The potential of crowdsourced data for optimizing the fertilization of field crops in Croatia

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Graduate thesis

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Content

1. Introduction

Soil fertility is the basis of sustainable agriculture. Understanding how to preserve and improve soil fertility is critical to long-term productivity and environmental protection. With a growing global population, the need for increased food yields is increasing. Soil fertility plays a key role in ensuring sufficient food for all, soil quality affects crop yield, quality and sustainability. Maintaining soil fertility is essential for optimal use of resources such as water, fertilizers and energy. Fertile soil supports healthy plant growth, increases resistance to pests and diseases, and affects the nutritional value of crops. It is crucial for the development of rural areas and the maintenance of agricultural economic activity. Also, fertile soil plays a significant role in adapting to climate change. It increases the soil's ability to retain moisture, reduces erosion and increases resistance to extreme weather conditions. Understanding soil fertility allows farmers to properly dose fertilizers and nutrients, reducing resource loss and potentially negative environmental impact. The productive capacity of the soil depends on the often complex interactions between the biological, chemical and physical properties of the soil. Good agricultural practice aims to manage the various factors that make up each of these three traits to optimize crop yields in environmentally sound ways. Factors that contribute to the chemical properties of soil are: soil acidity, which rarely affects crop growth, but can affect the availability of other nutrients, the amount of mineral substances such as phosphorus, potassium and magnesium, and organic substances that affect soil structure and nutrient availability (Johnston and Fellow, 2005). Physical soil properties refer to soil structure (arrangement of soil particles) and soil texture (proportion of clay, sand, and loam), while biological soil properties refer to the density and diversity of soil organisms (Johnston and Fellow, 2005).

Optimizing cultivation is of great importance for better fertility of field crops, and the key elements of optimization are proper soil cultivation, sowing and planting time, irrigation and, as the most important element, fertilization. For each field crop, in order to obtain good yields, a sufficient amount of nitrogen, phosphorus and potassium should be provided (Table 1).

Table 1. Recommended amounts of nitrogen, phosphorus and potassium for selected field crops

Crop	**Nitrogen (N) kg/ha**	**Phosphorus (P_2O_5) kg/ha**	**Potassium (K_2O) kg/ha**
Wheat	140 - 200	70 - 130	80 - 140
Maize	150 - 200	100 - 120	120 - 180
Barley	80 - 110	80 - 90	100 - 120
Oat	60 - 100	60 - 80	70 - 110
Sugarbeat	140 - 160	80 - 130	200 - 300
Rapeseed	120 - 160	80 - 120	140 - 180
Soybean	30 - 150	60 - 120	60 - 170

Source http://www.petrokemija.hr/Portals/0/Gnojidba/Ratarstvo.pdf

In order for fertilization to be carried out properly, it is necessary to determine the nutrient supply in the soil, which is possible only through soil analysis. According to the Law on Agricultural Land (Official Gazette 39/13), the Rulebook on the Methodology for Monitoring the State of Agricultural Land (Official Gazette 043/2014) and the Ordinance on the Protection of Agricultural Land from Pollution (Official Gazette 009/2014), monitoring of the condition of agricultural land is carried out periodically in the Republic of Croatia at least every four years, and those liable for implementation are:

- Users registered in the register of producers of integrated and ecological production according to the requirements of such production.
- Users of agricultural land owned by the state who use the land through lease agreements, common pasture leases and pond leases.
- Beneficiaries of long-term leases and concessions during the first year after taking possession and the last year before the contract expires, and periodically at least every four years during the duration of the lease.

Based on the available nutrients in the soil, the difference that needs to be added in the form of mineral and organic fertilizers is calculated in order to meet the needs of plants and soil in the production process, and to comply with the legal regulations prescribed by the aforementioned laws of the Republic of Croatia. Soil testing includes basic agrochemical analysis, evaluation of the mechanical composition of the soil, and fertilization recommendations.

1.1. Aim of the paper

The aim of this paper is to analiyse crowdsource data in arable crops production in Croatia and to desribe the significance in crowdsorucing data in optimizing crops fertilization in Croatia.

The introduction of crowdsourcing into agricultural practice in the Republic of Croatia will result in more precise fertilization and increased yields of agricultural crops and a reduction in the negative impact on the environment.

Crowdsourcing will improve the exchange of knowledge and data among farmers in the Republic of Croatia, which will improve the cultivation of field crops.

The problem of this research is the lack of precise data on soil fertility and optimal fertilization in agriculture in Croatia, while the subject of the work is to investigate how crowd-sourced data can contribute to improving the precision and efficiency of fertilization in agriculture in Croatia. The paper will explore how crowd-sourced data can be used to improve fertilization, increase yields and reduce negative environmental impacts in agricultural practices.

2. Literature review

Digitalization of agriculture in the last few years is an important factor in soil quality measurement. Sensors and transmission data measure moisture, pH value, nutrient content and other soil parameters and send them via wireless networks. GIS (Geographic Information Systems) enable the creation of detailed spatial maps with information on soil fertility, which enables farmers to understand variations in soil quality within their fields and adapt agrotechnical practices to these variations.

Combining data on soil quality with data on yields, climate and other factors helps make precise decisions about fertilization and crop management. Unlike conventional agricultural production, digital agriculture treats the surface as heterogeneous. Precision agriculture enables the targeted application of fertilizers and other agrochemical substances, reducing potential surpluses and negative effects on the environment.

Digital platforms also enable the collection, storage and analysis of a large amount of data on soil quality and enable long-term monitoring and analysis of changes in soil fertility, providing a basis for informed decision-making. Also, the development of mobile applications allows farmers to quickly and easily enter data on soil quality in the field (Shafi et al., 2019).

Radočaj et al. (2022) point to the key aspects and advantages that precision agriculture and the use of advanced technologies have in fertilization, and the emphasis is on the accuracy, efficiency and sustainability of agricultural production. According to the aforementioned authors, digitization of processes, including data collection in the field, data processing and creation of fertilization recommendation maps, is the basis of precision agriculture. This enables efficiency and adaptation of fertilization according to local crop needs, prevents soil degradation and ensures sustainability. Management information systems are becoming crucial in precision fertilization. They facilitate the decision-making process and the use of collected data, contributing to a more precise approach to fertilization. Advances in technology enable the development of more sophisticated and affordable software packages for spatial data processing. This includes the processing of data obtained by remote sensing and the application of various methods and techniques. Interpolation methods play an important role in precision fertilization, enabling a better understanding of soil needs. Each method has a certain level of uncertainty, but with proper knowledge of their capabilities, the optimal method and parameters can be chosen to achieve maximum prediction accuracy. Data obtained by remote sensing play a key role in the fertilization process in precision agriculture. They enable the monitoring of crop and soil status on a global scale and contribute to the quick and accurate assessment of important parameters such as soil moisture and fertilizer requirements.

The development of hybrid methods for crop and soil quality modeling represents a step forward compared to conventional and modern approaches to machine learning. These methods enable more accurate assessments and integration of remote sensing data. Automation through the use of satellites and autonomous systems enables almost instantaneous data processing and generation of final products such as weed and soil moisture maps without the need for complex remote sensing knowledge.

The purpose of the experiment conducted by Schwaiger (2021) was to evaluate the effectiveness of VRNA (Variable Fertilizer Application Rate) using an optical crop sensor on the ground through three different fertilization schemes. A conventional scheme in which fertilizer was applied as usual, an incentive scheme in which crops with lower yield expectations received more fertilizer and a compensatory scheme in which crops with higher yield expectations received less fertilizer. Three fertilization schemes were randomly distributed without repetition on 21 plots, measuring 35 m in length and 21 m in width; each plot had three measurement sites. The rate of fertilizer application at each of the measurement points was recorded by the sensor's internal processor and summed for each scheme. In terms of yield, all crops were collected by harvesting with the help of GPS using a combine harvester. These three schemes represent different approaches to the application of fertilizers in agriculture, aimed at optimizing crop yields. The conventional scheme represents a standard approach to fertilizer application. The incentive scheme adjusts fertilizer application based on sensor-determined crop yield expectations, providing higher amounts of fertilizer to crops with lower yield expectations. On the other hand, the compensatory scheme reduces the amount of fertilizer applied to crops with a higher expected yield in order to avoid excess nitrogen. The use of digital technology, such as crop sensors and precision fertilizer spreaders, enables the adjustment of fertilizer application based on the actual needs of the crop, which can result in better and more sustainable yields. The results of this experiment are shown in Table 2.

Table 2. Variable rates of fertilizer application in three fertilization schemes (Schwaiger, 2021)

Scheme	Description	Use of digital technology	N fertilizer rate of application [kg N/ha]	Yield [kg/ha]
Conventional	Fertilizer application as usual at a constant rate	None (no use od figital technologies)	55	6,829
Stimulative	Crops with a lower expected yield receive more fertilizer to compensate for nitrogen deficiencies	Crop sensor and device for precise fertilizer spreading	63	6,742
Compensatory	Crops with a higher expected yield receive less fertilizer to compensate for excess nitrogen	Crop sensor and device for precise fertilizer spreading	43	6,412

Crowdsourcing as the outsourcing of data collection through a network of farmers (collaborators) who do not do this as part of their regular professional activities is increasingly used in the digitization of agriculture. In agriculture, it can be called "farmsourcing" if it involves professional stakeholders in the agricultural sector who voluntarily exchange information. The aforementioned form of crowdsourcing was used during the four-year collection of 4 groups of data on the cultivation of field crops from 13,239 requests for soil analysis (Lončarić, 2022). The analysis of the obtained data will be discussed in detail in this paper.

2.1. Crowdsourcing

The term "crowdsourcing" was first used in 2006 by J. Howe, editor of Wired magazine (Howe, 2006). The term "crowdsourcing" quickly became popular in the social environment of the Internet and the blogosphere. Crowdsourcing, understood as the outsourcing of tasks or data collection by a large group of non-experts, is increasingly used in scientific research and operational applications. The term "crowdsourcing" has gradually been assigned to many scientific and operational initiatives aimed at gathering input from a large group of people. Crowdsourcing is related (but not defined) as a new organizational form inspired by Internet companies like Amazon.com that use crowds or online communities as a way to outsource various tasks. Brabham (2008) proposed a scientific definition of crowdsourcing as "an online, distributed model of problem solving and production that exploits the collective intelligence of an online community to achieve specific organizational goals". Often referred to as community-based monitoring, citizen sensing, or citizen monitoring, most crowdsourcing initiatives aim to collect environmental and wildlife observations by volunteers (Minet et al., 2017 according to Roy et al., 2012). In addition to this main field of application, crowdsourcing initiatives have also been observed in the fields of astronomy, meteorology, cartography, mathematics and human health. These initiatives, linked to the concept of citizen science, have attracted increasing interest from the scientific community. This interest is not only based on the potential outcomes that crowdsourcing-based projects can bring in the area of research interests, but also on the research of crowdsourcing as an independent scientific subject. Although the use of volunteer contributions in scientific research goes back long before the internet era (Minet et al., 2017 according to Koerten and van den Besselaar, 2014), contemporary crowdsourcing initiatives are often mediated through online platforms. Additionally, ICT tools such as mobile phones significantly contribute to the development of civic sensitivity initiatives.

The quality of information collected through crowdsourcing initiatives is often a point of discussion in various projects, as well as data quality assurance procedures that are necessary to improve the quality of information collected (Minet et al., 2017 according to Allahbakhsh et al., 2013). Some authors claim that "higher quality information can be extracted from large amounts of lower quality data", which is related to the "big data" paradigm (De Longueville, 2016).

2.1.1. Crowdsourcing in agriculture

Although not always explicitly referred to as crowdsourcing, there is a long tradition of introducing participatory approaches to research and development projects in agriculture. Such approaches are often designed to facilitate interactions between farmers and researchers and to collect and aggregate agricultural information from farmers themselves (van Etten, 2011).

Dissemination of knowledge about agricultural research and development is usually organized by national or regional agricultural agencies, also known as extension services, or private agricultural consultants. Their goal is to transfer scientific knowledge and new technologies to farmers. However, there remains a gap between scientists and farmers. Scientists often do not understand or are not aware of the needs of farmers. Also, many research results are often not adapted to the needs of farmers, even when the results are relevant. In some countries, investment in agricultural extension services has decreased due to cuts in public funding, or their missions have changed significantly, delaying the dissemination and transfer of research and technology.

In agricultural research, concepts such as citizen science or participatory science are often applied to involve farmers in research and development. Although the term "crowdsourcing" is not always used, these approaches are strongly supported by the development of the Internet. The use of crowdsourcing in agriculture is often linked to participatory approaches in research and development projects, also helping to bridge the gap between scientists and practical farmers. The application of crowdsourcing in agriculture can provide relevant inputs for researchers, but it also contributes to linking knowledge between researchers and practitioners and encourages interaction among farmers. Therefore, there is great potential for the development of crowdsourcing applications in agriculture that can benefit both scientists and practitioners.

