TECHNICAL SCIENCE RESEARCH IN UZBEKISTAN
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ESTIMATION OF SOIL NITROGEN, PHOSPHOROUS AND POTASSIUM USING IOT BASED SENSOR

IOT ASOSIDAGI SENSOR YORDAMIDA TUPROQDAGI AZOT, FOSFOR VA KALIY MIQDORINI BAHOLASH

ОЦЕНКА СОДЕРЖАНИЯ АЗОТА, ФОСФОРА И КАЛИЯ В ПОЧВЕ С ИСПОЛЬЗОВАНИЕМ IOT-ДАТЧИКОВ

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Abstract

This study focuses on the development and application of a sensor-based system for monitoring key soil nutrients, namely Nitrogen (N), Phosphorus (P), and Potassium (K). An Arduino-based platform was employed to deploy sensors at multiple locations within the soil, enabling continuous real-time data acquisition. The collected data were systematically processed and analyzed to assess the spatial distribution and concentration of nutrients across the study area. The results were further interpreted through spatial visualization using the Inverse Distance Weighting (IDW) interpolation technique.

The analysis revealed notable spatial variability in soil nutrient levels. Nitrogen concentrations were generally low in several areas, indicating a clear requirement for nitrogen fertilization. In contrast, phosphorus levels were predominantly high, suggesting that additional phosphorus application is unnecessary in most regions. Potassium levels showed localized deficiencies, highlighting the need for targeted potassium fertilization in specific zones.

Overall, the findings provide valuable insights into the dynamics of soil nutrients in agricultural environments and demonstrate the effectiveness of modern technological approaches in supporting precision agriculture and improving nutrient management practices.

Annotatsiya .Ushbu tadqiqot tuproqdagi asosiy oziqa moddalari, ya'ni Azot (N), Fosfor (P) va Kaliy (K) ni monitoring qilish uchun sensorlarga asoslangan tizimni ishlab chiqish va qo'llashga bag'ishlangan. Arduino platformasiga asoslangan tizim yordamida tuproqning turli nuqtalariga sensorlar joylashtirildi va real vaqt rejimida uzluksiz ma'lumotlar yig'ildi. Yig'ilgan ma'lumotlar tizimli ravishda qayta ishlanib, tadqiqot hududi bo'yicha oziqa moddalarning fazoviy taqsimoti va

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konsentratsiyasi tahlil qilindi. Natijalar Inverse Distance Weighting (IDW) interpolatsiya usuli yordamida fazoviy vizualizatsiya orqali tasvirlandi.

Tahlil natijalari tuproq oziqa moddalari darajasida sezilarli fazoviy oʻzgaruvchanlik mavjudligini koʻrsatdi. Azot miqdori bir qator hududlarda past boʻlib, bu azotli oʻgʻitlarga boʻlgan ehtiyojni aniq koʻrsatadi. Fosfor esa asosan yuqori darajada kuzatildi, bu koʻpchilik hududlarda qoʻshimcha fosforli oʻgʻitlash zarur emasligini bildiradi. Kaliy miqdori esa ayrim zonalarda yetishmovchilikni koʻrsatib, aniq hududlarga yoʻnaltirilgan kaliyli oʻgʻitlash zarurligini anglatadi.

Umuman olganda, ushbu tadqiqot natijalari qishloq xoʻjaligi muhitida tuproq oziqa moddalari dinamikasi haqida muhim ma’lumotlar beradi hamda zamonaviy texnologiyalar asosida amalga oshirilgan yondashuvlar aniq dehqonchilik (precision agriculture) va oʻgʻitlashni samarali boshqarishda muhim rol oʻynashini koʻrsatadi.

Аннотация. Данное исследование посвящено разработке и применению сенсорной системы для мониторинга основных питательных веществ почвы, а именно азота (N), фосфора (P) и калия (K). Система на базе Arduino была использована для размещения датчиков в различных точках почвы, что позволило осуществлять непрерывный сбор данных в режиме реального времени. Полученные данные были систематически обработаны и проанализированы для оценки пространственного распределения и концентрации питательных веществ на исследуемой территории. Результаты были визуализированы с использованием метода интерполяции Inverse Distance Weighting (IDW).

