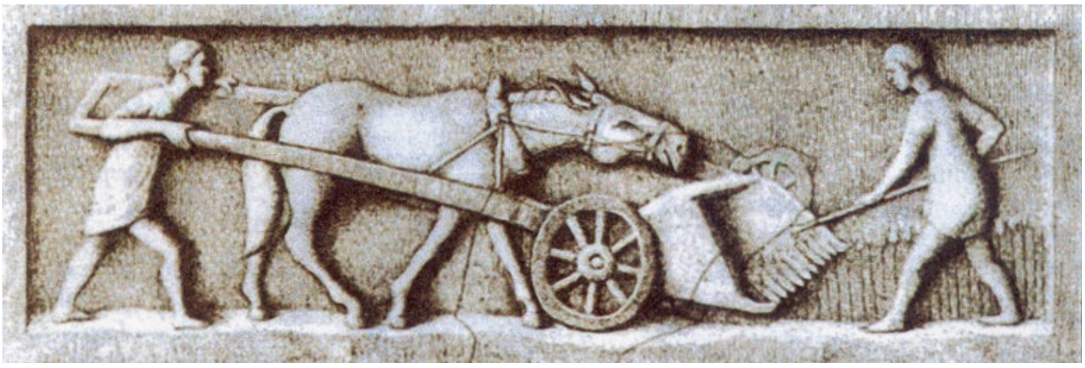
Volume 11, Number 1 (2024)

Columella

Journal of Agricultural and Environmental Sciences



HUNGARIAN UNIVERSITY OF
AGRICULTURE AND LIFE SCIENCES
Gödöllő

Columella

Journal of Agricultural and Environmental Sciences

This peer reviewed journal of Szent István Campus of the Hungarian University of Agriculture and Life Sciences, Gödöllő, Hungary publishes papers in the English language.

Technical assistance is provided by the respective Scientific Committees of the Hungarian Academy of Sciences

The journal is published in yearly volumes of two issues annually.

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E-mail: columella@uni-mate.hu

HU ISSN 2064-7816 (print)
HU ISSN 2064-9479 (online)
DOI: 10.18380/

Printed in Gödöllő, Hungary
Printed by MATE Egyetemi Szolgáltató Nonprofit Kft.
HU-2100 Gödöllő, Páter Károly utca 1.
Director: Ivett GADANECZ

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Journal of Agricultural and Environmental Sciences

Volume 10. Number 2 (2023)

HU ISSN 2064-7816 (print)
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Szent István Campus, Gödöllő
HUNGARY

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Spatio-temporal decision uncertainty of selected soil physical parameters can enhance variable rate irrigation

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Abstract: The effectiveness of crop irrigation via sprinkler systems could be improved by environmental variability inherent to field conditions, thus leading to the sub-optimal irrigation of certain sections. To rectify this discrepancy, in-situ soil characteristics were methodically correlated with the region's hydrological circumstances and root zone, assigning a distinct level of uncertainty to each decision point. A stochastic geodatabase was then generated, offering prospective applications in precision agriculture. The experimental agricultural field in Nyírbátor, Hungary, served as the reference point, with the constraints posed by variability being surmounted through a dual-layer iteration of random sampling structures employing the sequential Gaussian simulation (SGS) method. For this purpose, 25 physical, 9 chemical, and 11 soil microelements were examined from samples extracted from 105 boreholes in an 85-hectare cornfield while adopting a regular sampling scheme within a 100 x 100 m grid. Each soil parameter estimation underwent the following process: 1. Organization of data and application of exploratory statistics for outlier identification; 2. Normal score transformation; 3. Exploratory variography; 4. Sequential Gaussian simulations, leading to the construction of a series of plausible, equally probable realizations; 5. Computation of medians and the 95% confidence intervals. These methodologies were deployed concerning the soil characteristics, with porosity being selected as the representative soil parameter for the Nyírbátor cornfield. Porosity was our focus physical parameter because the micro and macro soil structures greatly influence the hydraulic characteristics of the soil such as water infiltration, hydraulic conductivity and moisture retention. Comparative assessments of the Hydrus 3D hydrological models of kriged and sequential Gaussian simulation surfaces were conducted. Results highlighted the efficacy of sequential Gaussian simulation in encapsulating the field's heterogeneity, and the accompanying uncertainty served as a decision-making tool in the diversified water application across the field. The results were validated using field data observations of soil moisture in the corn field from 2020 and 2021 respectively and nonetheless, the uncertainty divergence between the Hydrus outputs unveiled the knowledge deficit concerning actual spatial patterns of soil porosity. The established workflow offers a cost-efficient dynamic methodology for water resource management, potentially curtailing overall irrigation expenditure by variably applying water to parcels based on uncertainty estimates.

Keywords: Spatio-temporal decision uncertainty, Sequential Gaussian simulation, cost-effective irrigation

Received 2 October 2023, Revised 2 May 2024, Accepted 2 May 2024

Introduction

Water application through irrigation enhances crop productivity and contributes significantly to the water balance of agricultural fields. One of the most significant limitations that reduces the efficiency of water applicators such as sprinkler heads is the presence of field variability that leads to some subareas being over or under-irrigated. Temporal variability in this context is caused by the type of irrigation device used, Spatial variability is attributed to the type of crop grown and soil in the farming unit, making it challenging to schedule uniform water distribution. The varying magnitudes of the existing physical properties create uncertainties across the entire agricultural fields and thus managing water resources in precision farming is paramount, for the right amount of water at the targeted spot and time. Several strategies of irrigation based on soil moisture balance modelling and soil moisture content sensing have been greatly used in scheduling variable rate irrigation to improve water use efficiencies (Li et al., 2018; Sui et al., 2015), as well as enabling the monitoring of water fluctuations within the soil profile (Zhao et al., 2018). Current soil water balance methods heavily rely on meteorological weather station data to forecast available soil moisture, making them cheaper and are highly preferred and used methods in precision irrigation (Sui & Vories, 2020). Other physical models in relation to sprinkler applicators focus on improving water distribution patterns, based on shape and nozzle size to improve applicator efficiencies (Borges Júnior & Andrade, 2021; Hua et al., 2022). The use of various static and real- time datasets in precise water applications can contribute to the efficiency of agricultural decisions, with several model-based irrigation methods being used for scheduling irrigation (Bwambale et al., 2023).

Soil physical and chemical properties are among the factors greatly attributed to spatial field variabilities, hindering the successful automation of water application by irrigation applicators. However certain soil properties possess specific spatial autocorrelations with a distribution over space whose heterogeneity can be estimated (Nyengere et al., 2023). Investigating spatial patterns for the soil parameters is vital in modeling environmental processes and sustainable agricultural production regarding specific soil and water management (Quigley et al., 2018), but our limited ability to observe environmental parameters requires incorporating a specific degree of uncertainty for each decision to be completed (Bi et al., 2023). Since our possibility to observe nature entirely is impossible, the observations can be considered representative only to a limited extent and beyond this extent, every determined value is just an assumption. This assumption is established using optimal spatial estimates, such as some interpolated surfaces of the input parameter. The spatial estimation of specific soil properties, such as porosity, can be vital for identifying field parcels that require greater attention and management. Soil porosity plays a pivotal role in water conduction, air circulation and as such, directly influences the hydraulic characteristics of soil such as moisture retention, infiltration, and hydraulic conductivity (Indoria et al., 2017).

Applying geostatistical techniques can be useful in predicting and interpreting the variables of given parameters at unsampled points, whose map outputs can then be used for decision-making (Faechner et al., 2000). The most applied complex environmental and numerical models typically ignore the input dataset's uncertainty; instead, they have a built-in function. These interpolation techniques consider spatial correlations between observed values as of great importance in predicting values at unsampled points (exact interpolators), and as such, small values are overestimated and large values are under-estimated due to the ignorance of the estimated statistics of the values (Deutsch & Journel, 1992). This reduces the certainty for concrete decision-making due to the blurred variability and spatial patterns generated by these models.

These limitations in this study are overcome using a two-level iteration of randomized sampling structures using the sequential Gaussian simulation to reproduce the sample value statistics and show the spatial continuity of the data (Deutsch & Journel, 1992; Rossi et al., 1993). Our project uses a stochastic modeling approach to estimate the uncertainty of selected soil parameters over space. The uncertainty meant assuming measured values of soil parameters to differ from reality (actual realizations). Specifically, the study aimed at (i) analyzing the spatial variability of selected soil physical properties that directly affect soil water retention on a commercial agricultural field, and (ii) improve automatized irrigation efficiency through site specific interventions based on uncertainty. As an example to demonstrate the cruciality of uncertainty in irrigation, this study based on the model of soil moisture and water fluxes in a maize field to further improve the optimization of irrigation (Magyar et al., 2023).

Materials and Methods

The experimental study area

The experimental field is situated in the alluvial cone plains of the North-Western part of Hungary (Fig 1). Sandy loam soils are the dominant soil type, with corn grown extensively for dairy feeding. Along the middle field, boundaries are delineated by asphalt roads, with an irrigation channel filled with treated wastewater from the animal farms. The groundwater table is about 2.5 m deep, and the horizontal fragmentation of the landscape is low due to melioration and drainage activities performed in the previous century. On the hottest summer days, the maximum temperature can exceed 34 °C, and about 350–360 mm of rainfall is received in the summer half of the year. The region's climate suits slightly heat-sensitive and water-intensive agricultural crop production. Thus, a Reinke 2060 PL sprinkler linear irrigation system is installed to supplement water requirements to crops during water scarcity periods as recommended by Tamás et al. (2018) within the WATERAGRI project framework.

Data Collection

Spatially referenced data, such as soil field perimeters, were meticulously extracted using ArcGIS Pro software, a highly advanced and widely utilized geospatial processing program. Coordinates were determined using real time kinematic global positioning system (RTK-GPS), which offers centimeter-level precision in positioning, significantly enhancing the accuracy of data collection (Sun et al., 2010).