Defined as the realization of specific data or data collection, crowdsourcing applications in agriculture can not only provide inputs that meet the needs of agricultural researchers, but also contribute to closing the circle of knowledge dissemination between researchers and practitioners and encourage interaction among farmers. Therefore, there is a huge potential for the development of crowdsourcing applications in agriculture that can benefit both scientists and practitioners. Farmsourcing as a concept similar to crowdsourcing refers to the involvement of farmers, farm owners and other relevant parties in the process of collecting data and information related to soil quality and other aspects of agricultural production. Farmsourcing is increasingly being used intensively in agriculture in the digitization of agriculture (Lončarić et al., 2022)

Table 3. Overview of crowdsourcing projects related to applications in agriculture (Minet et al., 2017)

Name	Website	Short Description	Crowdsourcing Component	Reference
Pl@ntNet	www.plantnet-project.org	Plant species identification through image analysis	Task	Goëau et al., 2013
PlantVillage Image	www.plantvillage.org	Detection of plant diseases using image analysis	Task	Hughes & Salathé, 2015
none	none	Weed species identification through image analysis	Task	Rahman et al., 2015
GeoWIKI	http://geo-wiki.org	Satellite-based land-use mapping	Task	Fritz et al., 2009
DIYlandcover	http://mappingafrica.princeton.edu	Satellite imagery-based land-use mapping	Task	Estes et al., 2016
none	none	Reporting on-farm crop variety trials	Local visual observations	van Etten et al., 2016
PocketLAI	www.cassandralab.com	Mobile app for leaf area index measurements	Data from sensor measurements	Francone et al., 2014
PhotosynQ	www.photosynq.org	Web platform for plant measurement projects	Data from sensor measurements	Kramer, 2016
Akkerweb	www.akkerweb.nl	Web platform for farming information and applications	Data from sensor measurements	None
Potato Crop Management	www.potatocropmanagement.com	Platform for data collection and yield forecasting	Data from sensor measurements	None
LandPKS	http://landpotential.org	Integrating scientific and local knowledge for farmers	Knowledge	Herrick et al., 2013
FarmHack	http://farmhack.org	Platform for sharing agricultural prototypes	Knowledge	None
Croprotech	https://croprotect.com	Sharing scientific information on weeds, pests, and diseases	Knowledge	Bruce, 2016
PlantVillage	www.plantvillage.org	Q&A platform for plant culture and diseases	Knowledge	None
AgTalk	http://talk.newagtalk.com	General Q&A platform for agriculture	Knowledge	Hansen et al.

Table 4. Inputs for farmsourcing projects (Minet et al., 2017)

	Short description	**Source**	**Target**	
Agricultural land-use /land cover data	Delineation of agricultural parcels and description of land use and land cover (crop sequencing)	From satellite, airborne or UAV imagery digitalisation and visual observations	Environmental and crop modelling, yield forecasting, …	OpenStreetMap (Minet et al., 2015); Geo-Wiki (Fritz et al., 2012); Collect Earth (Bey et al., 2016); DIYlandcover (Estes et al., 2016)
Soil data	Soil parameters useful for agricultural applications: texture, structure, organic matter content, pH, nutrient content (N, P, K), water content	From ground or near remote sensing, from soil surveys, from laboratories database	Farmers and recommendation systems	Rossiter et al., 2015
Weather data	Records of weather variables (temperature, precipitation, relative humidity)	From meteorological stations network	Farmers, warning and recommendation systems	Muller et al., 2015, Overeem et al., 2013
Crop phenology and calendar information	Records of phenological events and of field interventions	From UAV or close range remote sensing, from farmers	Crop modelling, yield forecasting, legal aspects	none
Pests and diseases	Observations of pests and diseases, photographs	From farmers, from technical expert	Pests and diseases monitoring, warning systems, time scheduling for farmers	PlantVillage Image (Hugues & Salathé, 2015); Rahman et al., 2015
Yield and vegetation status	Yield data per field, vegetation status measurements, fractional cover, biomass, leaf area index, …	From UAV or close range remote sensing, from farmers	Crop modelling, yield forecasting, crop monitoring	PocketLAI, Francone et al., 2014
Prices	Prices of agricultural products	From farmers and marketers	Farmers and marketers	Pommak
General agricultural knowledge	General knowledge and know-how about agriculture: can be information about crop calendar, farming practices, agricultural machinery issues, crop and animal productions, pests and diseases, stocks and market information, information about regulations, etc.	From farmers	Farmers	Agtalk; PlantVillage; Hansen et al.,

In particular, we will refer to data on the type of soil that may be of interest for agricultural applications: textural classes, structure, organic matter content, pH, nutrient content (especially mineral nitrogen subject to rapid changes). This data can be of direct interest to farmers to improve current soil maps. Rossiter et al. (2015) reviewed existing applications of crowdsourcing projects that target soil data and list soil properties that can be collected to improve soil maps. Crowdsourcing platforms for soil data could benefit from regular soil analysis by extension services and private laboratories, which can communicate their soil research results to a centralized web platform. Data on soil fertility are the basis for successful planning and management of agricultural production, and have a significant impact on yield, crop quality and environmental protection (Minet et al., 2017).

2.2. Farmsourcing

Farmsourcing in agriculture can be used in a variety of ways to collaborate and involve farmers in data collection, analysis and decision-making to improve agricultural practices and achieve sustainable production. Through famsourcing, farmers can be involved in soil sampling on their plots by collecting data on the physical and chemical properties of the soil. Farmers can record information about applied fertilizers, pesticides, agrotechnical measures and other changes on the farm and use such information to monitor the impact on soil and crop quality. They can also participate in the analysis of results, interpretation of data and decision-making based on the collected information. Through farmsourcing, it is also possible to track changes in soil quality over time, record seasonal variations and identify patterns. Most importantly, through farmsourcing, farmers share their experiences and examples and can participate in the development of applications and software aimed at measuring soil quality (Minet et al., 2017). Depending on infrastructure and technological capabilities, farmsourcing can use different digital tools and approaches to facilitate information sharing and collaboration among farmers. The ways in which the exchange of information, data and cooperation can be ensured are as follows:

- Digital Applications for Agriculture:

Farmers can enter information about their crops, agrotechnical practices, applied fertilizers and pesticides, and about changes on their farms.

Applications often allow you to enter photos, GPS location and other relevant data.

- Online Registers and Databases:

Creation of online registers or databases where farmers can enter their information

- Common Platforms:

Development of platforms that enable farmers to communicate, share information and experiences, exchange data and collaborate

- IoT (Internet of Things) Technologies:

Using Internet-connected sensors and devices that automatically collect and transmit soil quality data

- Integration with GIS Systems:

The integration of farmsourcing data into geographic information systems (GIS) enables the creation of spatial maps with information on soil quality.

- Data on Yields:

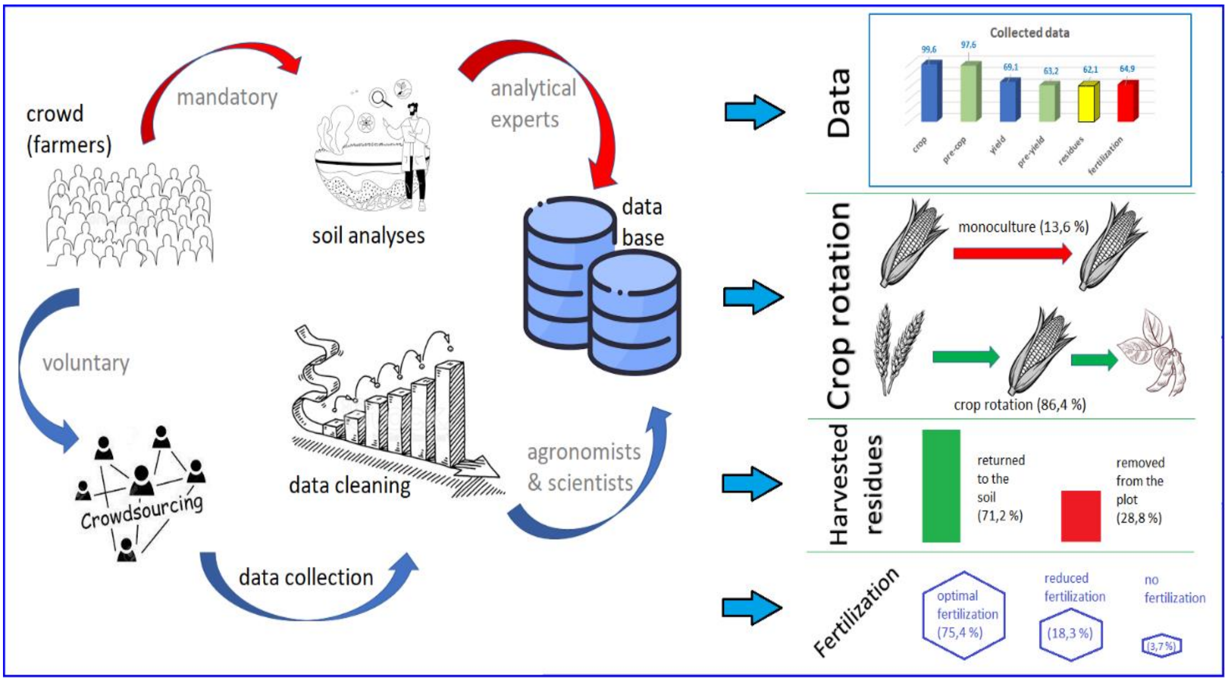
Collecting yield data and comparing it with soil quality information can help better understand the relationships between soil quality and crops.

- Digital Diaries and Records:

Farmers can keep digital diaries and records of all farm activities, including soil changes (Minet et al., 2017).

2.2.1. Farmsourcing in Croatia

As already mentioned in the paper, digitization in agriculture includes various strategies for collecting information, with special attention being paid to the active participation of farmers in this process. One of the key approaches is precisely crowdsourcing, or the model known as farmsourcing, which means that data is collected through cooperation with a network of farmers who voluntarily contribute information. During the mandatory soil analysis, in addition to basic information such as identification of agricultural plots and applicants and information on planned crops, there is a number of additional data that are essential for optimizing fertilization and preserving soil fertility. The crowdsourcing or farmsourcing format was used in 2018 for four groups of data on the cultivation of field crops - crop, pre-crop and yields; organic fertilization; harvest residues; mineral fertilization. The data presented below were collected from 13,239 requests for soil analysis (Figure 3.1).



Picture 1. Crowdsourcing soil data in Croatia (Lončarić et al., 2022)

3. Material and Methods

Agricultural producers in the Republic of Croatia are obliged to carry out soil fertility control in an authorized laboratory every 4 years. Control of soil fertility includes mandatory agrochemical analysis and interpretation of soil analysis results. The producer is obliged to provide the authorized laboratory with identification data on the plot for which he requests analyzes within the framework of fertility control. A fertilization plan based on advice or pre-instructions for fertilization is not mandatory, but it is usually an integral part of the report along with the interpretation of the analysis results and is very important for the systematic maintenance of soil fertility.

A fertilization plan with advice for soil improvement measures and fertilization is most often created using the Decision Support System, and certain input data are required for the most efficient functioning. Therefore, within the framework of submitting a request for soil fertility control, a questionnaire survey of the producer is carried out, filling in a questionnaire that collects data on the producer, production areas and crop production method. Filling out the questionnaire is done online and represents a certain crowdsource data collection system because the producer willingly and arbitrarily shares production data, and in return receives a better fertilization plan with the possibility of choosing the optimal fertilization according to different criteria.

The crowdsource format in this research was used during 4 year collection data on arable crops growing. There were 4 groups of collected data:

1. data on crops and yields (planed crop, target crop yield, precrop species and precrop yield),
2. fertilization with organic fertilizer (type of fertilizer, amount and year of application);
3. harvest residues (management with harvest residues)
4. mineral fertilization (applied mineral fertilization in relation to the recommended fertilization).

Data were collected in period 2018-2021 year, and in total data within 13,239 requests for soil analysis were collected.

Questions for collection data on crops and yields:

1. crop species
2. traget yield of crop
3. precrop species
4. achieved yield of precrop

Producers assessed the achieved yield of the pre-crops using four offered levels of realized yield:

1. very low yield (up to 60% of the target yield)
2. low to moderate yield (60-90% of target yield)
3. targeted yield (90-110 % of target yield)
4. very high yield (> 110 % of target yield).

Questions for collection data on fertilization with organic fertilizer:

1. type of applied organig fertilizer
2. amount of aaplied organic fertilizer
3. year of application.

Questions for collection data on harvest residues management:

1. type of harvest management residues
2. the yearly amount of crop residues

Respondents answered the question about the management with harvest residues by choosing one of the 3 options offered:

1. harvest residues were plowed (incorporated into the soil),
2. harvest residues were burned,
3. harvest residues were taken away from production areas.