Анализ показал значительную пространственную изменчивость уровня питательных веществ в почве. Концентрация азота в ряде участков была низкой, что указывает на необходимость внесения азотных удобрений. В то же время уровень фосфора в большинстве зон был высоким, что свидетельствует об отсутствии необходимости дополнительного внесения фосфорных удобрений. Содержание калия демонстрировало локальные дефициты, что указывает на необходимость целевого внесения калийных удобрений в отдельных зонах.В целом, полученные результаты предоставляют важную информацию о динамике питательных веществ в сельскохозяйственных почвах и демонстрируют эффективность современных технологических подходов в поддержке точного земледелия и оптимизации управления питанием растений.

1. INTRODUCTION

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Maintaining optimal soil fertility is essential for sustainable agricultural production and long-term food security, particularly under the agro-climatic conditions of Uzbekistan. Primary macronutrients such as Nitrogen (N), Phosphorus (P), and Potassium (K) play a crucial role in plant development, directly affecting crop productivity, quality, and resistance to environmental stress. Traditionally, soil nutrient assessment in agricultural practice has relied on periodic sampling and laboratory-based analysis. However, these conventional approaches are often labor-intensive, time-consuming, and may not provide timely information for decision-making.

In recent years, the adoption of Internet of Things (IoT)-based technologies has significantly transformed modern agricultural systems by enabling real-time and remote monitoring of soil conditions. IoT-enabled soil sensors represent an advanced tool in precision agriculture, allowing continuous measurement of soil parameters such as nutrient content, moisture, and pH levels. These systems utilize wireless communication to transmit data to cloud-based platforms, where it can be processed and accessed by farmers and agronomists in real time. Such capabilities support timely and data-driven decisions regarding fertilization, irrigation, and crop management, ultimately improving resource efficiency and crop yield.

Recent studies highlight the growing importance of IoT technologies in agricultural nutrient management. These systems enhance monitoring accuracy and provide timely insights into soil conditions, contributing to improved soil health and sustainable farming practices. Furthermore, the integration of IoT with advanced data analytics, machine learning, and artificial intelligence enables predictive modeling of nutrient requirements based on historical data and environmental conditions. This approach allows optimization of fertilizer application according to crop demand, thereby increasing efficiency while minimizing environmental impacts such as nutrient leaching and soil degradation.

Despite these advancements, several challenges remain, including sensor accuracy, data security, and the economic feasibility of large-scale implementation. Addressing these limitations is essential for the broader adoption of IoT-based agricultural technologies. Additionally, improving user accessibility, providing farmer training, and enhancing digital literacy are critical factors for successful implementation.

This study aims to develop and implement an IoT-based sensor system for estimating soil N, P, and K levels under conditions relevant to Uzbekistan. The research contributes to improving nutrient management strategies and supports the adoption of precision agriculture practices for sustainable farming.

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2. MATERIALS AND METHODS

2.1 Design of Arduino-Based NPK Sensor System Using IoT

The system was developed using an Arduino-based platform integrated with IoT technology to enable real-time monitoring of soil nutrients.

Hardware components included:
1.Arduino board
2.NPK sensor
3.Communication module
4.Wi-Fi or cellular module
4.Power supply
Software components included:

1.Arduino IDE
2.IoT platform for data transmission and monitoring

The sensor system was assembled according to standard circuit design principles. The NPK sensor was connected to the Arduino board based on its technical specifications. Communication modules were integrated to enable data transmission. Proper power supply connections were ensured for stable system operation. The sensor system provided measurement accuracy up to 1 mg/L.

The Arduino program was developed to collect and process data from the sensors. Communication protocols were implemented to transmit data to the IoT platform. The system was tested under field conditions to evaluate its accuracy and reliability.