Soil samples were procured from 105 designated locations across an extensive 85-hectare irrigated maize field. This sampling was performed at two distinct strata, precisely at 30 cm and 60 cm depths, adhering to a systematic sampling design arranged in a 100 m-by-100 m grid (Fig 1). This regular grid-based sampling was employed to ensure homogeneity in the data collection process, thereby minimizing the introduction of sampling bias and allowing a representative understanding of the spatial variability within the field. Furthermore, the selected grid size helped to obtain an optimal distribution and patterns of soil properties without losing significant information (Soulis, 2013). In each location, soil samples were collected from five distinct soil horizons, delineated by depth: 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm and analyzed for their respective physical and chemical properties. This stratified approach to sampling ensured comprehensive coverage of the soil profile, allowing for the elucidation of patterns and trends in soil properties across different depths, each of which may exert different influences on water and nutrient dynamics and, consequently, on crop productivity.

The array of the geodatabase associated with the experimental field encompassed a broad range of the soil's physical and chemical parameters as depicted in Fig 2. These parameters offered valuable insights into the inherent and derived properties of the soil, influencing critical factors such as water holding capacity, nutrient availability, and soil

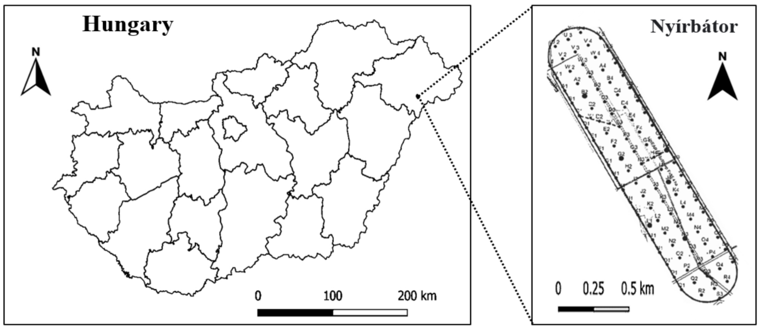

Figure 1: Map showing the location of the experimental site in Nyírbátor, Hungary.

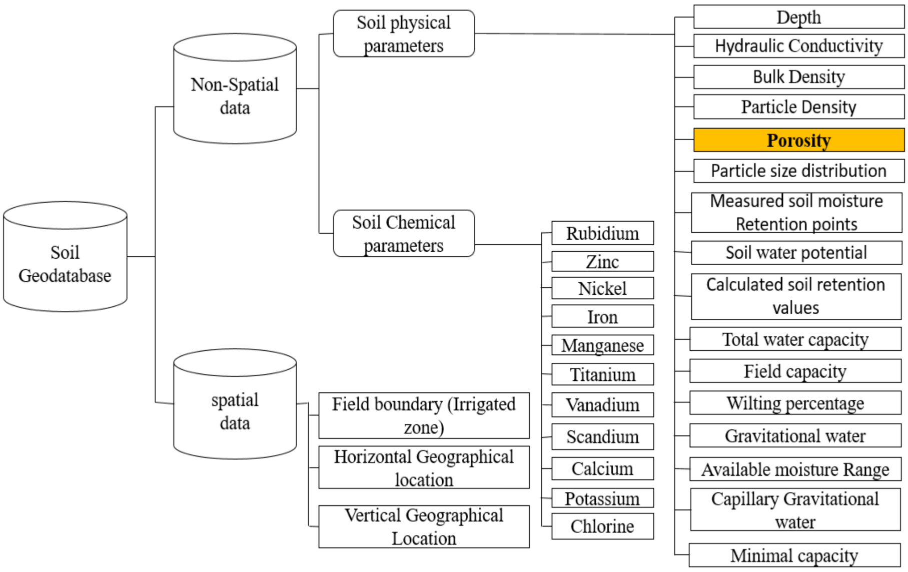

Figure 2: Geodatabase of the Nyírbátor cornfield.

structure, all of which are critical determinants of crop growth and productivity. The extensive geodatabase, a comprehensive and integrated repository of geographically referenced data, was constructed incorporating these crucial soil parameters. This incorporation was achieved via a systematic collation and assimilation process, ensuring accurate alignment of the non-spatial data with the corresponding spatial data. The geodatabase was seamlessly integrated into the Geographic Information System (GIS) project, a powerful toolset for manipulating, analyzing, and displaying geospatial data. Integrating the geodatabase within the GIS environment facilitated an efficient framework for storing and retrieving diverse soil-related data (Kabolizadeh et al., 2023). This framework provided a robust platform for the rigorous analysis of these multi-dimensional datasets, enabling extracting meaningful patterns, relationships, and trends. Furthermore, it served as a sophisticated tool for interpreting the data, allowing the translation of raw data into actionable information and knowledge. This dynamic amalgamation of non-spatial data into a GIS project allows for a more comprehensive and granular understanding of the complex interactions and relationships between various soil properties and their influence on agricultural practices and outcomes.

Sequential Gaussian simulation

This manuscript has an abridged exposition of the employed model features, with Deutsch and Journel (1992) and Goovaerts (1997) providing more expansive elucidations. For this investigation, point source soil data were enlisted, and soil porosity was selected as the demonstration variable, denoted as P at disparate locations symbolized as y.

The key to successful irrigation nests on having an in-depth knowledge of the micro and macro soil structure as this greatly influences the movement of water in the soil. Topsoil for many soil types is usually unsaturated and thus an investigation of its voidness is usually vital for water management and assessing the hydraulic behaviors within the soil (Wang et al., 2023).

The multivariate distribution of $P(y)$ at a specified count (n) of locales is articulated as $y1, y2, y3...yn$ and can be represented via the function:

$$[f(y1\ldots,yn;p1,\ldots,pn)] \tag{1}$$

Equation (1) can subsequently be expanded into the product of its location-specific (n) univariate conditional distributions:

$$\begin{aligned}&f(y1,\ldots,yn;p1,\ldots,pn) = f(y1;p1)xf(y2;p2|\\&P(y1) = p1)x\ldots f(yn;pn|\\&P(yt) = Pt, t = 1,\ldots,n-1)\end{aligned} \tag{2}$$

For instance, the probability distribution of porosity at the second location, $P(y2)$, assuming the porosity value at the first location $P(y1)$ to be $p1$, is depicted as $f(y2;p2P(y1) = p1)$. A random sequence of the prior univariate conditions generates a realization of $P(y)$, indicated as $p(y)$, thus establishing novel conditions for the porosity samples. The algorithm uses the distribution $f(y1;p1)$ to randomly select a realization, $y1$, to represent $P(y1)$. This process is iteratively executed until the final distribution, $f(yn;pnP(yt) = Pt, t = 1\ldots,n-1)$, is conditioned, with the final realization, pn, randomly extracted from the conditional distribution.

The execution of the sequential Gaussian algorithm was achieved by adhering to the following procedural steps (Deutsch & Journel, 1992):

1. The initial dataset representing soil porosity was subjected to a normal score transformation. This step, a form of data standardization, aimed to convert the original, irregularly distributed porosity data into a normalized dataset, consequently facilitating subsequent stages of analysis.
2. Subsequently, a grid was superimposed onto the transformed data points. This grid establishment step acted as a preparatory phase for the spatial analysis, providing a structured format that enabled the accurate and precise localization of data points.
3. Grid nodes, marking the intersections of grid lines, were systematically identified, and subjected to a simple kriging estimation procedure. Simple kriging is a geostatistical method, leveraged spatial autocorrelation within the data to provide an unbiased estimation of values at unsampled grid nodes.
4. The local probability distribution at each node was defined by utilizing the expected values and the kriging variances. This step allowed the assignment of a distribution to each grid node, providing a probabilistic understanding of the soil porosity at each location.
5. The algorithm then randomly selected values from these defined probability distributions to be assigned as the grid node values. This stochastic process ensured that the assigned values appropriately reflected the inherent variability and uncertainty within the dataset.
6. The entire procedure was iteratively

carried out for all the grid nodes. This exhaustive approach ensured that the complete spatial extent of the field was covered, producing a comprehensive spatial representation of soil porosity.

After completing these steps, multiple equally probable spatial distributions of porosity $P(y)$ were generated. These distributions, also known as stochastic images or realizations, represented varying potential states of soil porosity across the field, reflecting this soil property's inherent spatial variability and uncertainty (Fig 3).

Results and discussion

The inaugural step in the data analysis process was ascertaining the vertical distribution and the associated probability of porosity data throughout the soil profile (Fig 4). The process aimed to comprehend the changes in porosity values with increasing depth, thereby providing a vertical profile of soil porosity. An assessment of median porosity values at the 60 cm depth reveals a symmetrical distribution pattern (Fig 4b). This symmetrical dispersion signifies a central tendency in the dataset, where the bulk of the data points clusters around the median, demonstrating the relatively homogeneous nature of soil porosity at this depth.

Further scrutiny reveals the mean porosity value at 30 cm depth to be approximately 38.46%, while the same at 60 cm is marginally lower at 38.3%. A detailed examination of these values and the corresponding graphs insinuates a high probability that most porosity values cluster around 38.3% at the 60 cm depth. This indication of a potential central tendency reinforces the understanding of soil porosity distribution at this depth. Additionally, the insignificant standard deviation associated with the porosity values at the 60 cm depth suggests a high degree of consistency within the dataset. This implies that 95% of the porosity values are expected to lie within the $38.3 \pm 2.9\%$ range. This calculated range encapsulates the spread of porosity values around the mean, thereby providing a measure of the data variability and offering further insights into the overall uncertainty of the soil porosity distribution.

The spatial continuity of soil porosity was examined by applying semi variograms, which were utilized to visually represent the variation of the soil parameter across the spatial extent of the field (Fig 5). This geostatistical analysis method facilitated identifying trends in spatial continuity in specific orientations.

A substantial degree of spatial continuity in soil porosity was discerned, extending in the northeastern and northwestern direction of the field at 60cm and 30 cm depth respectively. Conversely, a markedly smaller degree of continuity was detected in the southwestern direction at 60 cm and at 30 cm depth stretching from west to the eastern direction of the field. These distinct patterns of spatial continuity reflect the impact of anthropogenic factors that have influenced soil characteristics and the resultant spatial distribution of higher porosity values throughout the field. In areas exhibiting high soil porosity, it was inferred that the water demand would likely be elevated due to highly porous soils' reduced moisture retention capacity. This information provides invaluable insights for effectively managing water resources during irrigation. Specifically, it allows for identifying areas necessitating more frequent or higher volumes of water application, facilitating a targeted approach in irrigation management that accommodates the spatial variability in soil porosity.