Questions for collection data on mineral fertilization:

1. mineral fertilization with nitrogen (N)
2. mineral fertilization with phosphorus (P_2O_5)
3. mineral fertilization with potassium (K_2O)

Respondents were asked about mineral fertilization in the previous growing season and could choose one of the five answers for mineral fertilization with nitrogen, phosphorus and potassium (separately for each of the three main nutrients):

1. mineral fertilization was not applied
2. fertilization was applied with less than 40% of the recommended amounts
3. fertilization was applied with 40-70% of the recommended amounts
4. mineral fertilization was applied according to recommendations
5. slightly higher (>120%) mineral fertilization was applied than recommended.

3.1. Data analyses

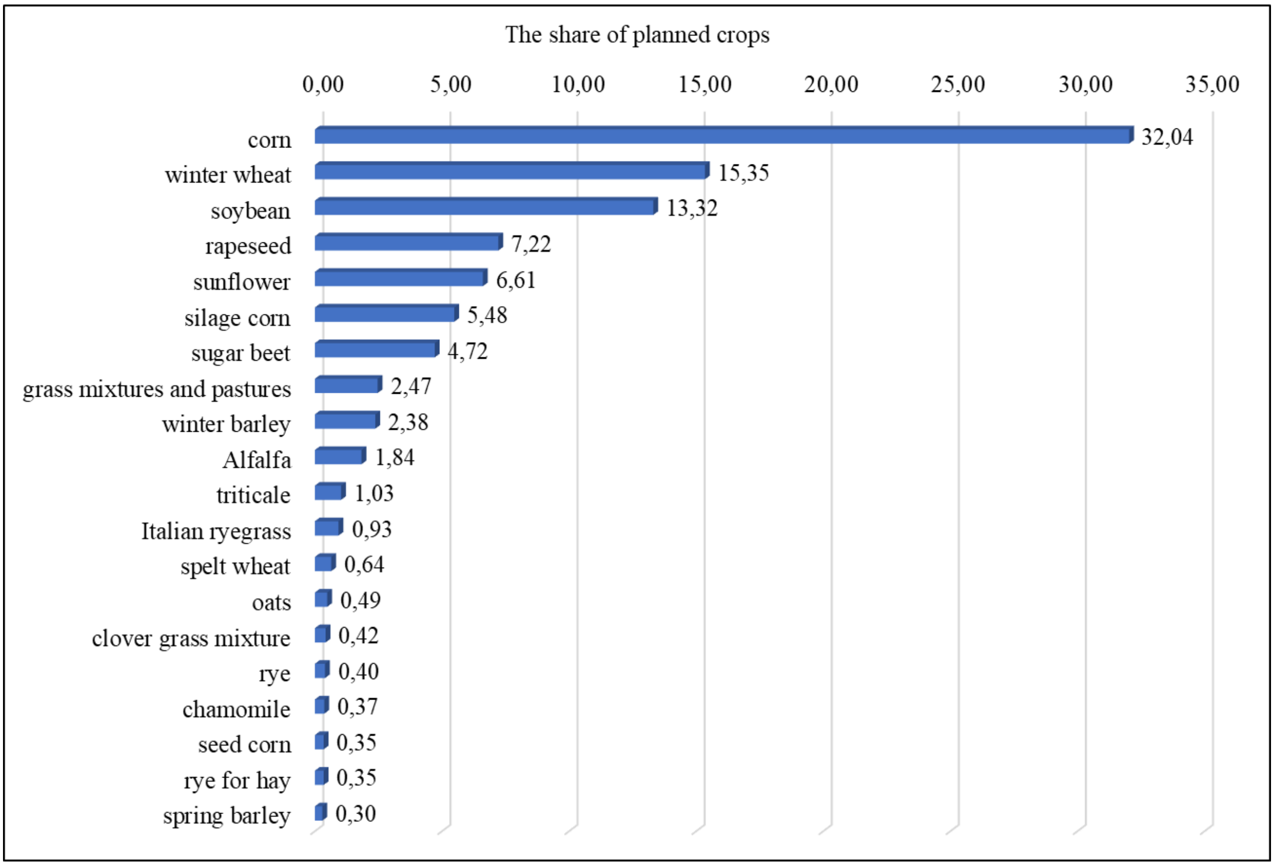
The all collected data were analysed in MS Excel for descriptive statistics and using SAS Enterprise Guide, version 8.1 Update 1 (8.1.1.4580), Copyright 2019, SAS Institute Inc., Cary, NC, USA.

4. Results

4.1. Crops and yields (planned crop, target yield, precrop and precrop yield),

In this group of data, a total of 82.37% of data was collected, and to the greatest extent, producers submitted data on the planned crop (99.59%) and pre-crop (97.56%). However, significantly less producers answered what the target yield is in the production they are planning (69.15%), and they shared information about the achieved yield of the pre-crop to an even smaller extent (63.20%).

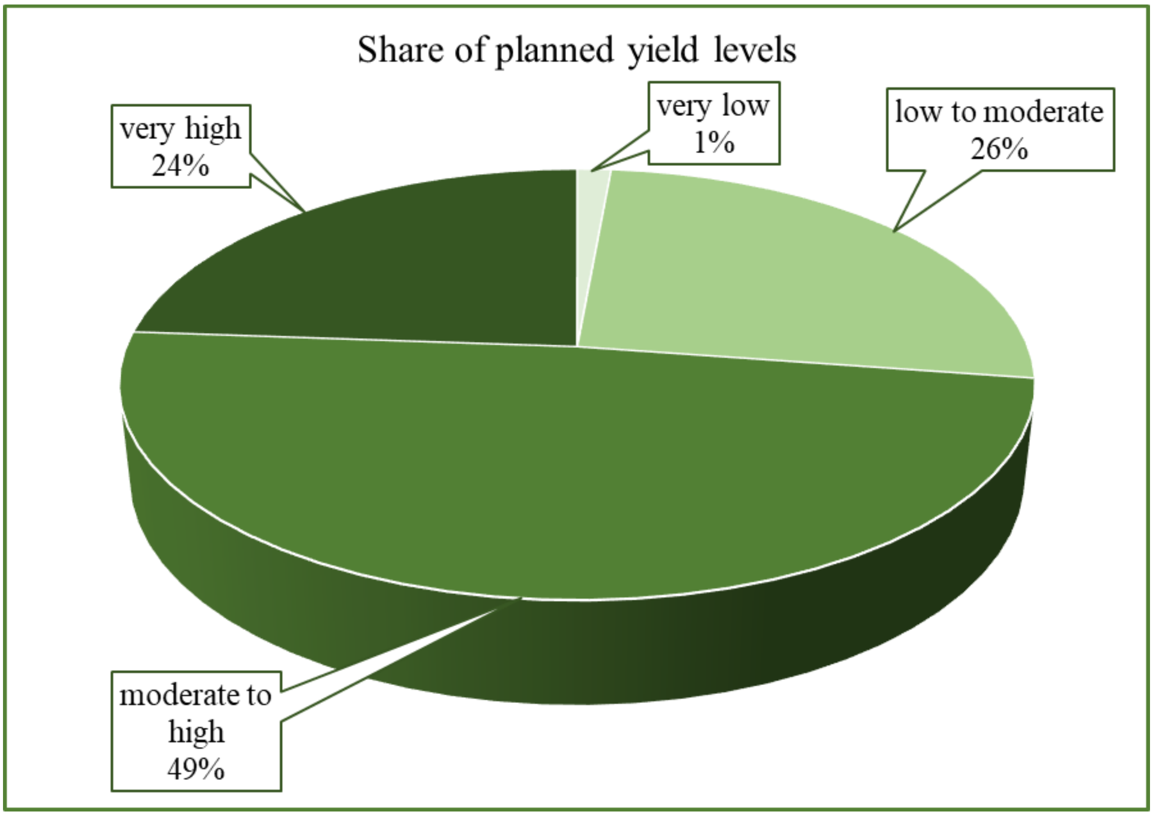
4.1.1. Planned crop
Only 54 out of 13239 records (0.41%) do not contain an answer about the planned crop. The most represented crop is corn, almost one third (32.04%), but together with silage and seed corn, 37.87%. It is followed by wheat with 15.35% and soybeans with 13.32%. The five most common crops account for 74.54%, and if we include silage and seed corn, more than 80% (Graph 1). A total of 20 different crops make 96.72% of requests for soil analysis.



Graph 1. The share of planned crops in requests for soil analysis

4.1.2. Target yield

The majority of producers (48.79 %) plan a target yield of a moderate to high level, followed by a low to moderate level (25.93 %), and a very high planned yield (23.86 %). There are the fewest producers (1.41%) who plan a very low yield (Graph 2).

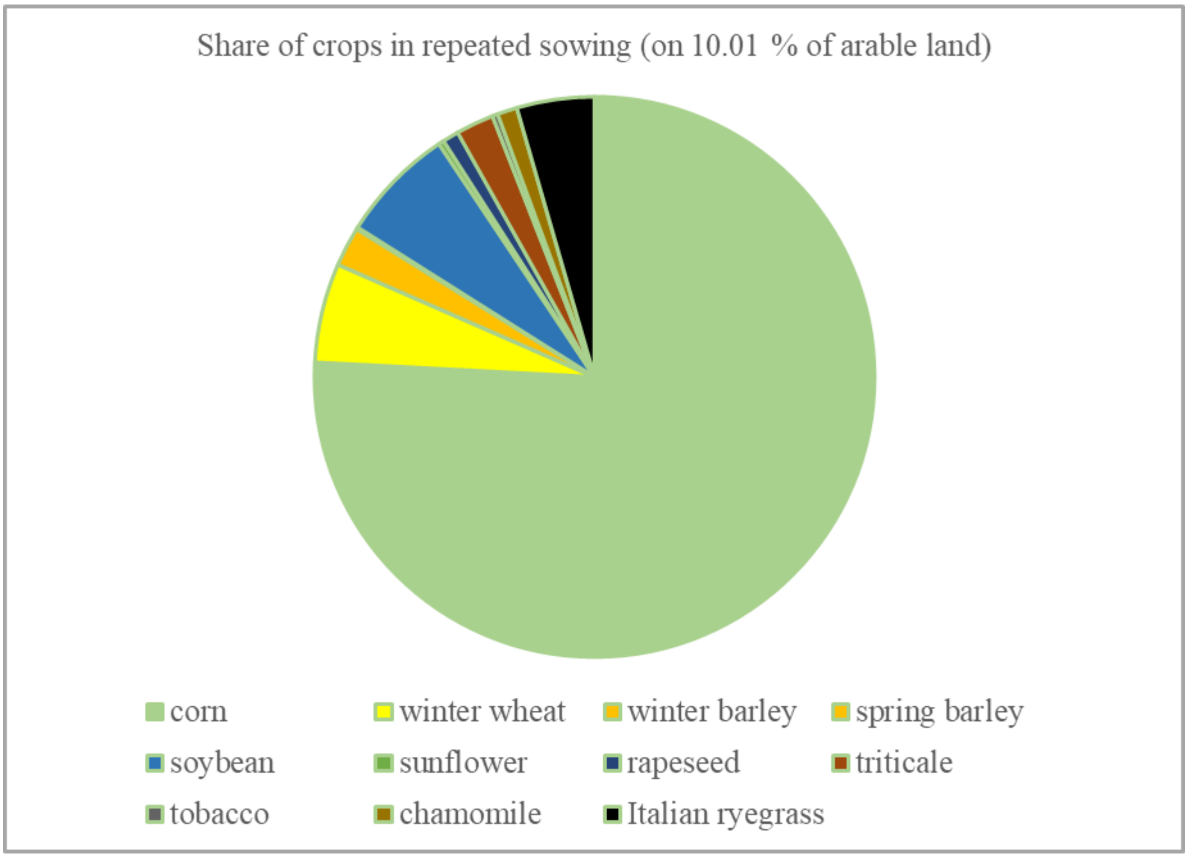


Graph 2. The levels of target yields

4.1.3. Previous crop

The data analysis revealed repeated sowing of the same crop on a total of 1,325 areas (10.01% of all analyzed arable land). The most common was repeated sowing of corn (82.49 %), followed by soybeans (4.83 %), wheat (4.15 %), Italian ryegrass (3.25 %), barley (1.74 %), triticale (1, 58 %), chamomile (0.83 %), oilseed rape (0.68 %), sunflower (0.23 %) and tobacco (0.23 %) (Graph 3).

Also, wheat, barley and triticale were grown in total in repeated sowing on 99 plots, but to this should be added the cases when different types of small grains were sown one after the other (another 195 times). In this case, the sowing was repeated practically on a total of 11.48% of particles (not counting alfalfa, clover, lawns and clover-grass mixtures).