2.2 Estimation of Soil N, P, and K

The NPK sensor probes were installed at multiple locations within agricultural fields. These sensors continuously measured nutrient concentrations in the soil. The collected data were processed using computational algorithms to determine the levels of nitrogen, phosphorus, and potassium based on calibration models.

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The analyzed data were further visualized using spatial interpolation techniques (IDW method), allowing the creation of nutrient distribution maps. Based on established agronomic standards adapted to regional conditions, soil samples were classified into low, medium, and high nutrient categories.

3. RESULTS AND DISCUSSION

The analysis of soil samples from different locations revealed significant spatial variability in nutrient content.

Nitrogen (N):

The results indicated that nitrogen levels ranged approximately from 12 to 44 kg/ha across the studied areas. According to agronomic standards applicable to Uzbekistan, these values correspond to low nitrogen availability. The lowest nitrogen levels were observed in open field areas and cultivated lands, indicating widespread nitrogen deficiency. Even the highest recorded values remained within the low category, emphasizing the need for systematic nitrogen fertilization strategies. These findings are consistent with regional studies showing that nitrogen is often a limiting nutrient in agricultural soils, particularly under intensive cropping systems.

Phosphorus (P):

Phosphorus levels varied significantly, ranging from low to high across different locations. Some areas exhibited low phosphorus content, particularly in intensively cultivated fields, while moderate levels were observed near irrigated zones. High phosphorus concentrations were detected in areas with long-term fertilizer application or organic matter accumulation, such as orchards. These results suggest that phosphorus management should be site-specific, as excessive application in already sufficient areas may not be necessary.

Overall, the findings highlight the importance of spatially targeted nutrient management in Uzbekistan's agricultural systems. The use of IoT-based sensor technologies provides an effective approach for monitoring soil fertility and supports precision agriculture practices aimed at improving productivity while ensuring environmental sustainability.

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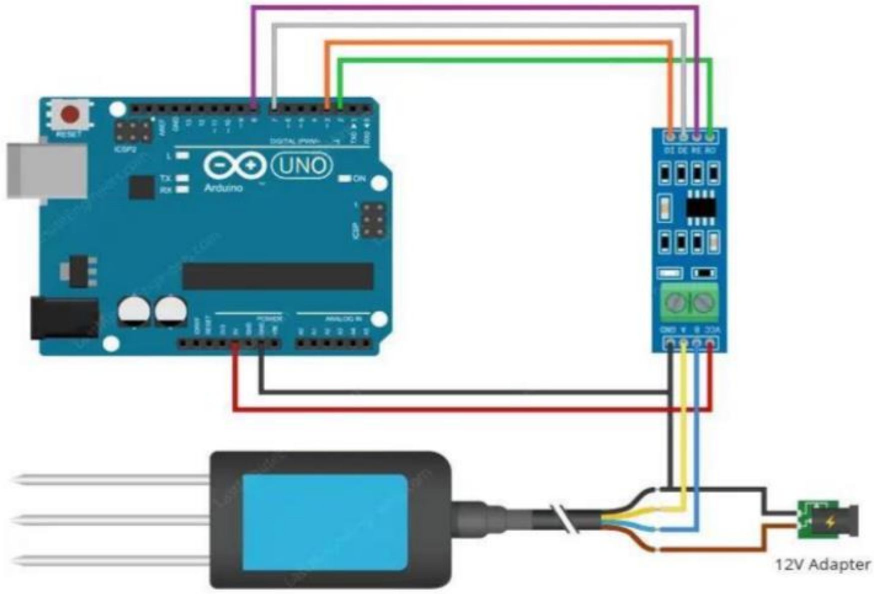

Table 1. Spatial distribution of soil nitrogen (N), phosphorus (P), and potassium (K) across study locations