Figure 6 presents a spatial autocorrelation analysis of the simulated porosity values. The x-axis of this figure represents the distance separating individual sample points. At the same time, the y-axis denotes the semi variance, a metric quantifying the degree of

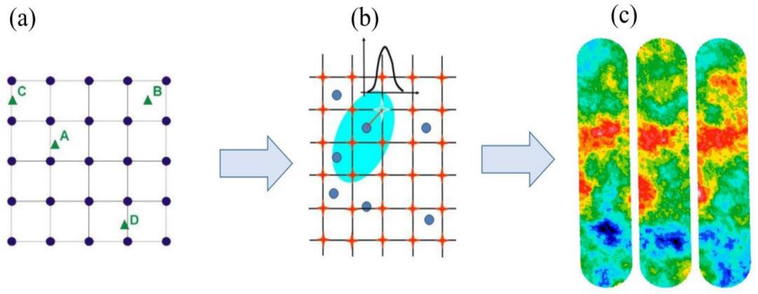

Figure 3: Simulation Workflow: Grid nodes and sample points (a); the local probability distributions at each node (b) and the Resultant 100 Equally Probable Realizations (c).

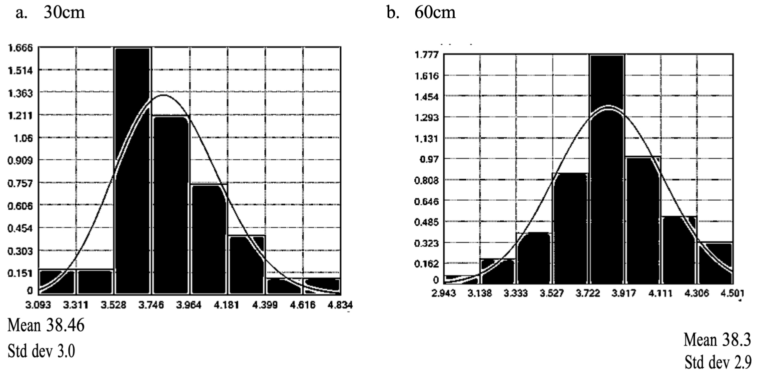

Figure 4: Porosity realizations at 30 cm and 60 cm depth.

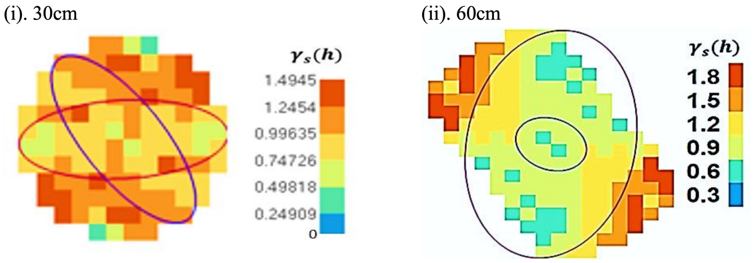

Figure 5: Semi variogram map showing spatial continuity of soil porosity at 30 cm and 60 cm depth.

spatial dependency between pairs of porosity samples. This analysis provides an additional layer of understanding regarding the spatial structure of soil porosity across the field, further contributing to the optimization of water management strategies.

In Figure 6. (a) and (b) respectively, an examination of soil porosity at a lag distance of 240 m and 668.3 m reveals the cessation of spatial autocorrelation amongst soil porosity values. Correspondingly, there is a termination of the increase in semi variance observed at these distances. This cessation signifies that beyond these distances, the spatial

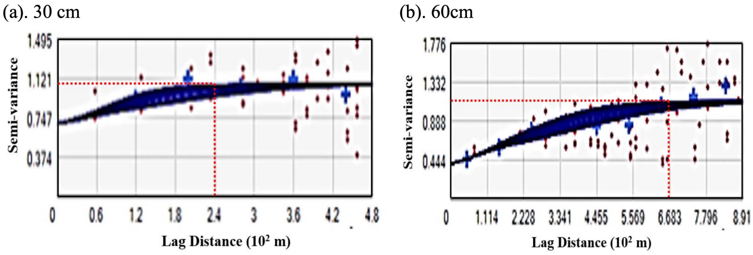

Figure 6: Spatial autocorrelation of soil porosity values at 30 cm and 60cm depth.

distribution of soil porosity values no longer exhibits the pattern of correlation previously observed closer to the surface. This pattern, characterized by a high degree of spatial autocorrelation amongst nearby points, signifies that the soil porosity values are more similar at shorter distances than at greater separations. Thus, observations positioned closer to each other exhibit a lower semi variance, indicating a higher correlation, as compared to the semi variance and correlation of more distantly positioned observations.

This trend, evidenced by the leveling of the semi variance, informs us that the spatial continuity of soil porosity observed at the shallower depth ceases at 240 m and 668.3 m distance within the agricultural field at 30 cm and 60 cm depth respectively. This critical observation can significantly inform water management strategies, particularly in determining the depth, distance and intervals at which irrigation is most effective, considering the variable porosity and spatial distribution.

Comparison of alternative porosity estimations

A comprehensive series of one hundred simulations for porosity values as well as other physical and chemical parameters within the constructed geodatabase were undertaken, encompassing an extensive spatial area of 850 m × 1000 m, equivalent to 85 Ha for all the variables. This simulation suite involved assigning values and normal scores to several nodes within the designated grid, each of which was subjected to an intricate simulation process. The grid node simulation was performed using the simple kriging interpolation method coupled with applying anisotropic semi variograms. This technique enabled the systematic calculation and projection of porosity data across the grid based on known data points, accounting for anisotropy or the directional dependence of spatial continuity.

Each of these simulated realizations possesses an equal probability of occurrence and a high degree of likelihood. As such, the mean of the values at each grid node from all simulations, termed E-type estimations (ensemble average mapping), was calculated to provide a comprehensive spatial representation of the porosity data and all other parameters (Fig 7). These E-type estimations are consolidated outcomes of the multiple probable simulations and provide a spatially averaged overview of soil porosity across the field. The resultant E-type estimations divulge the spatial configuration of the mean for all the 100 equiprobable simulations, offering a graphical representation on the maps. These maps provide invaluable insights into the spatial variation of soil porosity across the field, facilitating the implementation of site-specific farm management decisions (Faechner et al., 2000). This precise and comprehensive overview of spatial patterns can aid in optimizing irrigation strategies, considering the spatial variability of soil porosity.

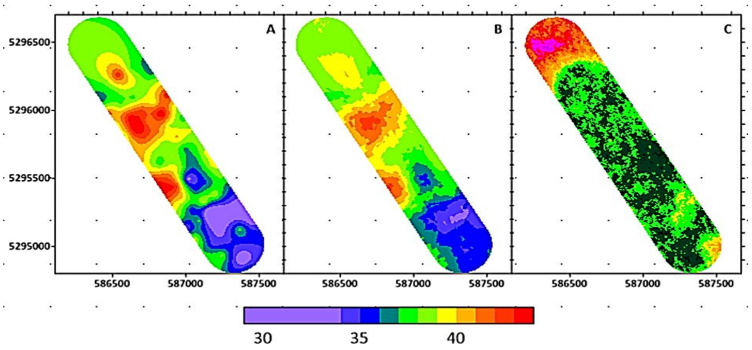

Figure 7: Estimation by Simple Kriging (A), The expected value of 100 stochastic images based on SGS (B), the width of the confidence interval for porosity Estimation (C).

Depicted in Figure 7 (a) and (b) are the representations of the Kriged and Sequential Gaussian Simulation (SGS) realizations, respectively, both demonstrating analogous spatial patterns due to low degrees of spatial interpolation. A prominent feature shared by both representations is the existence of high porosity values in the central areas of the field. This observation can be attributed to soil conditions characterized by larger particle size distributions, inherently leading to high soil porosity within these regions. Nevertheless, the model predicts moderate to low porosity values in other field regions, contingent upon the spatial distribution and proximity of specific soil physical parameters. Beyond the determined range, these porosity values are observed to be independent. Consequently, there are instances where higher values may be predicted while lower porosity values may be derived in other scenarios. Such fluctuations highlight the inherent variability in soil physical properties across the field. Moreover, Figure 7 (C) presents the confidence intervals of the simulated porosity values, effectively illustrating areas of heightened uncertainty. In regions lacking sufficient observational data, an increase in uncertainty is evident. This uncertainty stems from a dearth of information regarding the field's specific soil conditions, reinforcing the necessity of further soil sampling to mitigate these uncertainties and enhance the precision of soil porosity predictions.

Figure 8 exhibits the outcomes of 100 three-dimensional (3D) Hydrus estimations obtained using 100 distinct yet equiprobable porosity estimations as input grids. Discrepancies in the outputs of the Hydrus model highlight the impact of limited knowledge pertaining to the inherit spatial patterns of soil porosity. In the simple kriging approach, the average was taken outside the range of known values. Conversely, the sequential Gaussian simulation (SGS) algorithm aimed to preserve variations within the datasets, thus offering a more practical means of capturing uncertainties and variabilities in soil porosity.

SGS, as demonstrated in the results, showcased minimal heterogeneities within the field, effectively representing the spatial continuity of porosity following the corresponding locations. In contrast, the Kriging method underestimated larger porosity values while overestimating smaller ones. This disparity underscores the inherent limitations of kriging in accurately capturing the true magnitude and distribution of soil porosity. Using SGS allows for a more comprehensive depiction of the spatial variations and uncertainties in soil porosity. It provides valuable insights into the spatial connectivity and continuity of porosity across the field. In con-

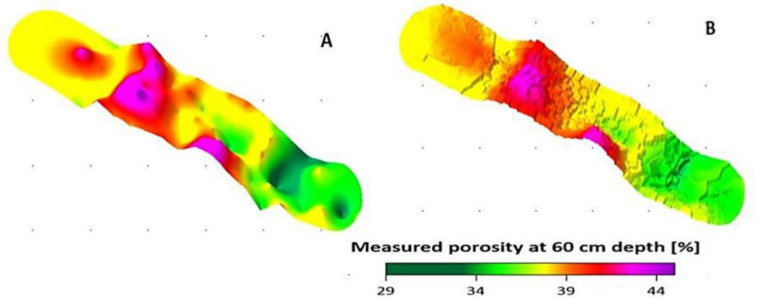

Figure 8: Comparison of the results of the kriged (A) and simulated surfaces(B).

trast, kriging falls short of capturing these essential aspects due to its inherent assumptions and limitations. These findings emphasize the significance of employing advanced modeling techniques like SGS, which offer a more robust and accurate representation of the spatial patterns and uncertainties in soil porosity. Such methods enable researchers and practitioners to make more informed decisions regarding soil management practices and water resource optimization in agricultural systems.