Graph 3. Crops in repeated sowing

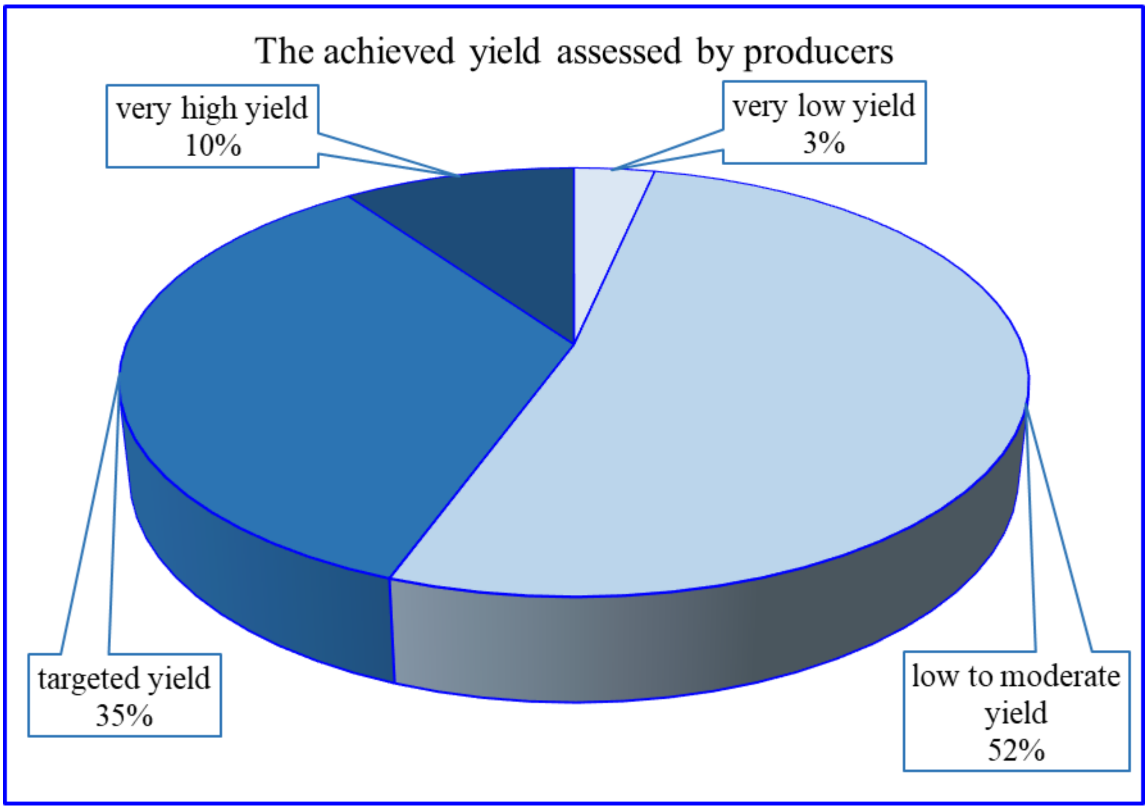
4.1.4. Previous crop yields

Producers assessed the yield of the pre-crops using four offered levels of realized yield:

1. very low yield (up to 60% of the target yield)
2. low to moderate yield (60-90% of target yield)
3. targeted yield (90-110 % of target yield)
4. very high yield (> 110 % of target yield).

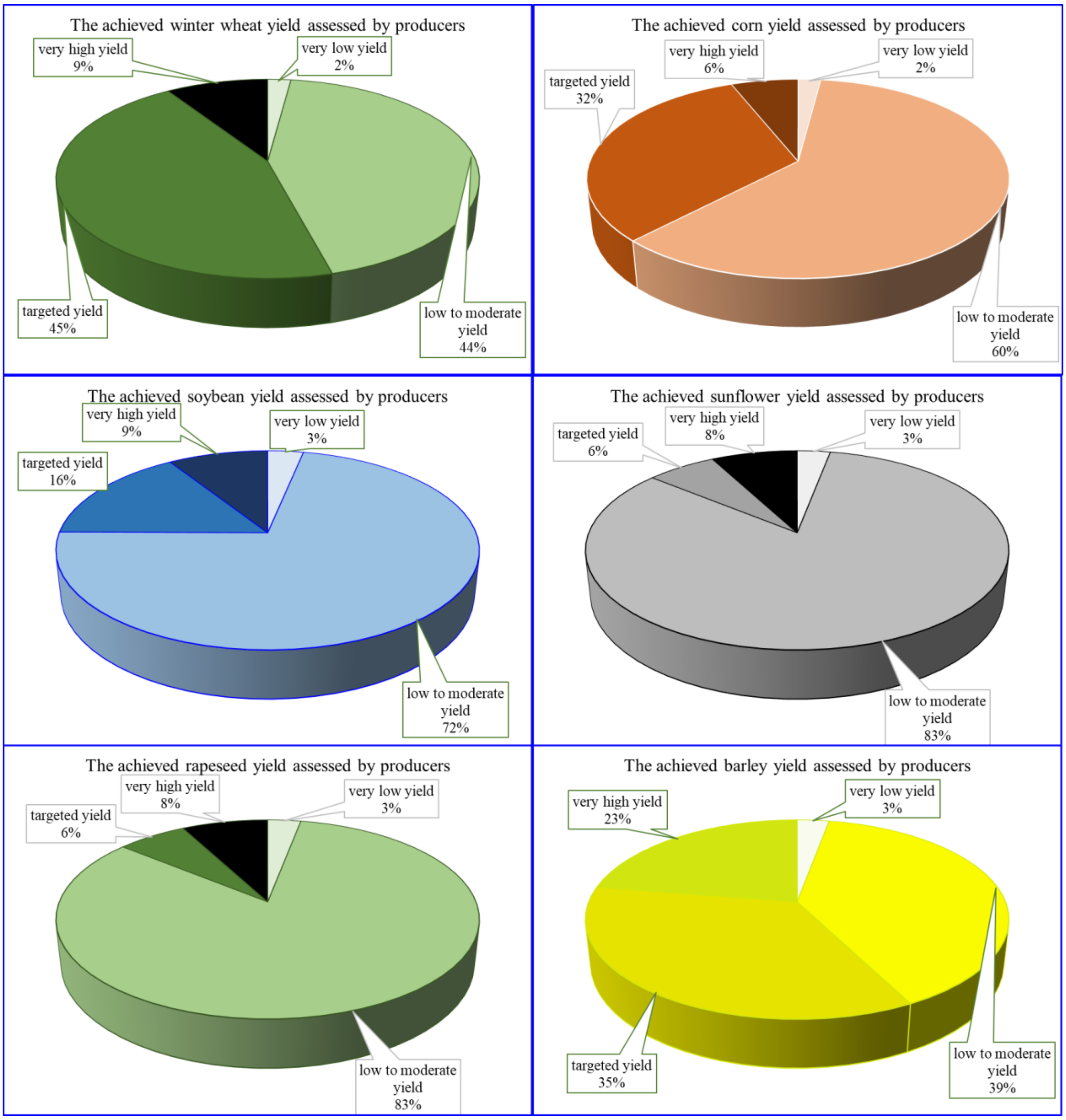
This answer was collected in 8,365 out of a total of 13,239 questionnaires, i.e. 63.20%.

Most often (in 52.19 % of cases) the producers assessed that they during four years achieved a low to moderate yield (60-90% of target yield), but only in 34.64 % of cases they achieved exactly the targeted yield, i.e. 90-110 % of the target yield. This means that according to the producer's assessment, in 86.83% of cases the yield was realized in the range of 60-110% of the planned yield. The remaining 13.17% of cases refer to very high yield in 9.78% of cases (>110% of target yield) and very low yield in only 3.39% of cases (< 60% of planned yield) (Graph 4).



Graph 4. The achieved yield evaluated by producers (average for all crops)

The highest share of the achieved target yield was for wheat (45%) and barley (35%), and the lowest for sunflower and rapeseed (6%). At the same time, in all crops, a very low yield was achieved only in 2-3% of cases, while a very high yield was achieved mostly in barley (23%) (Graph 5).



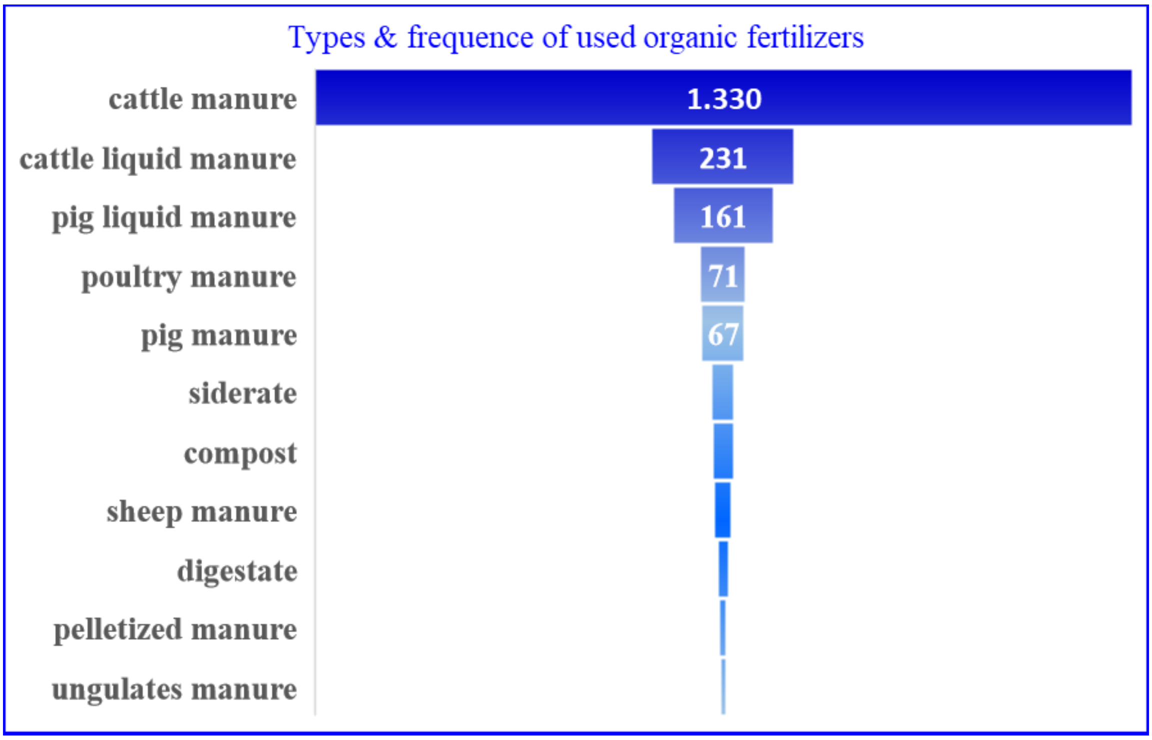
Graph 5. The achieved yield of crops evaluated by producers

4.2. Fertilization with organic fertilizers (type, amount and year of application)

Collected data show that organic fertilizers was applied to only 15,34% of the analyzed soils. Producers who state the type of organic fertilizer used, in 27.1% of cases do not state the amount of fertilizer they applied, and in 30.6% of cases do not state the year of application, i.e. whether they applied fertilizer one, two, three or four years ago.

The most common was the use of cattle (78.8%) and pig (11.5%) manure (Graph 6). These two fertilizers were used in more than 90% of cases, most often solid fertilizers (70.80%), and significantly less liquid manure (19.81%).

Other organic fertilizers used are poultry manure (3.59%), siderates (1.67%), composts (1.57%), sheep manure (1.31%), digestate (0.76%), pelleted organic fertilizers (0.40%) and ungulates manures (0.30%).



