment after sowing before sprouting with Harness+ Idaho+ Roundup Max; 2nd treatment at the 5 leaf stage with Master Power; 3rd treatment at the tasselling stage with the insecticide Belt. Harvesting was done with a Case combine harvester.

Agrochemical data analysis was conducted in a certified laboratory, with soil samples taken from a depth of 0 cm-20 cm using an automatic sampler. The organic matter content was determined using an oxidation–reduction method; mineral nitrogen content was determined using acidic method, the content of mobile phosphorus and exchangeable potassium by the Chirikov method in an acetic acid extract. The content of trace elements was determined using an atomic absorption spectrophotometer. Soil pH was determined in a chloride potassium extract.

Results and Discussion

LLC "AVIS UKRAGRO GROUP" periodically samples soil for agrochemical analysis, allowing for the evaluation of some soil fertility parameters. As shown in fig. 1, the organic matter content in this field ranges from 1.7%–4.5%, with the majority of the area being low–humus soils. There are fewer areas with low content, primarily in eroded sections due to water erosion, as seen in the maps, with a slope towards the ravine in the lower left corner (orange colour).

Figure 1. Organic matter content in soil, %.

Regarding the soil reaction at our field, the agrochemical analysis revealed that it is predominantly slightly acidic and close to neutral, with more acidic soils located in higher relief areas (Fig. 2).

Due to the low soil pH, the availability of essential micronutrients may be significantly limited, potentially leading to poor corn growth. As the pH of the soil decreases, the availability of all micronutrients, except molybdenum, decreases.

Figure 2. Soil pH indicator.

The following fig. 3 shows the nitrogen availability map. As in most chernozem soils of Ukraine, nitrogen is insufficient for plants, so nitrogen as a key macroelement is always applied when growing crops. There are areas with very low nitrogen content, typically where water stagnation occurs due to excessive rainfall, as was the case in the summer of 2023. Prolonged water stagnation in the soil leads to gleying processes, and NNO_3 may undergo denitrification, meaning nitrate nitrogen transitions into ammonia or nitrogen oxide and is lost from the soil. This is characteristic of peat soils, swampy soils, those subject to flooding, and areas located at the bottoms of ravines, river valleys, and sometimes fields with poorly drained depressions.

Figure 3. Lightly hydrolyzed nitrogen content in soil, mg per kg.

Phosphorus content in the soil is moderate (yellow colour), a significant portion of the field has an increased content, and there are areas with high content, while on the slopes of the field, it is very low due to phosphorus being washed away by atmospheric water (Fig. 4). The same figure shows the zoning of the application of ammonium phosphate.

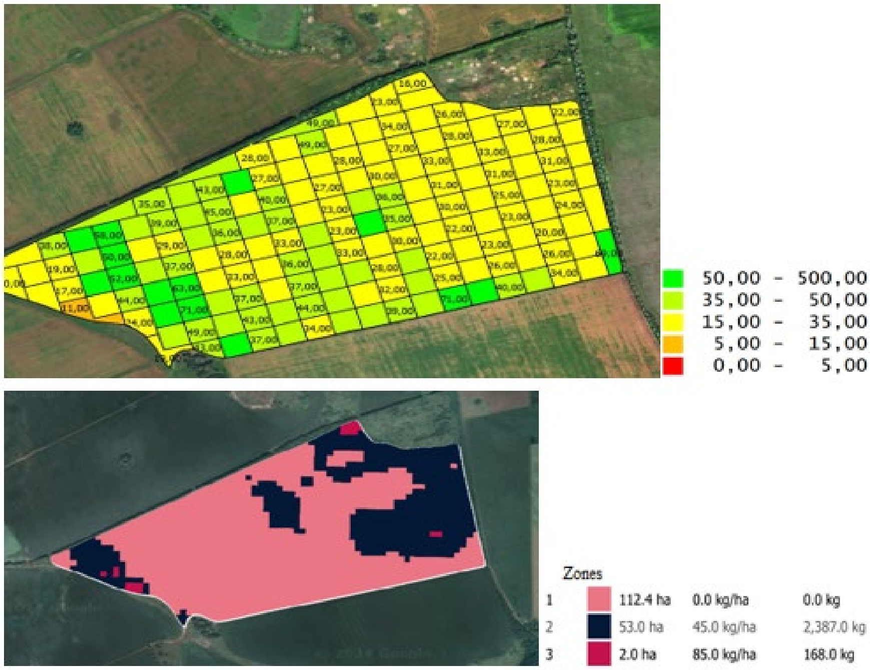

Figure 4. Phosphorus content in the soil and the zoning of ammonium phosphate application in the field, mg kg^{-1}.

The potassium content (K_2O) in different soils ranges from 0.5% to 3% and depends on the mechanical composition. More potassium is contained in the clay fraction of the soil. For this reason, heavy clayey and loamy soils contain a higher concentration of potassium (2%–3%) than sandy and sandy loamy soils (1.5%-2%). The potassium content in the soil of our field (mg kg^{-1}) is predominantly medium and elevated, with two areas having high content (Fig. 5).