Comparison of the results to the Water balance of the Hydrus model

Figure 9 presents the outcomes of optimal soil moisture estimations using the Hydrus 2D model and sequential Gaussian simulation (SGS). The Hydrus 2D model was validated using field data observations of soil moisture in the corn field from 2020 and 2021 respectively. Notably, the simulated moisture content is closely aligned with the actual measured soil moisture content, indicating the efficacy of the modeling approaches (Magyar et al., 2023). The grey area in the figure represents the 95% confidence interval, with thicker areas indicating a higher degree of uncertainty in estimating soil water content (Karandish & Šimůnek, 2019). During the growth period of corn from May to August, a noticeable decline in soil moisture content was observed from planting to physiological maturity. This pattern aligns with established knowledge regarding the water requirements of corn crops, as water consumption increases during the active growth stages and diminishes towards maturity. The threshold porosity probability values derived from the simulations, particularly at 30 and 60 cm depths, are particularly informative during dry periods. These values hold the potential to reflect the specific water demands of the crops, considering the unique characteristics of the soil profile. Consequently, these estimations serve as valuable inputs for informed farm management decisions, aiding in optimizing irrigation strategies and resource allocation. By utilizing the simulation outputs and the generated threshold porosity probability values, practitioners and farmers can make data-driven decisions regarding irrigation scheduling, ensuring that water is applied judiciously and following the varying water demands of the crops throughout the growing season. This approach allows for more efficient water management, reducing unnecessary water usage and promoting sustainable agricultural practices.

Conclusion

Soil physical properties, especially porosity, play vital roles in the hydraulic behavior and distribution of water across the soil media. The knowledge of porosity variability within irrigated agricultural fields can help in the

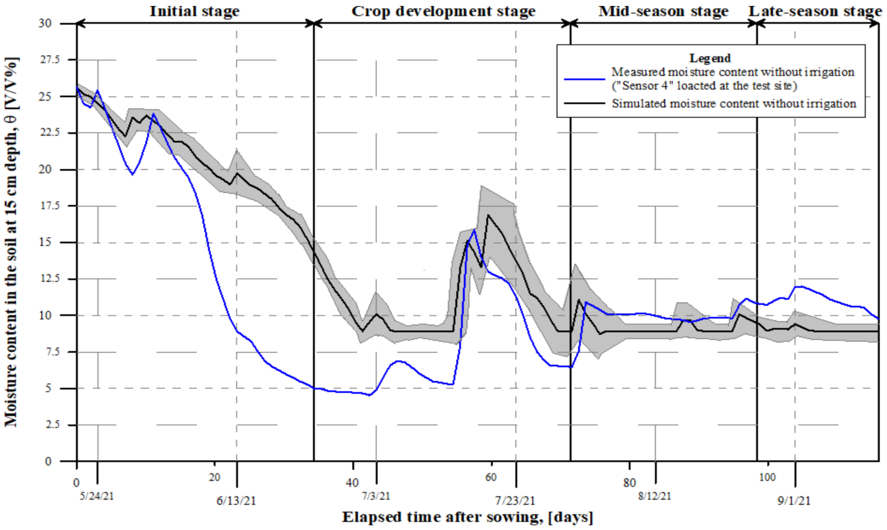

Figure 9: Measured and simulated soil moisture Contents for the Nyírbátor site in the vegetative period 2021 (Magyar et al., 2023).

development of effective water use strategies to minimize water wastages.

The spatial patterns generated by the sequential Gaussian simulation (SGS) were leveraged to delineate specific parcels within the cropland where soil porosity was projected to directly or indirectly impact water use and management. These simulations elucidated the uncertainty associated with soil parameters, specifically porosity, by revealing areas characterized by varying porosity, including high, low, and moderate values. The output that best represented the initial data was selected from the numerous realizations obtained from the simulations. This optimal output was determined by considering the general agreement with the observed data and the ability to capture the spatial variability and uncertainty in the porosity distribution.

The uncertainty analysis was conducted based on the confidence intervals derived from the expected porosity values. These confidence intervals provided a quantifiable measure of uncertainty, offering valuable insights for irrigation management decisions. By utilizing this uncertainty information, irrigation practices can be adjusted, with particular attention given to areas with porosity values below threshold limits or exceptionally high values. This approach enables a targeted and site-specific approach to irrigation management, focusing on areas where the soil porosity may pose challenges or opportunities for effective water use. Water resources can be utilized more efficiently by tailoring irrigation strategies to address the variability in porosity values, ensuring that water application aligns with the specific needs of different areas within the cropland. This proactive management approach contributes to sustainable water management practices, optimizing crop productivity while minimizing unnecessary water usage.

Recommendations

The physical and chemical nature of soil keeps on changing over time due to increased physical, chemical, and biological activities, altering the nature of soil. For high efficiency to be achieved during irrigation, we recommend an annual soil sampling, testing and simulations interval to keep in check of the continuous soil formation, physical and chemical alterations.

Acknowledgments

The authors acknowledge the support of the RRF 2.3.1 21 2022 00008 project within the Szechenyi Plan Plus Program framework. Special gratitude goes to the heads of institute of water and Environmental management, university of Debrecen; Prof. Dr. Tamás János and Dr. Nagy Attila for their enormous contributions to the success of this project.

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MAGYAR AGRÁR- ÉS
ÉLETTUDOMÁNYI EGYETEM

Columella
Volume 11, Number 1, 2024

Columella
Journal of Agricultural and Environmental Sciences

Wetlands in Serbia: Past, present and future

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Abstract: Within the territory of the Republic of Serbia, most wetland areas are situated in the north of the state. This is predominantly because of relief features which comprise lowland terrain intersected by the alluvial plains of large rivers such as the Danube, Tisza and Sava. The area also represents the southern part of the Pannonian plain. Extensive works on land reclamation - drainage of wetlands and canalizing rivers, contributed to the formation of large plots of fertile arable land - cultural steppe. Whereas in the 18th century, wetlands were covering 50% of the territory, nowadays remaining wetlands occupy only around 5%. However, these represent significant biodiversity islands and due to this are declared as protected RAMSAR areas of international importance. There are 11 RAMSAR areas in Serbia, of which 8 are in the territory of the Vojvodina Province. Despite protection these are still under pressure from pollution originating from outside borders, climate changes and invasive species. Monitoring water quality at three wetland special nature reserves in the period 2015–2019 revealed that in most cases it was below required water quality standards. In response to these changing conditions, managers of protected areas in Serbia are conducting active measures of protection. Finally, wetlands provide many benefits, and those could be designated as ecosystem services. The concept is helpful for better estimation of benefits, and making comprehensive future planning on how to maximize its benefits and simultaneously achieve sustainability goals. The ecosystem services–based methodology developed during the IDES project, could be useful tool for future planning of management activities.

Keywords: land reclamation, RAMSAR sites, active protection, ecosystem services, inland wetlands

Received 16 June 2023, Revised 21 December 2024, Accepted 3 February 2024

Introduction

According to Brinkman and Blokhuis (1986), “wetlands have been defined as areas that have free water at or on the surface for at least the major part of the growing season. The water is sufficiently shallow to allow the growth of a wetland crop or natural vegetation rooted in the soil.” The flat terrain and abundance of water make wetlands so attractive for performing a wide range of activities which satisfy human needs. Therefore, usually by applying land reclamation measures, wetlands have been drained converted to fertile land or urbanized. Intensive conversion and disappearing of wetlands on a global scale has occurred in the past few centuries since 1700 AD. Especially intensive loss of wetlands has happened in the past century, i.e. a loss of 64–71% of wetlands since 1900 AD ((Davidson, 2014)). It is worth mentioning that for inland wetlands the losses were larger and faster in comparison to losses of coastal natural wetlands. Nevertheless, the benefits of wetlands are numerous: water purification, buffering flooding events, provision of food and fibre, biodiversity conservation, carbon dioxide sequestration, and recently more often emphasized climate change mitigation.

The northern part of the Republic of Serbia, Autonomous Province of Vojvodina - APV (further in the text Vojvodina Province) includes southern parts of the Pannonian plain which are intersected by alluvial terrain surrounding large lowland rivers - the Danube, Tisa and Sava. For centuries these rivers were crucial for the formation of wetland conditions either by flooding or by meandering and changing their river beds, leaving remains of different inland wetland types. Therefore, floodplains can be defined as areas adjacent to a water body that are prone to flooding events at least one time a year, thus supporting wetland conditions for living organisms adopted to such changes in hydrological regime.

The paper aims to provide an overview of wetlands in Serbia focusing especially on its northern part, since most of the wetlands are located on the territory of Vojvodina Province. Furthermore, attention will be paid to: (1) past actions done to transform the landscape from wetlands to arable land, (2) present conditions characterized by ruminants of former wetlands and (3) prospects for improving their conditions in future.

History of land reclamation in northern parts of Serbia

A few centuries lasting, extensive and planned activities on the territory of Vojvodina resulted in the complete transformation of landscape and habitats. Extensive works on land reclamation - drainage of wetlands and canalizing rivers, contributed to the formation of large plots of fertile arable land - cultural steppe. The transformation simultaneously contributed to diminishing areas under wetlands. In the 17th and at the begging of the 18th century (Figure 1), wetlands covered 50% of the territory (Dragovic et al., 2005).

The history of land reclamation activities started in the Roman period during the reign of the Roman emperor Probus (276–282). The first works on the evacuation of excess inland waters were done around the city of Sirmium (today Sremska Mitrovica town) by digging two canals that could collect the water originating from the Fruška Gora mountain and conduct it to the Sava River. The canals exist even today. Those have been reconstructed, but have the same purpose. Later on at the beginning of the 18th century, the first large canals have been constructed. In the year 1718 began the construction of a canal – representing an artificial riverbed of the river Begej, in the length of 70 km from Timisoara (today Romanian city) to the village Klek in Serbia. The works were lasting for 5 years, but the goal has not been fully achieved, since the middle part of the Banat Region in Vojvodina has not been completely protected from inland waters. The second big project was building the Great Bačka Canal, which has the role to connect the River Danube with Tisa. In the 70s of the 18th century until completion of the works on this project in 1801, Hungarian engineer Kiss József, was devoted to the construction and supervision of works. The canal not only drained large areas under wetlands in the Bačka Region but enabled navigation and shortened transportation of goods which was previously done only along the Danube and Tisa River. The efforts to further draining within the Vojvodina Province by constructing canals continued during the 19th century and culminated in the second half of the 20th century by finishing works on the Hydrosystem Danube-Tisa-Danube (HS DTD). Simultaneously with digging canals, protective dikes have been constructed along major lowland rivers.