Graph 6. Types and frequence of used organic fertilizers

4.3. Harvest residues (management with harvest residues)

Respondents answered the question about the management with harvest residues by choosing one of the 3 options offered:

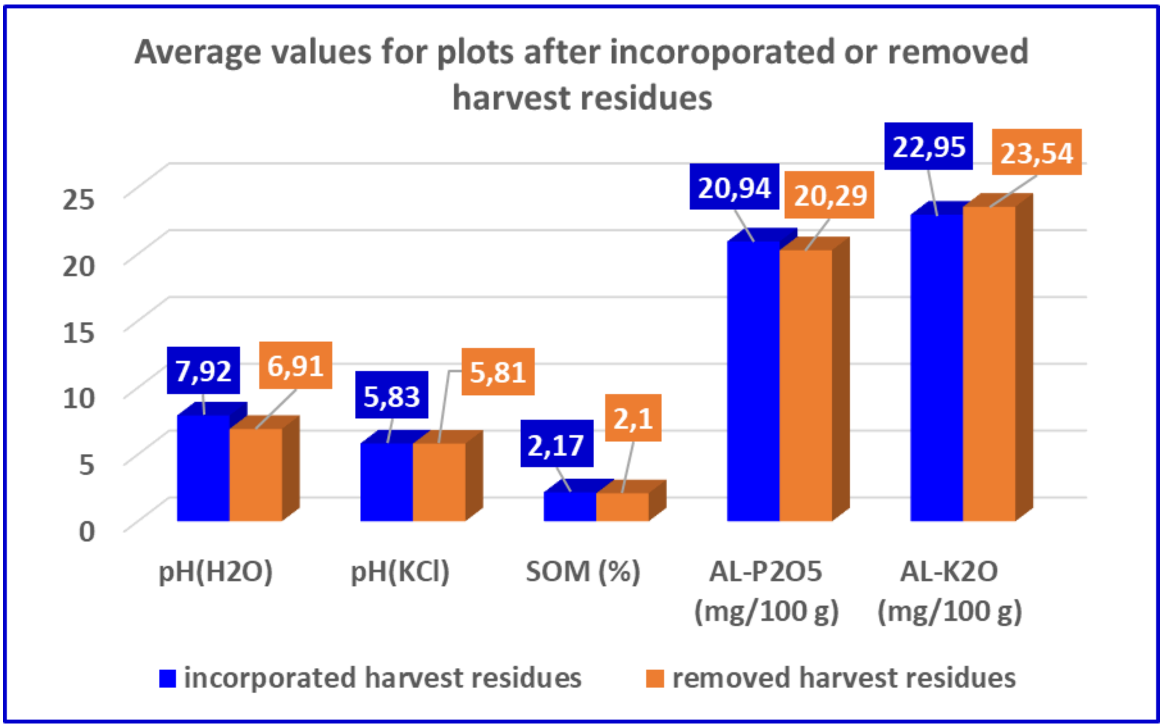
1. harvest residues were plowed (incorporated into the soil),
2. harvest residues were burned,
3. harvest residues were taken away from production areas.

Regarding harvest residues, responses were collected for 8,221 production plots, i.e. for 62.10% of requests for analysis of soil fertility control.

The incorporation of harvest residues in soil was determined on 5,855 parcels, i.e. for 71.22% of the parcels with collected data on harvest residues, while harvest residues were removed from 2,364 areas (28.76%). Harvest residues were burned only in 2 cases (0.02% of the area). However, for 37.9% of the areas, no answers were collected about the management with harvest residues, so it can only be concluded with certainty that the harvest residues were incorporated in soil on 44.23% of the analyzed areas, that they were taken away from 17.86% of the areas, burned on 0 .02% of the area, while no data was collected for 37.9% of the plots.

In addition, out of a total of 5,855 plots on which incorporating of crop residues was established, data on the amount of residues was determined for only 2,441 plots, i.e. for 41.69% of the areas on which residues were plowed. The average amount of plowed crop residues according to the farmer's assessment was 2.44 t/ha. However, considering that on 37.90% of the areas there was no answer about the procedure with harvest residues, it can only be stated with certainty that an average of 2.44 t/ha of harvest residues was plowed on 18.44% of the plots.

In average, on plots after incorporated harvest residues slightly higher pH and SOM content and AL-extractable phosphorus were measured, but also slightly lower AL-extractable potassium (Graph 7).



Graph 7. Comparison of plots after removed or incorporated residues

4.3.1. Management with harvest residues and organic fertilizers application

The collected data enable the analysis of the combined impact of fertilization with organic fertilizers and crop residue management, but only on plots with collected data. Thus, a higher

SOM content (2.21%) among plots after incorporation of harvest residues was determined on plots with applied organic fertilizers than on plots without organic fertilizers application (2.16%).

At the same time, slightly higher difference was measured amog fields after removal of harvest residual with and without organice fertilizer application. Thus, on the arable land from which the harvest residues were removed, and the application of organic fertilizers was carried out, a higher content of SOM was determined (2.16 %) than without the application of organic fertilizers (2.07 %).

The influence of management with crop residues, with or without a combination with the influence of organic fertilizers, on other soil properties is not significant, except for the content of available phosphorus, which was significantly lowest on the plots where organic fertilization was carried out, but producers did not respond (no answer) about crop residue management (Table 5).

Table 5. Soil properties on plots according to crop residues management and applied organic fertilizers

Harvest residues	Organic fertilizer application	Active pH_{H2O}	Exchainable pH_{KCl}	SOM (%)	AL-P_2O_5	AL-K_2O
removed	Yes	6.86	5.77	2.16	20.31	23.33
incorporated	Yes	6.80	5.76	2.21	22.92	22.80
No answer	Yes	6.66	5.19	2.58	14.46	22.92
AVERAGE	Yes	6.79	5.73	2.28	20.22	23.09
removed	No	6.93	5.82	2.07	20.26	23.63
incorporated	No	6.76	5.70	2.17	20.48	22.98
No answer	No	6.60	5.53	2.26	20.19	22.67
AVERAGE	No	6.72	5.65	2.19	20.35	22.96

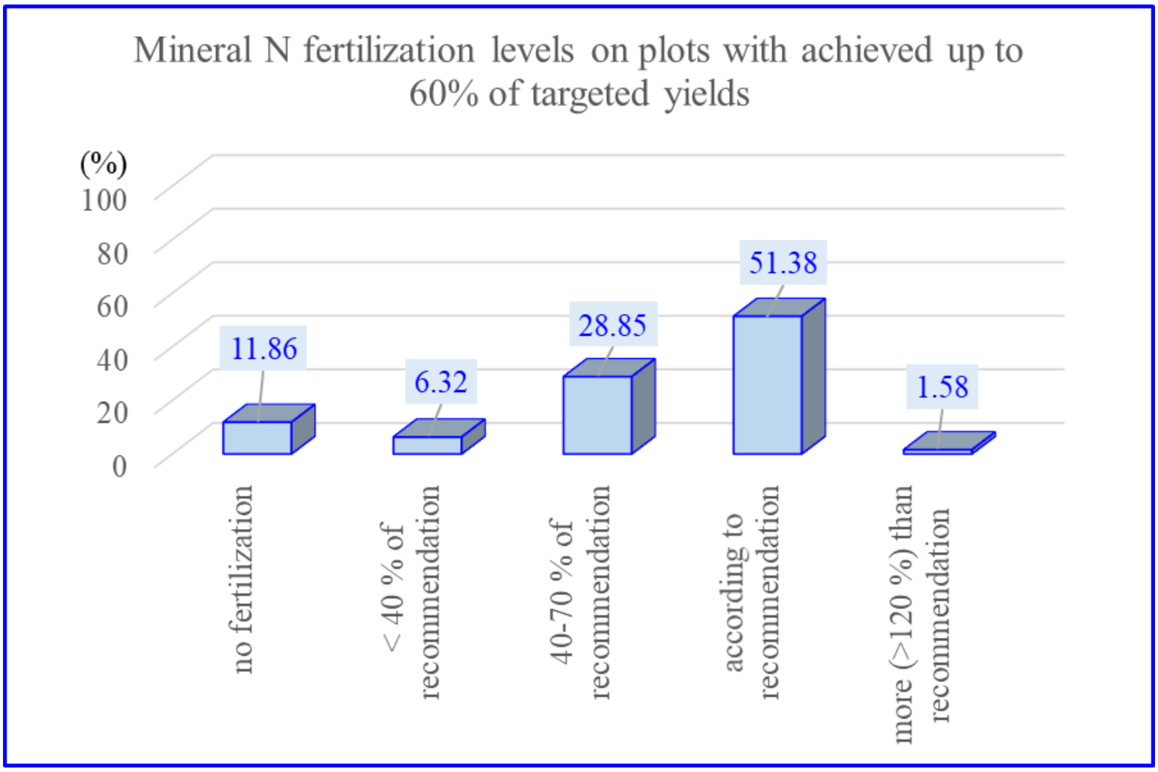
4.4. Mineral fertilization (relation of applied and recommended fertilization)

Respondents were asked about mineral fertilization in the previous growing season and could choose one of the five answers for mineral fertilization with nitrogen, phosphorus and potassium (separately for each of the three main nutrients):

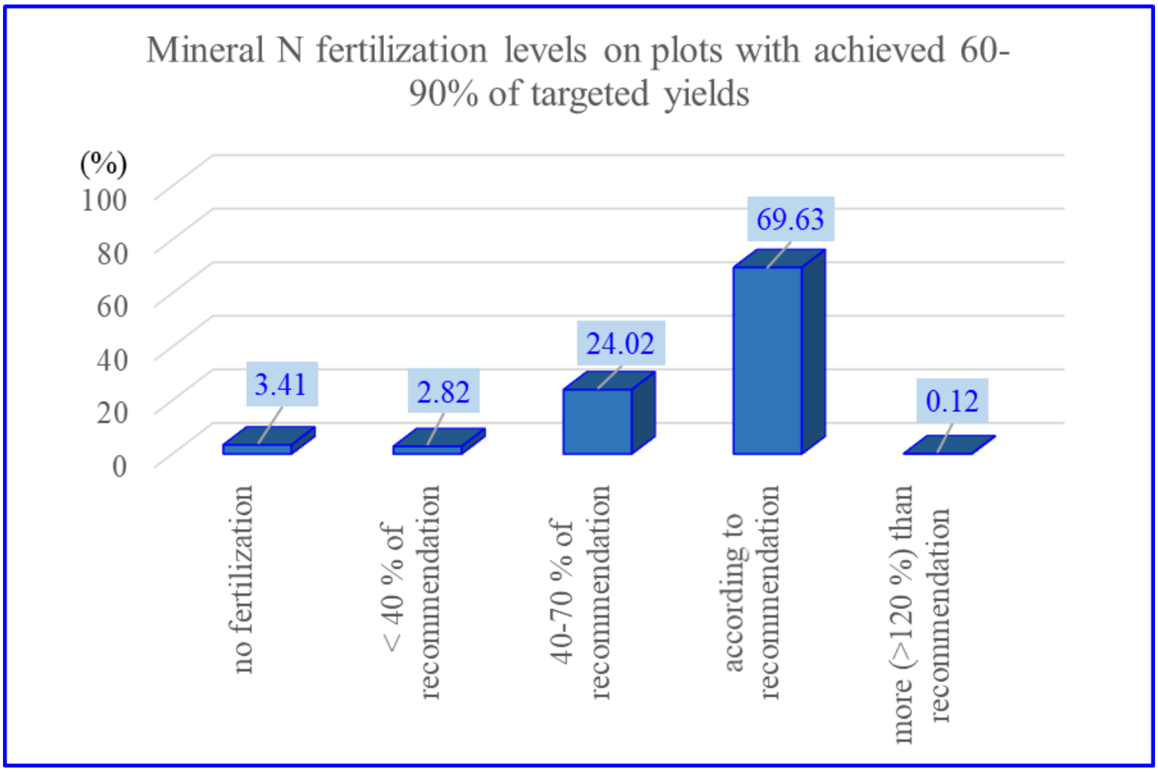
1. mineral fertilization was not applied
2. fertilization was applied with less than 40% of the recommended amounts
3. fertilization was applied with 40-70% of the recommended amounts
4. mineral fertilization was applied according to recommendations
5. slightly higher (>120%) mineral fertilization was applied than recommended.

Almost the same number of responses were collected for all three main nutrients (63.12% on average, i.e. 8,357 responses), but still the largest number of data for nitrogen fertilization (64.88%, i.e. 8,590 responses), slightly less for potassium fertilization (62, 34%, i.e. 8,253 answers) and the least for fertilization with phosphorus (62.15%, i.e. 8,228 answers).
In total, the largest number of respondents applied mineral fertilizers according to recommendations, an average of 75.44% with very small differences in fertilization with nitrogen (75.72%), phosphorus (75.27%) and potassium (75.34%). On average, 18.33% of respondents reduced mineral fertilization to 40-70% of the recommended fertilization. These two levels of fertilization cover a total of 93.77% of respondents. The remaining 6.23% are made up of 3.72% who did not apply mineral fertilization, 2.27% who reduced fertilization to less than 40% of the recommended amounts, while 0.24% of respondents fertilized with larger amounts than recommended.
The collected data enable the analyses of possible conection of mineral fertilization and achieved yields. At all four levels of achieved yields, the highest proportion of mineral fertilization with nitrogen is according to recommendations for fertilization (51.38-85.09%). However, the smallest share of fertilization according to recommendations (51.38%), in the comparison of all yield levels, is on the plots where the lowest yield was achieved (yield up to 60% of the target yield, Graph 8.). Furthermore, the increase in the share of plots with mineral nitrogen fertilization in accordance with recommendations to 69.63%, then 80.45% and to the highest 85.09% was determined for plots where a increased percentage of the target yield was achieved: 60-90% (Graph 9); 90-110% (Graph 10) and >110% (Graph 11) of the target yield.