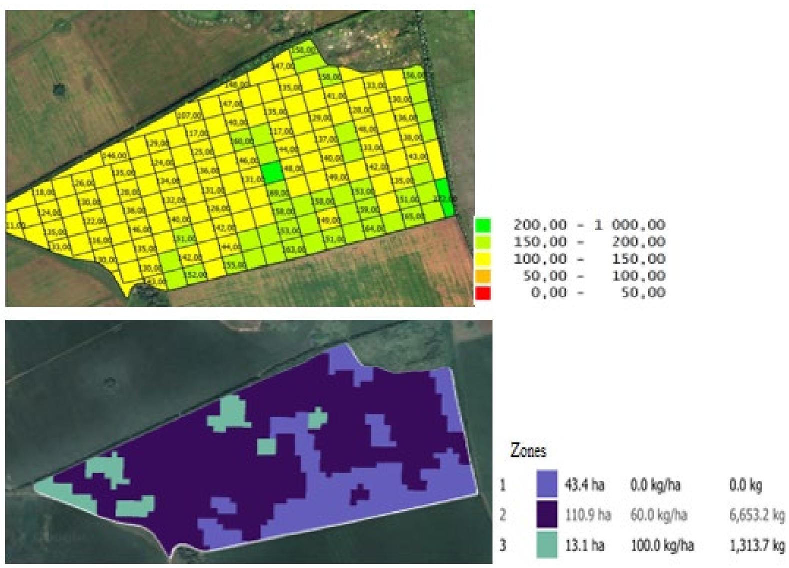

Figure 5. Exchangeable potassium content in the soil and the zoning of ammonium phosphate application in the field, mg kg^{-1}

In the farm, other elements were also determined, and it is worth noting that the calcium content is elevated to high, and on the slopes, it is even elevated, as the transitional horizons of the chernozem soil have a larger reserve of calcium carbonates. The copper and zinc content is high, iron is elevated, and sulphur and magnesium are both high and elevated. Thus, it can be concluded that the potential of the field is quite high based on the agrochemical indicators of soil fertility.

The average yield in field 312 of LLC "AVIS UKRAGRO GROUP" in the Vystorop department was 10.75 t ha^{-1}, significantly decreasing in the eroded areas (Fig. 6).

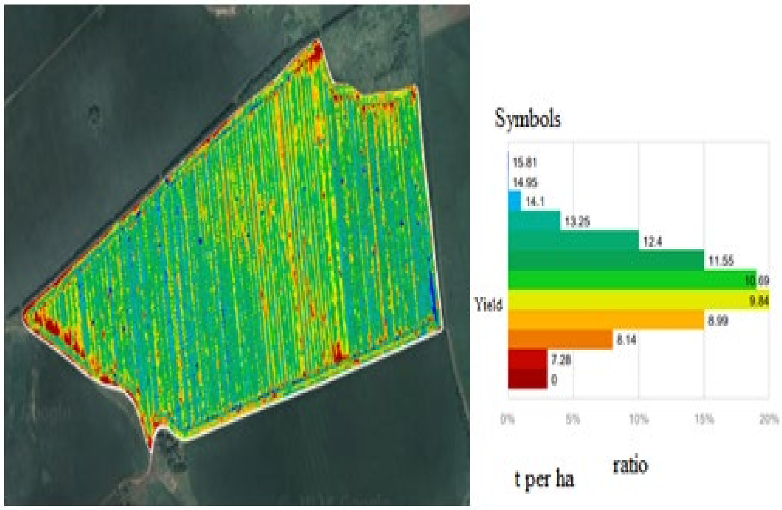

Figure 6. Corn grain yield in the field.

As we can see, when applying 60 kg of potassium chloride with a high content of exchangeable potassium in the soil at the level of 134 mg per 100 g of soil, the highest average corn grain yield of 10.2 t ha^{-1} was obtained (Fig. 5, 6, and Tab. 1). Applying 100 kg of potassium chloride gave the same grain yield as in the areas where no fertilizer was applied, where a high potassium content was found. It is clear that the crop will take up potassium with the grain, but all plant residues remain and will further serve as a source for future crops, contributing to the formation of organic matter and providing food for soil biota. Fertilizer prices in Ukraine are currently very high, which reduces profitability.

Table 1. Application of potassium chloride in certain areas (2023 prices).

Soil Potassium Content	Applied KCl rate, kg ha^{-1}	Yield, t ha^{-1}	Fertilizer cost, UAH
164 mg 100 g^{-1} of soil (high content)	0	9.71	–
134 mg 100 g^{-1} of soil (high content)	60 (34.8 a.s.*)	10.2	2232
118 mg 100 g^{-1} of soil (moderate content)	100 (58 a.s.)	9.69	3720

* active substance

In terms of the cost structure for growing corn using precision farming technology, mineral fertilizers represent a significant share nearly 15.8%, which includes the purchase and delivery of fertilizers. The application of mineral fertilizers accounts for 2.31% of the cost structure. It is also worth noting that large shares in the structure include: land lease payments 14.7%, general production costs 13.3%, and grain transportation 13.4%. The cost of seeds with delivery represents 8.19%.

Conclusions

The use of precision farming technology elements in the application of mineral fertilizers aims to equalize crop yields in the field for stable equipment operation and to optimize all technological operations. Timely agrochemical soil analysis allows for planning and forecasting product yields, while weather condition modelling and the use of satellite images enable adjustments to seeding rates, fertilization, and soil cultivation systems. The calculated rates of mineral fertilizers should be carried out according to the content of nutrients in the soil, taking into account the level of nutrient availability.

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