Before construction of HS DTD floods caused by inland waters have been significantly deteriorating arable land and have been causing losses of plant production. It has been recorded that on the territory of districts Bačka and Banat in Vojvodina Province severe floods were caused by inland waters in 1942 (Figure 2). The flood had affected more than 450 000 ha of arable land (Dragović et

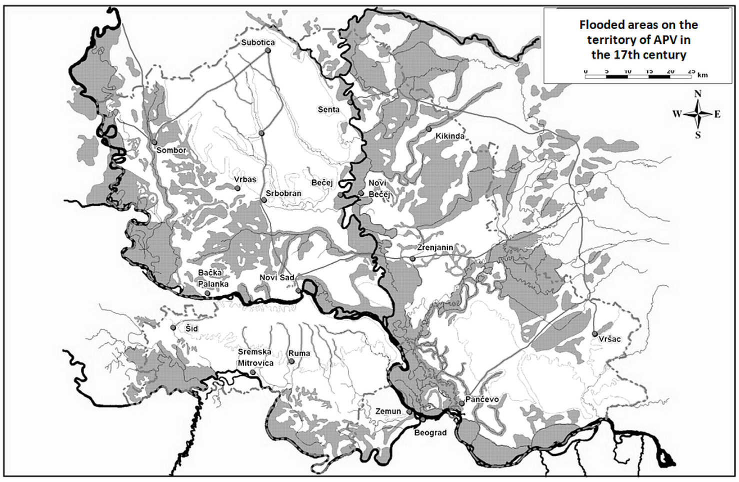

Figure 1: Flooded areas on the territory of Vojvodina Province in the 17th century (PWMC VV, 2023).

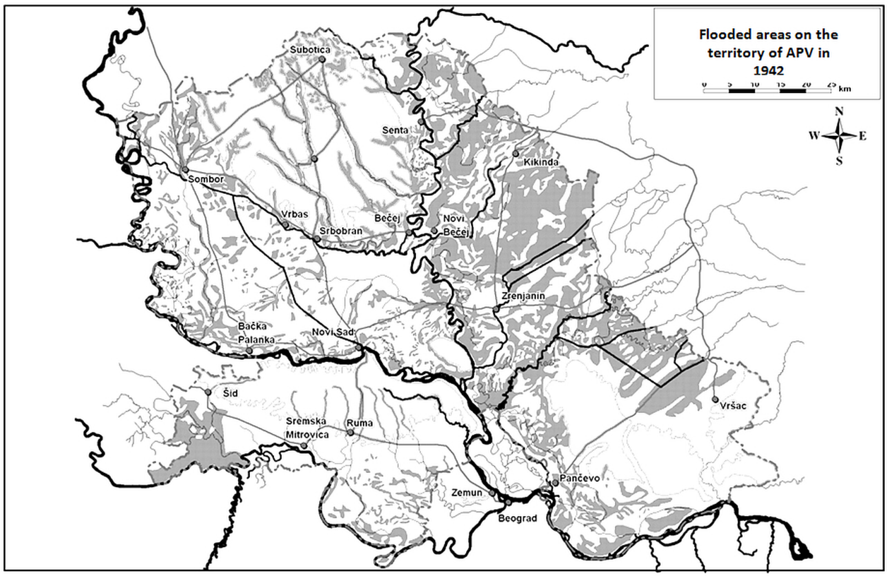

Figure 2: Flooded areas on the territory of Vojvodina Province in 1942 (PWMC VV, 2023).

al., 2005). Whereas in 1956 from the same reason 230 000 ha were devastated, while 800 000 ha were overwetted (Pantelić, 2002). Due to the completion of so extensive land reclamation works even during periods of high precipitation water management within the territory could have been successfully managed (Figure 3). Systematic works on drainage resulted in the fact that most of the area has been converted into arable soil contemporarily occupying 92% of the territory or nearly 2 million ha, while nowadays remaining wetlands occupy only around 5% (Dragovic et al., 2005).

At the end to conclude: two main activities – draining wetlands by *constructing canals* and canalizing rivers by *building protective embankments* resulted in:

- 960 km in length of huge canals of the Hydrosystem Danube-Tisa-Danube, of

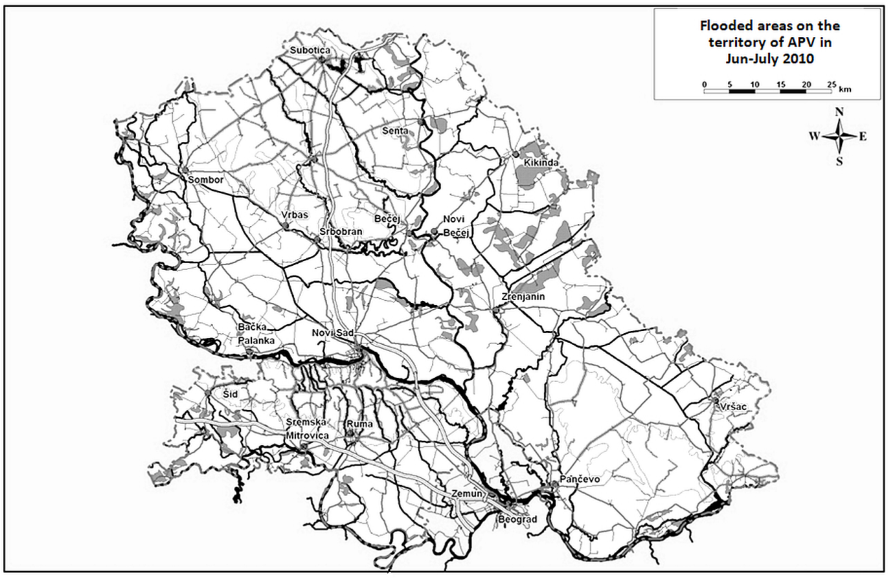

Figure 3: Flooded areas on the territory of Vojvodina Province in 2010 (PWMC VV, 2023).

which around 600 km are navigable;

- construction of small amelioration canals in lenght of 20 703 km;
- building protective dikes along huge rivers such as the Danube, Tisa, Sava, Tamiš and Begej, in lenght of 1362 km;
- establishing good air-water regime on arable land, enabling production of cultivated crops on around 2 million ha (PWMC VV, 2023)); while
- present areas under wetlands occupy only 0.33% of the territory (CLC, 2018).

Present remains of wetlands in Serbia

Since significant areas under wetlands have been lost for centuries on the territory of northern Serbia, present remains could be found mostly in the floodplains of large lowland rivers within the Pannonian plain. Only Vlasina and Pestersko polje is located away from this geographical unit (Figure 4). Vlasina is located in the southeast of the country near the border with Bulgaria, comprising a Vlasinsko reservoir (created in 1949) and surrounding hills, wet meadows, peat bogs, and the valley of the River Vlasina. Pestersko polje is close to the border with Montenegro and is the largest and highest karst field of the Balkan Peninsula. It originated from a lake which vanished with the erosion of the karst leaving peat bogs and small flooded areas exposed, thus creating a diverse landscape (Ramsar, 2023).

Even if they occupy relatively small areas these are significant and unique islands of biodiversity. Therefore, these wetland sites are declared as protected areas of national or even international importance. The idea that habitats are not compliant with countries' borders and that especially migratory birds are periodically migrating was an initial idea for establishing the Ramsar Convention. The convention is also known as "The Convention on Wetlands", an intergovernmental environmental treaty established on 2nd February 1971 in Ramsar, Iran by UNESCO, and come into force on 21st December 1975 (Ramsar, 2023). Under the convention, wetland sites of importance for migratory birds, are proclaimed as Ramsar Sites.

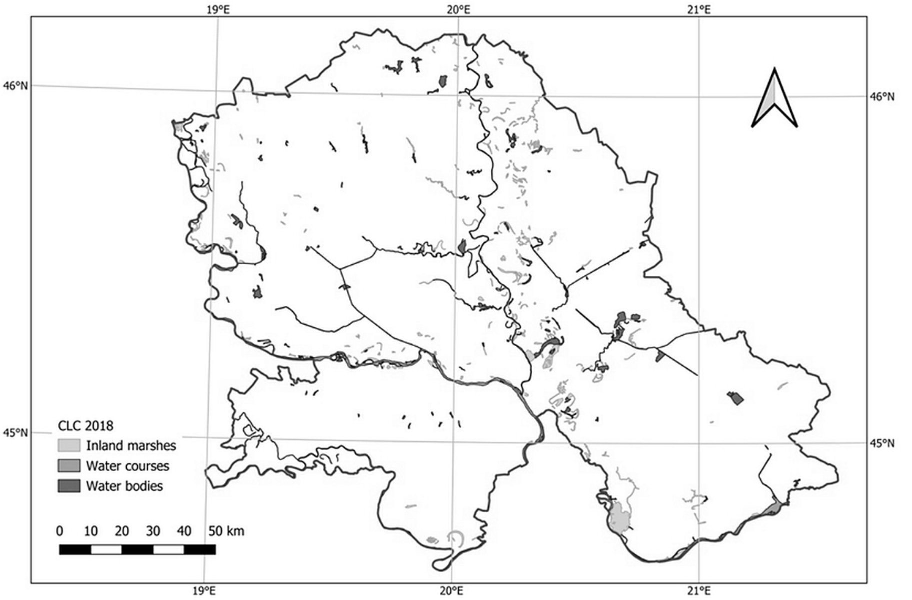

Figure 4: Wetland areas in Vojvodina Province, Serbia (*CORINE Land Cover (CLC)*, 2018).

In Serbia, the convention entered into force on the 27th of April 1992. Serbia currently has 11 sites designated as Wetlands of International Importance (Ramsar Sites), with a surface area of 130 411 ha ((Ramsar, 2023; for Nature Conservation of Serbia, n.d.)). Although there are 7 such sites located in the territory of Vojvodina Province their total area is smaller in comparison to the rest of Serbia, because the area of the Djerdap is larger than the sum of the rest of Ramsar areas in Serbia (Table 1).