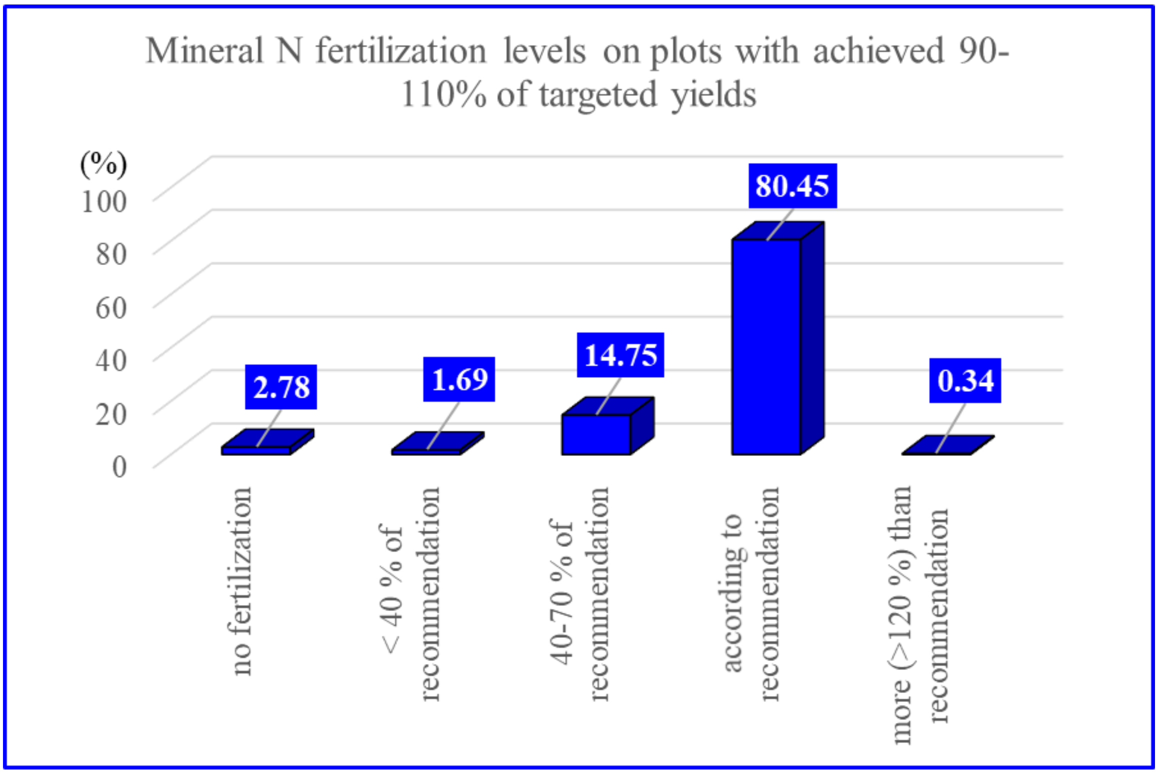
At the same levels of realized yields, a decrease in the share of reduced mineral fertilization with nitrogen (40-70% of the recommended fertilization) was determined, from 58.85% with the lowest yields to 5.7% with the highest yields (Graphs 8-11).



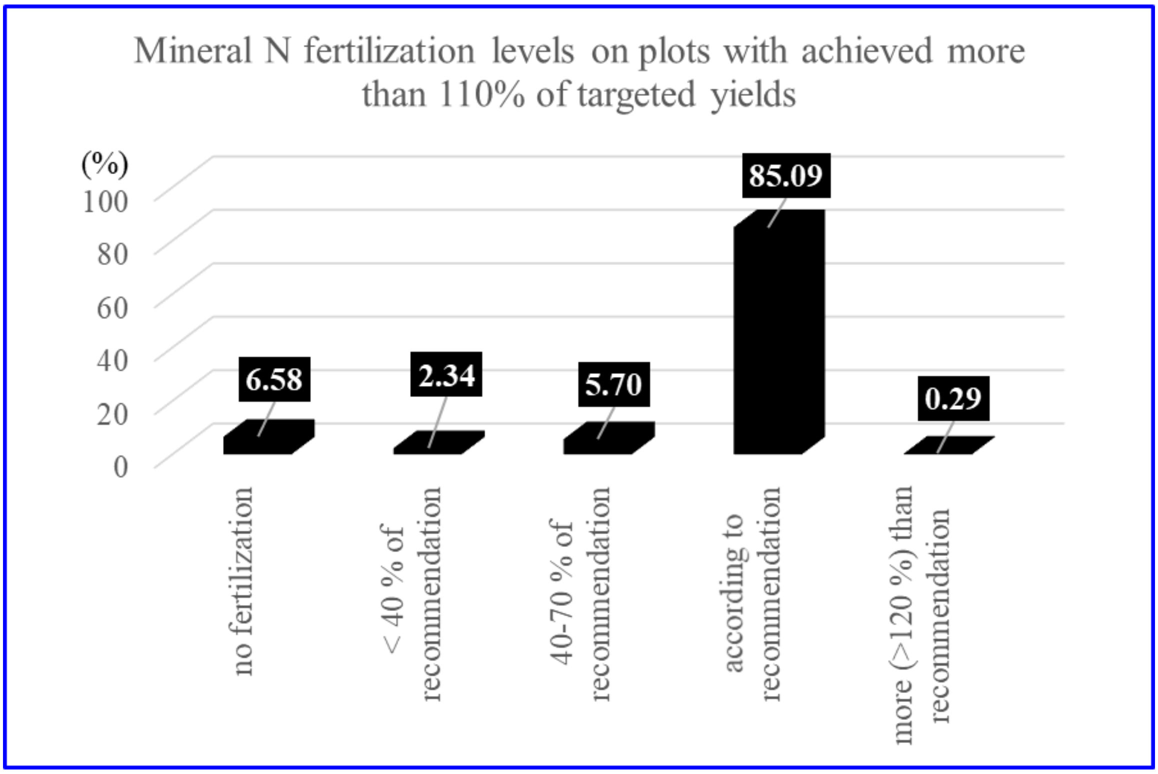
Graph 8. Mineral N fertilization on plots with achieved up to 60% of targeted yields



Graph 9. Mineral N fertilization on plots with achieved 60-90% of targeted yields



Graph 10. Mineral N fertilization on plots with achieved 90-110% of targeted yields



Graph 11. Mineral N fertilization on plots with achieved more than 110% of targeted yields

4.4.1. Soil properties impact on fertilization/yield relations

The relationship between soil properties (SOM, AL-phosphorus and AL-potassium content) and the relationship between applied fertilization and the level of achieved yield was analyzed for plots with complete data on planned yield, achieved yield and applied mineral fertilization (8.257 plots).

4.4.1.1. The lowest yield level (<60% of the target yield)

The lowest level of yield (<60% of the target yield) was achieved on 3.35% of plots with an average content of SOM (2.14%), AL-phosphorus (16.34) and AL-potassium (20.67 mg/100 g) (Graph 12). Fertilization was omitted on some plots (0.36%) with an average SOM content of 1.76% (Table 6), 19.68 mg/100 g of AL-phosphorus (Table 7) and 19.80 mg/100 g AL-potassium (Table 8).

The lowest level of yield was also achieved on a certain number of plots (0.05%) with the highest level of fertilization (>120% recommended) with an average of 3.32% SOM (Table 6), but only 3.15 mg/100 g of phosphorus (Table 7) and 10.05 mg/100 g of potassium (Table 8).

The largest share of areas (1.54%) with the lowest levels of yield was achieved with mineral fertilization according to recommendations with an average content of SOM 1.98%, phosphorus 16.58 mg and potassium 22.7 mg/100 g of soil.

Table 6. SOM content (%) on the plots with different N fertilization level and achieved yields

Level of fertilization with mineral N	Achieved <60% of targeted yield	Achieved 60-90% of targeted yield	Achieved 90-110% of targeted yield	Achieved >110% of targeted yield
No fertilization with mineral N	1.76	2.27	2.12	2.09
Applied mineral N <40% of recommended	2.65	1.99	2.30	2.53
Applied mineral N 40-70% of recommended	2.13	2.15	2.30	1.99
Applied mineral N as recommended	1.98	2.11	2.19	2.12
Applied mineral N >120% of recommended	3.32	2.23	2.22	2.55
Average	2.14	2.14	2.22	2.15

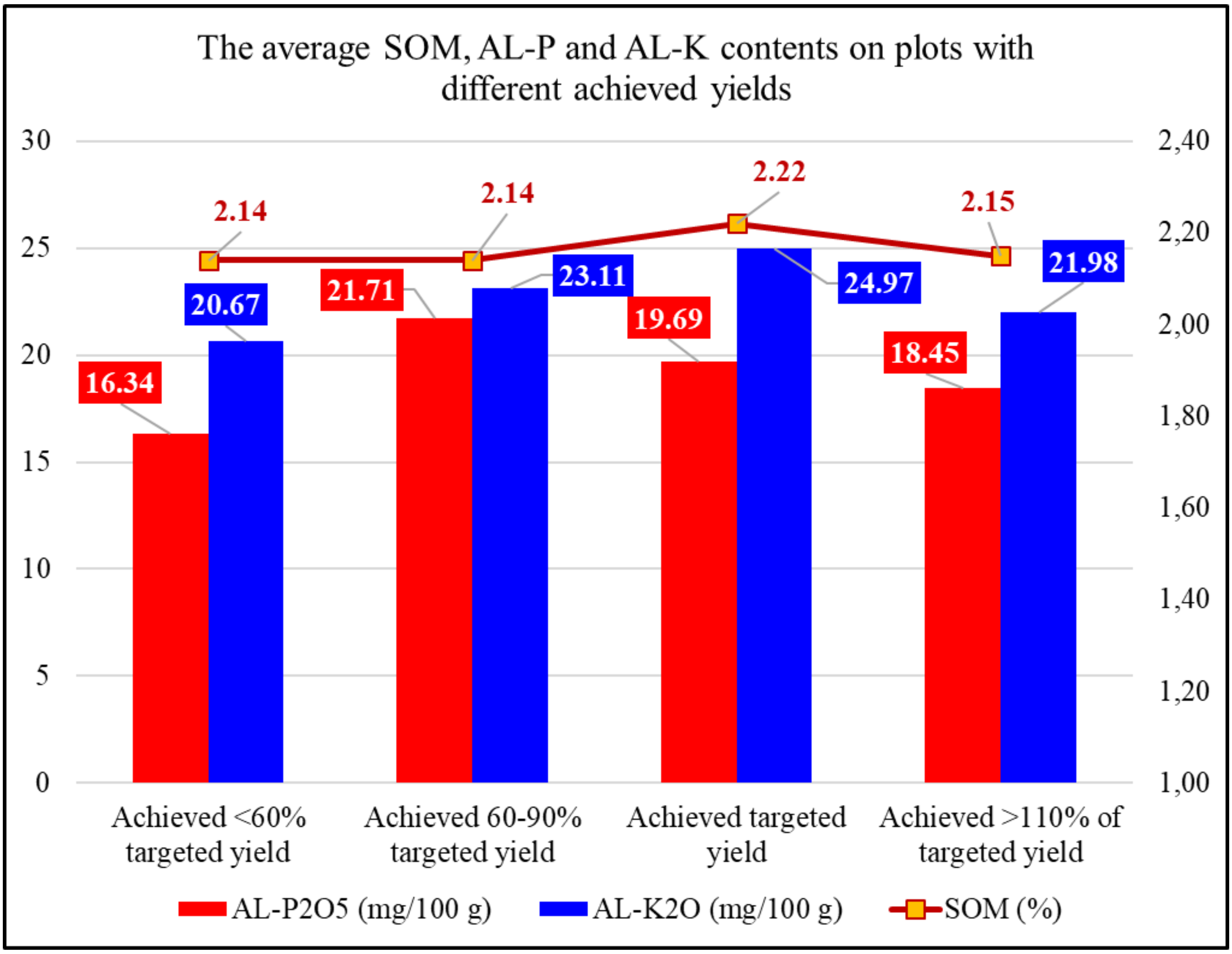
4.4.1.2. Level of reduced yield (60-90% of target yield)

The level of 60-90% of the target yield was achieved in total on 52.21% of plots with complete data. The average SOM content was 2.14%, 21.71 mg/100 g of AL-phosphorus and 23.11 mg/100 g of AL-potassium (Graph 12).

Fertilization was carried out most often on these areas (33.85% of all plots with complete data) according to recommendations, 60-90% of the target yield was achieved with an average content of SOM 2.11% (Table 6), phosphorus 19.52 mg/100 g (Table 7) and potassium 23.20 mg/100 g (Table 8).

Table 7. AL-phosphorus content on the plots with different N fertilization level and achieved yields

Level of fertilization with mineral N	Achieved <60% of targeted yield	Achieved 60-90% of targeted yield	Achieved 90-110% of targeted yield	Achieved >110% of targeted yield
No fertilization with mineral N	19.68	20.91	12.35	17.32
Applied mineral N <40% of recommended	13.48	43.83	19.62	29.37
Applied mineral N 40-70% of recommended	13.52	24.49	18.01	15.38
Applied mineral N as recommended	16.58	19.52	20.15	18.76
Applied mineral N >120% of recommended	3.15	18.14	16.77	18.10
Average	16.34	21.71	19.69	18.45



Graph 12. The averege SOM content, AL-P and AL-K contents on plots with different level of achieved yields

4.4.1.3. Level of achieved yield equal to target yield

The target yield was achieved on 34.65% of the areas with complete data. The highest average content of SOM (2.22 %), and potassium (24.97 mg/100 g), and slightly less phosphorus (19.69 mg/100 g) was found on these plots than on plots with a achieved 60-90 % of the target yield, but more than on the areas with the smallest and highest achieved yields (Graph 12).

The target yield with fertilization according to recommendations was achieved on 25.95% of all areas with complete data, and the share of plots with fertilization according to recommendations and achieved target yield is 80.44% of all plots with achieved target yield. An average of 2.19% SOM (Table 6), 20.15 mg/100 g of phosphorus (Table 7) and 26.57 mg/100 g of potassium (Table 8) was determined on these plots.

Table 8. AL-potassium content on the plots with different N fertilization level and achieved yields

Level of fertilization with mineral N	Achieved <60% of targeted yield	Achieved 60-90% of targeted yield	Achieved 90-110% of targeted yield	Achieved >110% of targeted yield
No fertilization with mineral N	19.80	21.96	21.11	18.97
Applied mineral N <40% of recommended	16.02	22.07	21.22	23.46
Applied mineral N 40-70% of recommended	19.55	23.79	18.72	18.86
Applied mineral N as recommended	22.70	23.20	26.57	22.47
Applied mineral N >120% of recommended	10.05	21.86	23.63	18.40
Average	20.67	23.11	24.97	21.98

5. Discussion

Respondents, i.e. producers who submit a request for soil analysis as part of the mandatory soil fertility control, by filling in the requested query with relevant answers, increase the accuracy of the interpretation of the results of the soil analysis and the quality of advice/recommendations they can receive based on analysis results. Namely, the recommendations for improve and fertilize the soil are the result of a decision support system (DSS), which is more precise with more accurate and complete input data.

The completion of data on the planned crop and the pre-crop (99.59% and 97.56%), indicates that producers are interested in interpreting the results in real production conditions adapted to the planned and previous crop.

As expected, the most represented crops in the planned production are corn, wheat, soybean, oilseed rape, sunflower and sugar beet, which shows that the collected data can be a representative sample of the actual structure of production in the Republic of Croatia.

However, the data on the planned target yield show that producers do not fully perceive their role in collecting data and optimizing fertilization. Namely, the data on the planned yield enables analysts to estimate the realistic target yield based on the results of the soil analysis, and only 69.15% of the producers filled in this data. Also, the possibility of subsequent verification of the reason for the discrepancy between analytical agrochemical results and target yields is also significant. Two possible situations are particularly significant:

1. (too)low target yield with analytical results that do not indicate significant production limitations,
2. high target yield with analytical results that are an indicator of a significant limitation in achieving a high yield (e.g. high soil acidity and/or low SOM content).

In the first case, the possibility of the producer's experiential knowledge that there are production limitations that are not visible from the results of agrochemical soil analysis is also significant, which is significant for the optimization of fertilization, but also for upgrading and validating the DSS model for interpreting the analysis results. However, this kind of repeated communication during data collection requires a better organization of supplementary data collection, sufficient interest of the producer and a better connection between the producer, laboratory, advisory services and IT stakeholders.

Also, in both cases, the analysis can offer the producer precise advice or at least multiple options to choose the best solution according to different criteria, for example to plan a higher yield or to reduce the risk of production by necessarily neutralizing the limiting factors of production.

About half of the producers plan a medium high yield, a quarter a very high yield and a quarter a relatively low yield. This is in accordance with established average soil fertility indicators and with the consequences of soil fertility degradation. A somewhat lower planned yield may be the result of a deliberate reduction of planned investments in fertilization and risks in production on less fertile soils. However, it may also be an indication of producers' unwillingness to neutralize production constraints or to not strive for long-term increases in soil fertility, perhaps not even to maintain existing soil fertility.

The collected data enable a more detailed analysis of the compatibility of potential soil fertility and planned yields, i.e. whether the planned yield on an area is unjustifiably high or low.

Given the high prevalence of corn and wheat in the sowing structure, it is not a big surprise that 10% of the area was sown again with the same crop. However, a more detailed analysis should be done to see if repeated sowing affects soil fertility. In this respect, the collected data are not sufficient because they should be supplemented with crop rotation in all 4 years of the period during which soil analysis is mandatory. Thus, after a repeated analysis, the influence of proper crop rotation or repeated sowing on the maintenance of soil fertility could be verified.

Even fewer producers (63.20 %) entered data on the achieved yield of pre-crops than data of target yield, and these data are very important for the analysis of the success of production, and the justification of planned and implemented fertilization as important segments of production optimization. However, the data collected in this research certainly help in analyzing the success of fertilization from the aspect of soil fertility and achieved yields, as it was determined that the majority of producers (52.2%) achieve a yield of 60-90% of the target yield, 34.64% achieve the target yield, 10% achieve a higher yield than the target yield, and only 3% a very low yield. By analyzing these data together with data on soil fertility and applied mineral and organic fertilization, as well as management of harvest residues, it is possible to achieve the following:

1. Optimize fertilization and the target yield on 52.2% of the area by increasing fertilization if it was insufficient or by reducing the planned yield if this is the reality due to insufficient soil fertility. In the first case, it is necessary to pay attention to the type of fertilizer and the time of application, the proportion and quality of organic fertilizers in fertilization, and the price of mineral and organic fertilizers and their

applications. Also, it is possible that the fertilization was not of sufficient quality even though a sufficient number of nutrients were applied, but the available data collected in this paper are not sufficient for such a detailed analysis. It would be possible to collect the missing data through systematic records of implemented agrotechnical measures instead of one-time data collection, which implies continuous data collection and continuous authorized access of the producer to the system.

2. Determine the reasons for the very low yield on 3% of the area and implement measures to neutralize production limiting factors, especially if the solution is possible by optimizing fertilization or choosing another crop in order to reduce the risk in production.
3. Maintaining a high level of yield on 10% of the area and increasing or at least maintaining the level of yield on 35% of the area with the systematic improvement towards more sustainable, cheaper and more diverse fertilization systems with the aim of maintaining soil fertility, reducing fertilization costs, reducing the use of mineral fertilizers and preserving the environment. The collected data allow finding better solutions in fertilization, although they are limited due to insufficient data on harvest residues and applied organic fertilizers.

The use of organic fertilizers is reduced for the most part to the application of manure, and the use of compost and sideration is negligible. However, even the use of manure is not sufficient, especially from the aspect of soil fertility. Few data were collected, the producers did not provide the necessary data on the amounts of applied manure. The available data enable an analysis of the justification of the application of organic fertilizers on the plots where they were applied, i.e. whether the distribution on the plots could have been more useful considering the available quantities and quality of fertilizers, considering the fertility of the soil and considering the total area and distance of the production plots of individual farms. The data on available quantities and quality of manures was not collected in this research, but can be collected by systematic authorized conection with producers or models based on available data. Data on available plots and plot distances, and for the purpose of calculating the profitability of organic fertilizer application, can be collected from existing databases or directly from the producer.

The collection of data on the management of harvest residues was successful on 62.10% of the plots, although information on the amount of harvest residues is often missing. However, this information can be estimated by modeling based on existing data. The result of these researches in terms of crop residues is modest, because it is possible to say with certainty that only 2.44 t/ha of crop residues are incorporated on 18.4% of the plots.

The collected data imply that the areas with incorporated harvests have a slightly higher content of SOM and phosphorus, but the differences are very small and the data are only available for crop production in season before the collection of samples. In this case, too, continuous data collection is necessary, but by modeling the existing data, it can be estimateed the impact of the current crop residues management on soil fertility.

The analysis of the collected data is particularly useful in terms of the simultaneous analysis of a large number of input data that are more often analyzed individually. For example, it is possible to analyze the impact of all possible combinations of mineral and organic fertilizers, incorporation or removal of crop residues on the yield and maintenance of soil fertility. Thus, in this research, despite incomplete data and a large number of unanswered questions regarding organic fertilization and crop residues, a higher average content of SOM in the soil was determined on plots with incorporating crop residues than with the removal of residues, and also with the use of organic fertilizers.

The largest number of producers, slightly more than three quarters, stated that they carried out fertilization with mineral forms of nutrients according to recommendations. However, the smallest relative share of fertilization according to recommendations is among producers who achieved a very low yield, a significantly higher share among producers who achieved 60-90% of the target yield, even higher among producers who achieved the target yield, and the highest among producers who achieved more than the target yield. These data indicate an undoubted connection between the optimization of fertilization and the achievement of the target yield.

The collected data are the source of a large amount of information that can be generated by creating a model with an emphasis on soil fertility indicators, the required and applied fertilization, and the achieved yield. There is a great potential for expanding the quality and scope of input data, but for this it is necessary to build a more effective system of continuous active connection of producers with a data collection system. It is desirable to conduct research on the motivation and willingness of producers to cooperate in the collection of better-quality data. Considering the large amount of data and possible multi-faceted mutual influences, the analysis of the collected data should certainly, in addition to regression models, be refined by the use of neural network models.

6. Conclusion

The level of cooperation of producers regarding the collection of data on production when submitting requests for soil analysis is satisfactory, but it could be significantly better, especially regarding data on the achieved yield of pre-crops, on the use of organic fertilizers, and on the management of harvest residues.

Data on the target yields that producers want to achieve are very significant because, in combination with the results of agrochemical soil analysis, it is possible to distinguish cases with (too)low target yield with analytical results that do not indicate significant production limitations, and to high target yield with analytical results that are an indicator of a significant limitation in achieving a high yield.

About half of the producers plan a medium high yield, a quarter a very high yield and a quarter a relatively low yield. This is in accordance with established average soil fertility indicators and with the consequences of soil fertility degradation. A somewhat lower planned yield may be the result of a deliberate reduction of planned investments in fertilization and risks in production on less fertile soils. However, it may also be an indication of producers' unwillingness to neutralize production constraints or to not strive for long-term increases in soil fertility, perhaps not even to maintain existing soil fertility.

By analyzing collected data together with data on soil fertility it is possible to optimize fertilization and the target yield on area with insufficient yield by improving fertilization plan, to determine the reasons of the very low yield on some plots and implement measures to neutralize production limiting factors, and to maintain a high yield level of successful production with the systematic improvement towards more sustainable, cheaper and more diverse fertilization systems with the aim of maintaining soil fertility, reducing fertilization costs, reducing the use of mineral fertilizers and preserving the environment.

According to collected data the use of organic fertilizers is not sufficient, but also data on available amounts and quality of manures, other fertilizers, and crop residues management should be more successful collected. A lot of missing data could be predicted by modeling collected data. In this research, despite incomplete data and a large number of unanswered questions regarding organic fertilization and crop residues, a higher average content of SOM in the soil was determined on plots with incorporating crop residues than with the removal of residues, and also with the use of organic fertilizers.

The largest number of producers carried out fertilization with mineral forms of nutrients according to recommendations and collected data indicate an undoubted connection between the optimization of fertilization and the achievement of the target yield. The collected data are the source of a large amount of information that can be generated by creating a model with an emphasis on soil fertility indicators, the required and applied fertilization, and the achieved yield. There is a great potential for expanding the quality and scope of input data, but for this it is necessary to build a more effective system of continuous authorized active connection of producers with a data collection system. It is desirable to conduct research on the motivation and willingness of producers to cooperate in the collection of better-quality data. Considering the large amount of data and possible multi-faceted mutual influences, the analysis of the collected data should certainly, in addition to regression models, be refined by the use of neural network models.

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8. Summary

Soil fertility is the basis of sustainable agriculture. Agricultural producers in the Republic of Croatia are obliged to carry out soil fertility control in an authorized laboratory every 4 years. Control of soil fertility includes mandatory agrochemical analysis and interpretation of soil analysis results. The producer is obliged to provide the authorized laboratory with identification data on the plot for which he requests analyzes within the framework of fertility control. A fertilization plan based on advice or pre-instructions for fertilization is not mandatory, but it is usually an integral part of the report along with the interpretation of the analysis results and is very important for the systematic maintenance of soil fertility. The aim of this paper is to analiyse crowdsource data in arable crops production in Croatia and to desribe the significance in crowdsorucing data in optimizing crops fertilization in Croatia. The crowdsource format in this research was used during 4 year collection data on arable crops growing. There were 4 groups of collected data:

1. data on crops and yields (planed crop, target crop yield, precrop species and precrop yield),
2. fertilization with organic fertilizer (type of fertilizer, amount and year of application);
3. harvest residues (management with harvest residues)
4. mineral fertilization (applied mineral fertilization in relation to the recommended fertilization).