Concerning the fact that the territory of Serbia is 8 860 800 ha, the territory under wetlands is represented only by 1.37% (1213 ha), whereas in Vojvodina Province of 2 163 00 ha, wetlands are represented by 0.33% (*CORINE Land Cover (CLC)*, 2018). According to Corine Land Cover (2018), there are three types of wetland areas within Serbia's territory, i.e. inland marshes, water courses and water bodies (Table 2).

Even in so small areas, anthropogenic pressure is still present. One of the factors is pollution originating from anthropogenic sources, and not limited by the borders of protected areas (e.g. air pollution or diffuse pollution loads from adjacent arable land). Currently, apart from anthropogenic pressure, climate changes reflected in longer and more severe drought periods are affecting wetlands. In addition, such a situation favours invasive species, thus causing changes in community composition and decreasing the biodiversity of native species.

Apart from pollution, other factors are disturbing wetland habitats. The most significant is that due to climate change, there is a trend of increasing drought periods and deficiency of precipitation, making wetlands extremely vulnerable. Furthermore, such a situation favours invasive species, thus changes in communities' composition and decreasing the biodiversity of native species (Grabić, Ljevnaić-Mašić, et al., 2022). In response to these changing conditions managers of protected areas in Serbia are conducting active measures of protection, which focus not just on sole isolation and protection of habitats, but rather active eradication of invasive species and taking actions to improve the water regime within protected wetlands (Grabić, Benka, et al., 2022).

Table 1: Ramsar sites in Serbia (Ramsar, 2023).

No.	Ramsar site name	On the territory of VP	Site no.	Designation date	Area (ha)l
1.	Djerdap	No	2442	08-06-2020	66 525
2.	Koviljsko-Petrovaradinski Rit	Yes	2028	08-03-2012	8 292
3.	Zasavica	No	1783	13-03-2008	1 913
4.	Vlasina	No	1738	13-11-2007	3 209
5.	Gornje Podunavlje	Yes	1737	13-11-2007	22 480
6.	Pestersko polje	No	1656	19-03-2006	3 421
7.	Labudovo okno	Yes	1655	19-03-2006	3 733
8.	Slano Kopovo	Yes	1392	14-05-2004	976
9.	Stari Begej – Carska Bara	Yes	819	14-03-1996	1 767
10.	Obedska Bara	Yes	136	28-03-1977	17 501
11.	Ludaško Lake	Yes	137	28-03-1977	593

Table 2: Wetland areas within the territory of the Republic of Serbia (*CORINE Land Cover (CLC)*, 2018).

Region	Type of wetland area (ha)			Total
	Inland marshes (CLC code 411)	Water courses (CLC code 511)	Water bodies (CLC code 512)	
Vojvodina Province	257	297	167	721
Whole Serbia	301	641	271	1213

DOI: https://doi.org/10.18380/SZIE.COLUM.2024.11.1.19

Water quality at three wetland special nature reserves

Whereas water quality (WQ) in large rivers such as the Danube and Tisa has been satisfactory on average belonging to a 2nd to 3rd WQ class (Salvai et al., 2022; Josimov Dundjerski et al., 2017; Grzywna et al., 2023), in some reaches of the HS DTD it has been significantly deteriorated by different point and diffuse pollution sources causing occasional fish kills and WQ classified as 5th class, or out of classes (Grabić, Ćirić, et al., 2016; Grabić et al., 2011). In Serbia, there is a state network of monitoring stations controlling WQ in watercourses, especially along the country's borders. However, the network rarely includes sampling sites at ponds and wetland areas. At those water bodies monitoring is performed under the jurisdiction/initiative of local authorities, for scientific purposes and is not done regularly. Due to such circumstances, we have voluntarily conducted monitoring at three protected wetlands. The monitoring of WQ was conducted in the period 2015–2017 at three wetlands, and special nature reserves: SNR Ludaš Lake, SNR Obed Pond and SNR Carska Pond. The monitoring revealed that in most cases it was below required water quality standards belonging to 3rd, 4th class or even was out of class, according to the water quality criteria of Serbian by laws on ecological status, in line with the WFD of the EU (Grabic et al., 2018; Grabić, Ćirić, et al., 2016). During the monitoring period, there were dry and humid years. For example, in 2017 a severe drought caused unfavorable hydrological conditions at Obedska Pond (Ilić et al., 2018) and Carska Pond (Zemunac et al., 2018). In 2017 total precipitation at the measuring station Zrenjanin, close to Carska Pond, was only 368.3 mm (RHMS RS – Republic Hydrometorological Service of the Republic of Serbia, n.d.). This resulted that the low water level in the pond was 40 cm lower than the average level for the summer period, influencing also bad water quality (personal observation of the author; (Grabic et al., 2018)). At Ludaš Lake phytoplankton overgrowth is evident, either by visual observation or by the use of remote sensing and multispectral cameras (Grabić et al., 2019), and through WQ parameters it was reflected in elevated concentrations of total phosphorus and nitrogen, whereas orthophosphates, nitrites and nitrates were low and close to zero, indicating that all nutrients were embedded in phytoplankton. In addition, the pH value measured around noon was high – above 8.5-9 also pointing to intensive photosynthetic activity (Grabic et al., 2018). Besides, agriculture represents significant pressure on protected wetland areas since the leaching of pesticides and surplus fertilizers affects WQ, again in the case of Ludaš Lake (Mezei et al., 2017).

Prospects and future challenges in managing wetlands in Serbia

Apart from WQ issues wetland areas in Serbia are facing additional threats such as invasive species (Grabić, Ljevnaić-Mašić, et al., 2022; Grabić, Benka, et al., 2022). In addition, autochthonous species as in the case of common reed (*Phragmites australis* (Cav.) Trin ex Steud.) may expand and become a nuisance, e.g. the Ludaš Lake (Grabić, Benka, et al., 2016). Furthermore, climate changes expressed in extreme weather events are also evident in wetland areas. In response to climatic changing conditions, managers of protected areas in Serbia are conducting active measures of protection, which focus not just on sole isolation and protection of habitats, but rather on active control of invasive species and taking actions to improve water regimes.

Wetlands provide many benefits, and those could be designated as ecosystem services

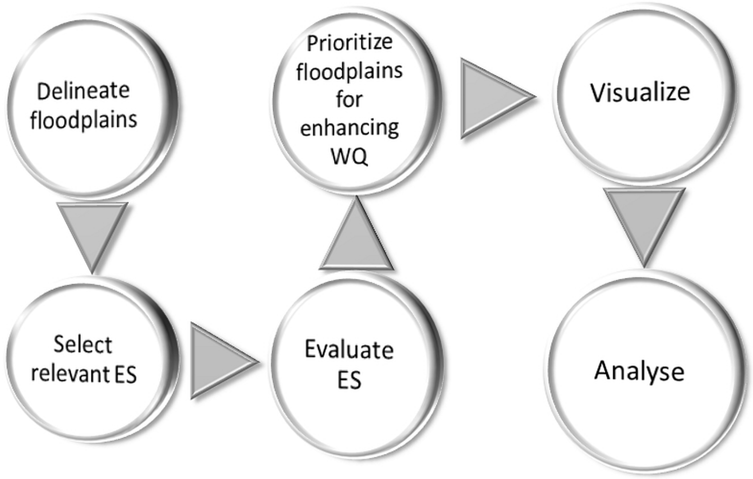

Figure 5: . Phases in the process of ES assessment using IDES tool.

(ES). The concept is helpful for better estimation of benefits, and making comprehensive future planning on how to maximise its benefits and simultaneously achieve sustainability goals. Furthermore, the relatively innovative concept of ES aims to evaluate the benefits posed by natural habitats, even in monetary terms. The ecosystem services–based methodology developed during the IDES project, tested in Serbia on wetlands within the Special Nature Reserve Koviljsko-petrovaradinski rit, showed to be a useful tool (Benka et al., 2022). Phases in conducting mentioned ES-based methodology are presented in Figure 5.

Although, manmade structures, constructed wetlands have proven to be efficient in municipal wastewater water purification (Josimov-Dundjerski et al., 2015) simultaneously contributing to landscape diversity in Vojvodina's landscape where arable plots are dominating. Finally, areas under wetlands in Serbia are being more appreciated, which brings some optimism concerning the Serbian wetlands issue. An argument to support this statement is that new areas are being proclaimed as protected, e.g. Backo Podunavlje was proclaimed as a biosphere reserve in 2017 (UNESCO, n.d.) and Djerdap was designated as the Ramsar area in 2020 (Ramsar, 2023).

Conclusion

Wetlands are an important and multifunctional part of northern Serbia's landscape which contribute to biodiversity, alleviate extreme hydrologic events, and recently contribute to mitigating climate changes. Ramsar sites in Serbia represent significant biodiversity islands. However, protected areas are still under a lot of pressure, e.g. pollution from outside borders, climate changes - getting drier and invasive species are amongst the most prominent threats. Although small in the area at present, occupying only about 1% of Serbia's territory, or 0.37% of the Vojvodina Province, there is a need of preserving existing wetlands and wisely manage them in future. Future management strategies have to be based upon clever acting focused on strengthening wetland health and supporting its biodiversity. Examining and appreciating ecosystem services and planning, to simultaneously satisfy wetland habitats and human needs, concerning various ecosystem services, has to be imperative.

Acknowledgements

This research was supported the by Ministry of Education, Science and Technological Development of the Republic of Serbia (451-03-68/2022-14/200117). In addition author wants to express her appreciation to the Archive center of the PWMC Vojvodina Vode for providing maps and access to the data.

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MAGYAR AGRÁR- ÉS
ÉLETTUDOMÁNYI EGYETEM

Columella
Volume 11, Number 1, 2024

Columella
Journal of Agricultural and Environmental Sciences

Examination and comparison the effects of extraction time and temperature for compost tea

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Abstract: Composting represents an efficient technology that enables the effective utilization of by-products and waste materials. Moreover, it proves to be highly suitable for processing raw materials and converting them into fertilizers that would not be recommended for direct application without undergoing pre-processing. This is particularly crucial in the case of poultry manure, which possesses potentially hazardous properties and necessitates pre-treatment. One increasingly prevalent form of compost is known as compost tea, which involves the immersion of compost in water. In this experiment, compost tea or compost solution were created using a product called composted and pelletized poultry litter (CPPL). Four compost:water ratio (CWR) (1/2.5, 1/5, 1/10, 1/20) were applied, along with three different extraction durations (24, 48, and 72 hours) and three distinct extraction temperatures (20 °C, 35 °C, and 50 °C). Since the 1/10 and 1/20 ratios were found to be the best for subsequent applicability and spreadability, their content parameters were measured further. After elimination of the experiment, the most important nutrients (nitrogen content (nitrate and ammonium), phosphorus and potassium) were determined. The results showed that the nutrient content was highest for all four parameters at the extraction temperature of 35 °C. For example, while at 20 and 50°C the NO_3^- content ranged from 263 to 768 mg/l and from 210 to 534 mg/l, at 35 °C it ranged from 498.33 to 2636.67 mg/l, irrespective of the mixing ratio and extraction time. If the extraction temperature is not taken into account, the nutrient content increased with the increase of the extraction time, so that the highest values were measured at 72 hours extraction time obviously. The data measured in the present experiment will serve as a basis for subsequent experiments with different indicator plants, investigating the effect of compost when applied as a solution.

Keywords: compost tea, nutrient content, poultry litter

Received 19 July 2023, Revised 7 February 2024, Accepted 9 February 2024

Introduction

Poultry manure is a valuable source of nutrients, especially nitrogen, and is widely used in agriculture as an organic fertiliser and soil conditioner. Its application, however, requires careful pre-treatment procedures to avoid negative effects on crop production and environmental pollution (Dede & Ozer, 2018). A tried-and-true technique for handling organic waste and byproducts is composting. Under conditions of sufficient moisture and oxygen, the organic matter of the waste and by-products is converted into humus-like material throughout the biological process, breaking down into simple components (CO_2, H_2O, SO_4, NO_3) (Alexa & Dér, 2001; Ayilara et al., 2020; Epstein, 2017; Sulzberger, 2006; Tawfik et al., 2023; Xu et al., 2023). Composting technology plays an important role in sustainable agriculture, as many studies have shown. Researchers highlight the importance of composting for greenhouse gas reduction, waste

DOI: https://doi.org/10.18380/SZIE.COLUM.2024.11.1.29

Table 1: Parameters of the composted and pelletized poultry litter.

Compost/water ratios	1/2.5, 1/5, 1/10, 1/20
Extraction times	24, 48, and 72 hours
Extraction temperatures	20 °C, 35 °C, and 50 °C

Internet1: https://bio-fer.hu/bio-fer-natur-extra/

recovery and environmental sustainability. They also highlight the economic, social and environmental benefits of composting, contributing to sustainable development and extending the life of landfills (Adekunle et al., 2010; Boldrin et al., 2009; Dastpak et al., 2020; Kiss et al., 2021; Marmolejo-Rebellón et al., 2020; Onwosi et al., 2020; Pergola et al., 2018, 2020; Sangamithirai et al., 2015; Sequi, 1996; Zakarya et al., 2018).

Due to its unfavourable qualities (high nitrogen, fiber, and moisture content), there is limited literature available on the composting of poultry manure. According to Georgakakis and Krintas (2000), the Hosoya composting system is excellent for composting byproducts with undesirable qualities, such as poultry manure. According to Hosoya (1996), Csiba and Fenyvesi (2012), and Szabó (2016), this technique, which is based on fermentation and drying, ultimately produces granulated material with a dry matter content of 80–85% (CPPL). Granulated products have the advantage that the heat treatment kills pathogenic bacteria, weed seeds, and hazardous ammonia fumes (Gaál, 2011).

Compost tea, also known as compost slurry, is a compost use that is becoming more and more popular. By extracting compost with water, a liquid form of the product known as compost tea is created (Al-Dahmani et al., 2003; Morales-Corts et al., 2018; Zaccardelli et al., 2018). According to Scheuerell and Mahaffee (2002) and Ingham (2005), compost teas can be made with or without aeration and with or without the addition of ingredients to promote microbial life. According to several studies (Edwards et al., 2006; Kim et al., 2015; Pane et al., 2016; Pilla et al., 2023; Radovich & Arancon, 2011; Shaban et al., 2015; Shrestha et al., 2011; Sujesh et al., 2017), compost solutions can be a valuable source of microbial biomass (bacteria, filamentous fungi, yeasts, etc.), organic matter, organic acids, soluble mineral nutrients, and plant growth regulators (González-Hernández et al., 2021; Scheuerell & Mahaffee, 2002; Wang et al., 2023). Compost tea research is becoming more popular due to the variety of compost teas and the growth of organic and sustainable farming (González-Hernández et al., 2021; Gorliczay et al., 2021; Litterick et al., 2004). Litterick et al. (2004) studied the mitigating effect of compost tea on phytopathogenic damage in grapes, potatoes, tomatoes, cucumbers, apples and roses. Research by Hargreaves et al. (2009) also found that compost tea provided most of the micro- and macronutrients in leaf fertilisation, better than compost from ruminant manure or even synthetic fertilisers. In the present study, the nutrient content of compost tea produced from composted and pelletized poultry litter (CPPL) was examined depending on extraction time and temperature.

Materials and methods

The raw material of the compost tea was composted and pelletized poultry litter (CPPL). The parameters of the CPPL are reported in Table 1.

In the experiment 4 compost/water ratios (CWR), 3 extraction temperatures and 3 dif-

Table 2: Parameters of the composted and pelletized poultry litter.

Compost parameters	Value
Moisture content (m/m%)	12
pH	7.2
TDS (m/m%)	73
Nitrogen (m/m%)	5.5
Phosphorus (m/m%)	3
Potassium (m/m%)	2.5
Ca (m/m%)	6
Mg (m/m%)	0.5
S (m/m%)	1
B (mg/kg)	31.4
Fe (mg/kg)	545
Mn (mg/kg)	374
Mo (mg/kg)	3.66
Zn (mg/kg)	367
Cu (mg/kg)	53.3

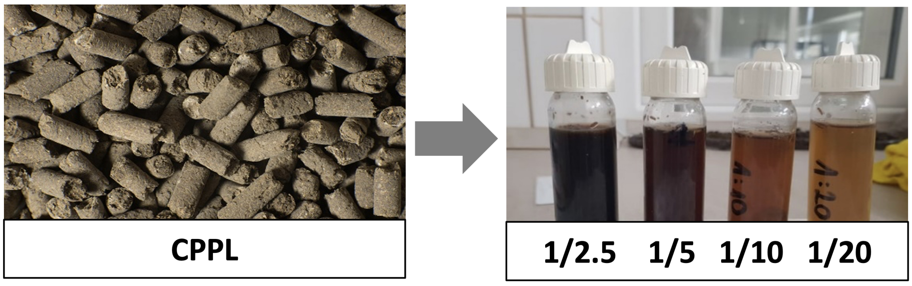

Figure 1: The CPPL and the compost teas/solutions in different mixing ratios.

ferent extraction times were used to make the differences as comparable as possible (Table 2).

After mixing the solutions, they were placed in an incubator at the given temperature for a given time. After the extraction time, the solutions were centrifuged (Figure 1).

For centrifuged samples nitrogen forms (nitrate, ammonium), phosphorus and potassium content were measured with a PF-12 Plus photometer and Visocolor ECO reagents. Measurements were performed in 3 replicates.

Statistical analysis of the data was carried out using R software. The normal distribution of the data was tested using the Shapiro-Wilk test. Since the data were found to be normally distributed, the Duncan test was used to quantify statistical differences at 5% significance level ($p = 0.05$). By comparing the factors (three different extraction times (24, 48, 72 hours), three different extraction temperatures (20, 35, 50 °C), and two different compost-to-water mixing ratios (1:10, 1:20)) to each other, the experiment was based on a multifactorial analysis, not just a three-factor one. Through multifactorial analysis, we assessed how each factor and their potential interactions contributed to the variability in the experimental results.

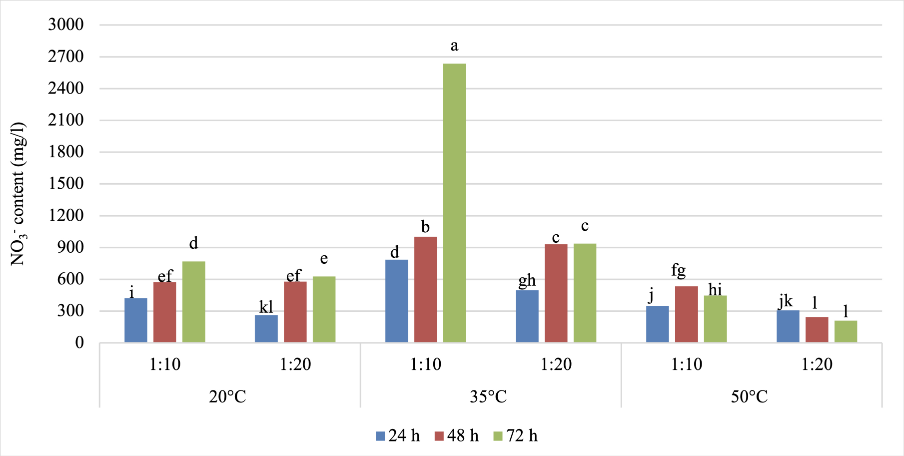

Figure 2: Nitrate content of compost tea prepared of composted and pelletized poultry litter (CPPL) at various compost:water ratios (1:10; 1:20), extraction temperatures (20, 35 and 50 °C) and extraction times (24, 48 and 72 hours). The letters above the columns indicate the different statistical groups.