Data were collected in period 2018-2021 year, and in total data within 13,239 requests for soil analysis were collected.

The level of cooperation of producers regarding the collection of data on production when submitting requests for soil analysis is satisfactory, but it could be significantly better, especially regarding data on the achieved yield of pre-crops, on the use of organic fertilizers, and on the management of harvest residues. Data on the target yields that producers want to achieve are very significant because, in combination with the results of agrochemical soil analysis, it is possible to distinguish cases with (too)low target yield with analytical results that do not indicate significant production limitations, and to high target yield with analytical results that are an indicator of a significant limitation in achieving a high yield. About half of the producers plan a medium high yield, a quarter a very high yield and a quarter a relatively low yield. This is in accordance with established average soil fertility indicators and with the consequences of soil fertility degradation. A somewhat lower planned yield may be the result of a deliberate reduction of planned investments in fertilization and risks in production on less fertile soils. However, it may also be an indication of producers' unwillingness to neutralize production constraints or to not strive for long-term increases in soil fertility, perhaps not even to maintain existing soil fertility. By analyzing collected data together with data on soil fertility it is possible to optimize fertilization and the target yield on area with insufficient yield by improving

fertilization plan, to determine the reasons of the very low yield on some plots and implement measures to neutralize production limiting factors, and to maintain a high yield level of successful production with the systematic improvement towards more sustainable, cheaper and more diverse fertilization systems with the aim of maintaining soil fertility, reducing fertilization costs, reducing the use of mineral fertilizers and preserving the environment. According to collected data the use of organic fertilizers is not sufficient, but also data on available amounts and quality of manures, other fertilizers, and crop residues management should be more successful collected. A lot of missing data could be predicted by modeling collected data. In this research, despite incomplete data and a large number of unanswered questions regarding organic fertilization and crop residues, a higher average content of SOM in the soil was determined on plots with incorporating crop residues than with the removal of residues, and also with the use of organic fertilizers. The largest number of producers carried out fertilization with mineral forms of nutrients according to recommendations and collected data indicate an undoubted connection between the optimization of fertilization and the achievement of the target yield. The collected data are the source of a large amount of information that can be generated by creating a model with an emphasis on soil fertility indicators, the required and applied fertilization, and the achieved yield. There is a great potential for expanding the quality and scope of input data, but for this it is necessary to build a more effective system of continuous authorized active connection of producers with a data collection system. It is desirable to conduct research on the motivation and willingness of producers to cooperate in the collection of better-quality data. Considering the large amount of data and possible multi-faceted mutual influences, the analysis of the collected data should certainly, in addition to regression models, be refined by the use of neural network models.

9. Sažetak

Plodnost tla temelj je održive poljoprivrede i proizvođači u Republici Hrvatskoj dužni su svake 4 godine provoditi kontrolu plodnosti tla u ovlaštenom laboratoriju. Kontrola plodnosti tla uključuje obveznu agrokemijsku analizu i interpretaciju rezultata analize tla. Proizvođač je dužan ovlaštenom laboratoriju dostaviti identifikacijske podatke o parceli za koju traži analize u okviru kontrole plodnosti. Plan gnojidbe temeljen na savjetima ili preporukama za gnojidbu nije obvezan, ali je obično sastavni dio izvješća uz interpretaciju rezultata analize i vrlo je važan za sustavno održavanje plodnosti tla. Cilj ovog rada je analizirati *crowdsource* podatke u proizvodnji ratarskih usjeva u Hrvatskoj te opisati značaj tih podataka u optimizaciji gnojidbe usjeva u Hrvatskoj. *Crowdsource* format u ovom istraživanju korišten je tijekom 4 godine prikupljanja podataka o uzgoju ratarskih kultura. Postojale su 4 skupine prikupljenih podataka:
1. podatci o usjevima i prinosima (planirani usjev, ciljani prinos, vrsta i prinos predusjeva),
2. gnojidba organskim gnojivom (vrsta gnojiva, količina i godina primjene);
3. žetveni ostaci (upravljanje žetvenim ostacima)
4. mineralna gnojidba (primijenjena mineralna gnojidba u odnosu na preporučenu gnojidbu).
Podaci su prikupljani u razdoblju 2018.-2021. godine, a ukupno su prikupljeni podaci u okviru 13.239 zahtjeva za analizu tla.

Razina suradnje proizvođača u prikupljanju podataka o proizvodnji prilikom podnošenja zahtjeva za analizu tla je zadovoljavajuća, ali bi mogla biti znatno bolja, posebno u pogledu podataka o ostvarenim prinosima predusjeva, o korištenju organskih gnojiva, te gospodarenju žetvenim ostacima. Podaci o ciljanim prinosima koje proizvođači žele postići vrlo su značajni jer je u kombinaciji s rezultatima agrokemijske analize tla moguće razlikovati slučajeve s (pre)niskim ciljanim prinosima s analitičkim rezultatima koji ne ukazuju na značajna ograničenja proizvodnje, te do visokog ciljanog prinosa s analitičkim rezultatima koji su pokazatelj značajnog ograničenja u postizanju visokog prinosa. Otprilike polovica proizvođača planira srednje visok prinos, četvrtina vrlo visok prinos i četvrtina relativno nizak prinos. To je u skladu s utvrđenim prosječnim pokazateljima plodnosti tla i posljedicama degradacije plodnosti tla. Nešto manji planirani prinos može biti posljedica namjernog smanjenja planiranih ulaganja u gnojidbu i rizika u proizvodnji na manje plodnim tlima. Međutim, to također može biti pokazatelj nespremnosti proizvođača da neutraliziraju ograničenja proizvodnje ili da ne teže dugoročnom povećanju plodnosti tla, možda čak ni da održe postojeću plodnost tla. Analizom prikupljenih podataka zajedno s podacima o plodnosti tla moguće je poboljšanjem plana gnojidbe optimizirati gnojidbu i ciljani prinos na površini sa sniženim prinosom, utvrditi

razloge vrlo niskog prinosa na pojedinim parcelama te provesti mjere za neutralizaciju ograničavajućih čimbenika proizvodnje, te održati visoku razinu prinosa uspješne proizvodnje uz sustavno unapređenje prema održivijim, jeftinijim i raznovrsnijim sustavima gnojidbe s ciljem održavanja plodnosti tla, smanjenja troškova gnojidbe, smanjenja upotrebe mineralnih gnojiva i očuvanja okoliša. Prema prikupljenim podacima korištenje organskih gnojiva nije dostatno, ali treba uspješnije prikupljati i podatke o raspoloživim količinama i kvaliteti stajskih i ostalih gnojiva, te zbrinjavanju žetvenih ostataka. Mnogi podaci koji nedostaju mogu se predvidjeti modeliranjem prikupljenih podataka. U ovom istraživanju, unatoč nepotpunim podacima i velikom broju neodgovorenih pitanja vezanih uz organsku gnojidbu i žetvene ostatke, utvrđen je viši prosječni sadržaj SOM u tlu na parcelama s unošenjem žetvenih ostataka nego kod uklanjanja ostataka, a također i kod uporabe organskih gnojiva. Najveći broj proizvođača izvršio je gnojidbu mineralnim oblicima hraniva prema preporukama, a prikupljeni podaci ukazuju na nedvojbenu povezanost optimizacije gnojidbe s postizanjem ciljanog prinosa. Prikupljeni podaci izvor su velikog broja informacija koje se mogu generirati izradom modela s naglaskom na pokazatelje plodnosti tla, potrebnu i primijenjenu gnojidbu te ostvareni prinos. Postoji veliki potencijal za proširenje kvalitete i opsega ulaznih podataka, no za to je potrebno izgraditi učinkovitiji sustav kontinuirane ovlaštene aktivne povezanosti proizvođača sa sustavom prikupljanja podataka. Poželjno je provesti istraživanje o motiviranosti i spremnosti proizvođača na suradnju u prikupljanju što kvalitetnijih podataka. S obzirom na veliku količinu podataka i moguće višestrane međusobne utjecaje, analizu prikupljenih podataka svakako bi, uz regresijske modele, trebalo doraditi i korištenjem modela neuronskih mreža.

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BASIC DOCUMENTATION CARD

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The potential of crowd-sourced data for optimizing the fertilization of field crops in Croatia

Ana Šunić

Abstract:
The aim of this paper is to analiyse crowdsource data in arable crops production in Croatia and to desribe the significance in crowdsorucing data in optimizing crops fertilization. The crowdsource format in this research was used during 4 year collection data on arable crops growing with 4 groups of collected data:
1. data on crops and yields, 2. fertilization with organic fertilizer, 3. harvest residues, 4. mineral fertilization. In total, data of 13,239 requests for soil analysis during 2018-2021 were collected. The level of cooperation of producers regarding the collection of data on production when submitting requests for soil analysis is satisfactory, but it could be significantly better, especially regarding data on the achieved yield of pre-crops, on the use of organic fertilizers, and on the management of harvest residues. About half of the producers plan a medium high yield, a quarter a very high yield and a quarter a relatively low yield. This is in accordance with established average soil fertility indicators and with the consequences of soil fertility degradation. By analyzing collected data together with data on soil fertility it is possible to optimize fertilization and the target yield on area with insufficient yield by improving fertilization plan, to determine the reasons of the very low yield on some plots and implement measures to neutralize production limiting factors, and to maintain a high yield level of successful production with the systematic improvement towards more sustainable, cheaper and more diverse fertilization. According to collected data the use of organic fertilizers is not sufficient, but also data on available amounts and quality of manures, other fertilizers, and crop residues management should be more successful collected. The largest number of producers carried out fertilization according to recommendations and collected data indicate an undoubted connection between the fertilization and the achievement of the target yield. There is a great potential for expanding the quality and scope of input data, it is necessary to build a more effective system of continuous authorized active connection of producers with a data collection system. It is desirable to conduct research on the motivation and willingness of producers to cooperate in the collection of better-quality data. Considering the large amount of data and possible multi-faceted mutual influences, the analysis of the collected data should certainly, in addition to regression models, be refined by the use of neural network models.

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Potencijal *crowed-sourcingom* prikupljenih podataka za optimiziranje gnojidbe ratarskih usjeva u Hrvatskoj

Ana Šunić

Sažetak:
Cilj ovog rada je analizirati *crowdsource* podatke u proizvodnji ratarskih usjeva u Hrvatskoj te opisati značaj u optimizaciji gnojidbe usjeva. *Crowdsource* format u ovom istraživanju korišten je tijekom 4 godine prikupljanja podataka o uzgoju ratarskih kultura s 4 skupine prikupljenih podataka: 1. podaci o usjevima i prinosima, 2. gnojidba organskim gnojivima, 3. žetveni ostaci, 4. mineralna gnojidba. Ukupno su prikupljeni podaci od 13.239 zahtjeva za analizu tla tijekom 2018.-2021. Razina suradnje proizvođača u prikupljanju podataka o proizvodnji prilikom podnošenja zahtjeva za analizu tla je zadovoljavajuća, ali bi mogla biti znatno bolja, posebno u pogledu podataka o ostvarenim prinosima predusjeva, o korištenju organskih gnojiva, te gospodarenju žetvenim ostacima. Otprilike polovica proizvođača planira srednje visok prinos, četvrtina vrlo visok prinos i četvrtina relativno nizak prinos. To je u skladu s utvrđenim prosječnim pokazateljima i posljedicama degradacije plodnosti tla. Analizom prikupljenih podataka zajedno s podacima o plodnosti tla moguće je optimizirati gnojidbu i ciljni prinos na oranicama s niskim prinosom, utvrditi razloge vrlo niskog prinosa na pojedinim parcelama i provesti mjere za neutralizaciju ograničavajućih čimbenika proizvodnje, te održati visoku razinu prinosa uspješne proizvodnje uz sustavno unapređenje prema održivijoj, jeftinijoj i raznovrsnijoj gnojidbi.
Prema prikupljenim podacima korištenje organskih gnojiva nije dovoljno, ali treba kvalitetnije prikupljati podatke o raspoloživim količinama i kvaliteti stajskog i ostalih gnojiva, te zbrinjavanju žetvenih ostataka. Najveći broj proizvođača provodi gnojidbu prema preporukama, a prikupljeni podaci ukazuju na nedvojbenu povezanost gnojidbe s ostvarenjem ciljanog prinosa. Postoji veliki potencijal za proširenje kvalitete i opsega ulaznih podataka, potrebno je izgraditi učinkovitiji sustav kontinuirane ovlaštene aktivne povezanosti proizvođača sa sustavom prikupljanja podataka. Poželjno je provesti istraživanje o motiviranosti i spremnosti proizvođača na suradnju u prikupljanju podataka. S obzirom na veliku količinu podataka i moguće višestrane međusobne utjecaje, analizu prikupljenih podataka svakako bi, uz regresijske modele, trebalo doraditi i korištenjem modela neuronskih mreža.

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