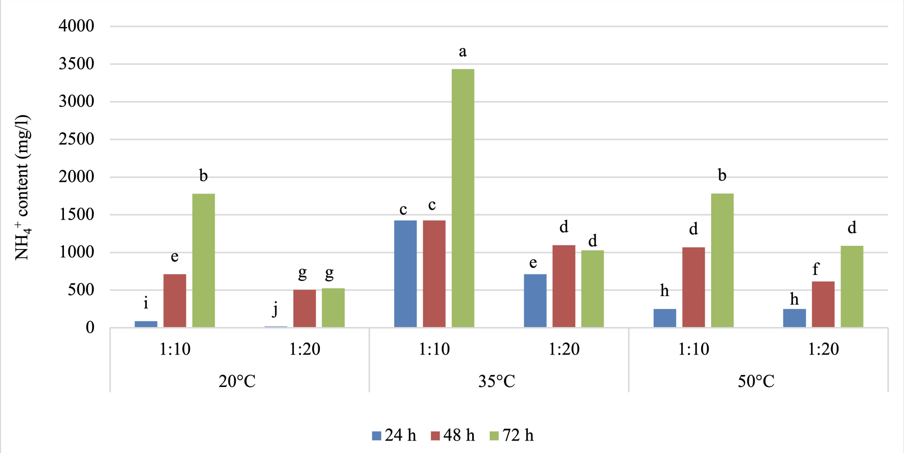

Figure 3: Ammonium content of compost tea prepared of composted and pelletized poultry litter (CPPL) at various compost:water ratios (1:10; 1:20), extraction temperatures (20, 35 and 50 °C) and extraction times (24, 48 and 72 hours). The letters above the columns indicate the different statistical groups.

Results

Nitrogen forms of compost tea

Among the nitrogen forms, the changes in nitrate and ammonium content were examined depending on various compost:water ratios (1:10, 1:20), extraction temperatures (20, 35 and 50 °C) and extraction times (24, 48 and 73 h). Figure 2 shows the trend in nitrate content.

Comparing the ratios, on average the more concentrated 1:10 solution has a higher nitrate concentration. For extraction temperatures of 20 and 35 °C, in general, the nitrate content increases with increasing extraction time and this is significantly detected in almost all cases. However, this trend is not observed at 50 °C. At the 1:10 ratio, the NO_3

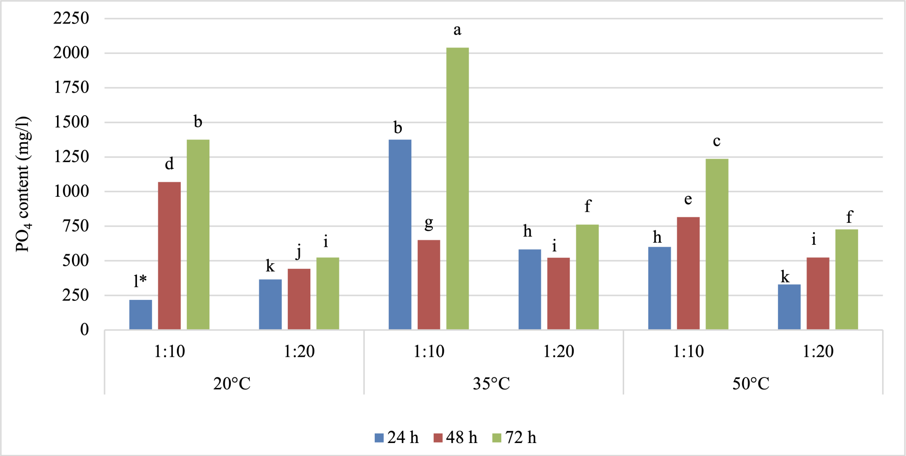

Figure 4: Phosphorus content of compost tea prepared of composted and pelletized poultry litter (CPPL) at various compost:water ratios (1:10; 1:20), extraction temperatures (20, 35 and 50 °C) and extraction times (24, 48 and 72 hours). The letters above the columns indicate the different statistical groups.

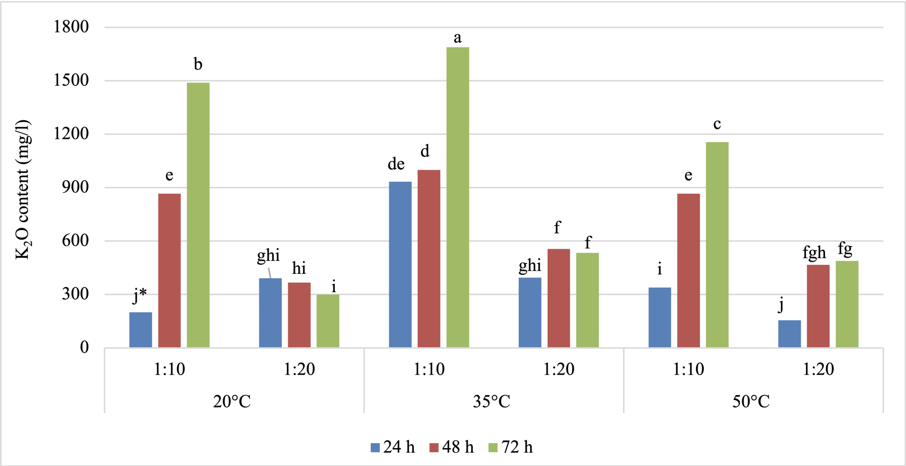

Figure 5: K_2O content of compost tea prepared of composted and pelletized poultry litter (CPPL) at various compost:water ratios (1:10; 1:20), extraction temperatures (20, 35 and 50 °C) and extraction times (24, 48 and 72 hours). The letters above the columns indicate the different statistical groups.

content of the 72 hours solution was lower than that of the 48 hours solution, whereas at the 1:20 ratio the nitrate concentration decreases with increasing extraction time.

The biggest jump is observed for the 35 °C 1:10 solutions, where a NO_3 content of 1000 mg/l was measured at 48 hours, while at 72 hours it was around 2600 mg/l. The highest value was observed in the latter solution. The lowest values were measured for the 50 °C extraction time at a ratio of 1:20 (regardless of the extraction time).

Figure 3 shows the trend in ammonium content. In the case of ammonium, the effect of extraction time on nutrient content was evident not only for solutions extracted at 20 °C and 35 °C, but also at 50 °C, as the ammonium content increased with increasing extraction time. Significant increases in nutrient content (other than the 35 °C 1:10 treatment) were also detected. In all but one of the treatments, solutions extracted for 72 hours had the highest values. As in the case of nitrate, the highest value was observed in the solution extracted at 35 °C for 72 hours at a ratio of 1:10. But in general, solutions with more concentrated ratios had higher ammonium contents.

Phosphorus content of compost tea

Also for phosphorus (Figure 4), the highest values were observed for solutions extracted for 72 hours, regardless of the extraction temperature and mixing ratio. As the extraction time increased, the nutrient content also increased for extraction times of 20 °C and 50 °C. For the 35 °C extraction time, the PO_4 content decreased at 48 hours compared to 24 hours and increased again at 72 hours. The highest values, as for nitrate and ammonium, were observed for the 1:10 solution extracted at 35 °C for 72 hours. Regarding the comparison of ratios for PO_4 content, as before, the more concentrated 1:10 solution had higher nutrient content, regardless of extraction time and temperature.

Potassium oxide content for the compost tea

The evolution of K_2O content was also generally characterized by a parallel increase in nutrient content with increasing extraction time (Figure 5). An exception to this was the 20 °C 1:20 adjustment, where the potassium content showed the opposite trend, i.e. decreased with increasing extraction time. The increase in nutrient content with extraction time was also significantly detectable in most cases.

The highest values were measured at the 72 hours setting, where the 1:10 setting at 35 °C was found to be the most prominent, as was the case for the other nutrients. For both the 20 and 50 °C settings, the higher value was measured in the 1:10 72 hours extraction time setting. In the case of potassium oxide, it can be said that the more dilute solutions with a compost:water ratio of 1:20 had lower nutrient content.

Discussion

In the realm of nutrient management, nitrogen (N), phosphorus (P), and potassium (K) stand out as the three most crucial macronutrients. These essential elements play a vital role in various plant processes, contributing to their overall health, productivity, and resilience (BassiriRad, 2005; Marschner, 2011). Nitrogen, a key component of amino acids and chlorophyll, is essential for protein synthesis, photosynthesis, and stress resistance. Plants primarily absorb nitrogen in the form of ammonium (NH_4^+) and nitrate (NO_3^-). The availability of these forms is crucial for optimizing plant growth and development (Bernhard, 2010; Cechin & de Fátima Fumis, 2004; S.-X. Li et al., 2013; Song et al., 2021). Phosphorus is an indispensable element for energy transfer, cellular signaling, and root, flower, and fruit development. It forms the backbone of adenosine triphosphate (ATP), the energy currency of cells, and is involved in nucleic acid synthesis. Adequate phosphorus nutrition ensures healthy plant growth and reproductive success (H. Li et al., 2015; Bechtaoui et al., 2021; Johan et al., 2021). Potassium, often referred to as the "quality element," plays a multifaceted role in plant physiology. It regulates water balance, enzyme activation, and carbohydrate and mineral transport. Moreover, potassium bolsters plant defense mechanisms against pests, diseases, and environmental stresses (Hasanuzzaman et al., 2018; Sardans & Peñuelas, 2021). In conclusion, nitrogen, phosphorus, and potassium, the NPK trio, are indispensable nutrients for plant growth and productivity. Their presence is paramount for optimizing plant health, resilience, and overall yield. This is why these three macroelements were investigated in the first round of this research.

Summarizing the results, it can be said that the nutrient content was significantly highest for all four parameters at the extraction temperature of 35 °C and over a longer extraction time, more nutrient dissolved from the compost. It is important to note that although nitrogen, phosphorus and potassium are important nutrients for plants, excessive amounts can be harmful. Excessive levels of nitrate and phosphorus in soil or water, for example, can cause environmental problems such as water pollution or environmental imbalances. Therefore, nutrient management in agriculture needs to be monitored to ensure sustainable crop production and to minimise the environmental impact. In the selection of the application in crop production, not only the nutrient content of the compost tea was considered, but also, for example, cost factors and energy aspects. Accordingly, solutions with a 1:10 ratio, extracted at 35 °C for 48 hours, were selected for further application and applied at a tenfold dilution.

Acknowledgements

This research was funded by the TKP2021-NKTA-32 project.

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Source of the graphics

Front cover:
Gallo-Roman harvesting machine, called Vallus. Source: U. Troitzsch - W. Weber (1987): Die Technik : Von den Anfangen bis zur Gegenwart

Rear cover:
Portrait of Columella, in Jean de Tournes, Insignium aliquot virorum icones. Lugduni: Apud Ioan. Tornaesium 1559. Centre d'Études Supérieures de la Renaissance - Tours

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Lucius Junius Moderatus Columella

(AD 4 – 70) is the most important writer on agriculture of the Roman empire. His De Re Rustica in twelve volumes has been completely preserved and forms an important source on agriculture. This book was translated to many languages and used as a basic work in agricultural education until the end of the 19th Century.