No	Location Name	N (kg/ha)	P (kg/ha)	K (kg/ha)	Category
1	New Building (upper left area)	22	28	85	N–Low, P–High, K–Low
2	Dormitory (upper right area)	26	32	95	N–Low, P–High, K–Low
3	Main Block Front	18	25	70	N–Low, P–Medium, K–Low
4	Main Block Back Side	20	27	75	N–Low, P–High, K–Low
5	Tree Garden (lower left green zone)	30	35	110	N–Low, P–High, K–Medium
6	Roadside Area	15	20	60	N–Low, P–Medium, K–Low
7	Central Open Field	17	22	65	N–Low, P–Medium, K–Low

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No	Location Name	N (kg/ha)	P (kg/ha)	K (kg/ha)	Category
8	Greenhouse / Technical Zone	28	40	120	N–Low, P–High, K–Medium
9	Open Dry Area (lower right zone)	12	18	50	N–Low, P–Medium, K–Low
10	Green Area (near central zone)	25	30	100	N–Low, P–High, K–Low

Spatial analysis of soil nutrient distribution across the study area reveals significant variability in nitrogen (N), phosphorus (P), and potassium (K) levels. However, a consistent pattern of nitrogen deficiency was observed in all sampled locations. Nitrogen values ranged from 12 to 30 kg/ha, indicating that all zones fall within the **low nitrogen category**, which is below the recommended threshold for optimal plant growth.

Similar to these findings, earlier studies by Gupta and Sharma [13,14] highlight that nitrogen is the most rapidly depleted nutrient in soil systems and frequently becomes a limiting factor in plant productivity. The present study strongly supports this observation, as none of the sampling locations met sufficient nitrogen levels, suggesting an urgent need for nitrogen supplementation across the entire study area.

In contrast, phosphorus levels exhibited moderate variability, ranging from 18 to 40 kg/ha. Certain locations such as the **technical/greenhouse zone (40 kg/ha)** and **dendropark area (35 kg/ha)** showed relatively high phosphorus content, while other zones such as roadside and open areas demonstrated medium levels. This indicates that phosphorus management should be site-specific rather than uniform.

Potassium (K) distribution also showed notable spatial variation, with values ranging from 50 to 120 kg/ha. The highest potassium concentration was observed in the **technical zone (120 kg/ha)**, whereas the lowest was recorded in the **dry open area (50 kg/ha)**. Overall, potassium levels varied from low to medium-high categories depending on land use type and vegetation cover.

The spatial heterogeneity of nutrient distribution clearly demonstrates the importance of precision agriculture approaches. The variation across short distances indicates that uniform fertilizer application would be inefficient and potentially environmentally harmful. Therefore, site-specific nutrient management strategies are essential for optimizing soil fertility and improving agricultural productivity.

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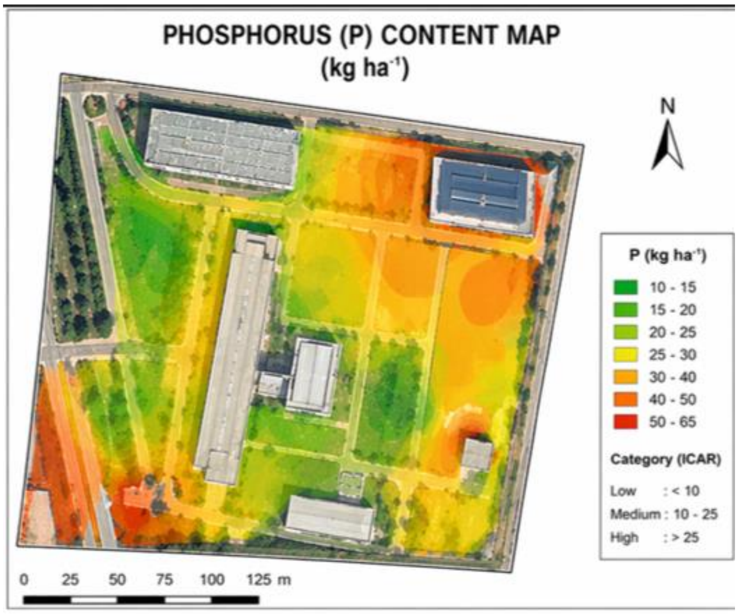

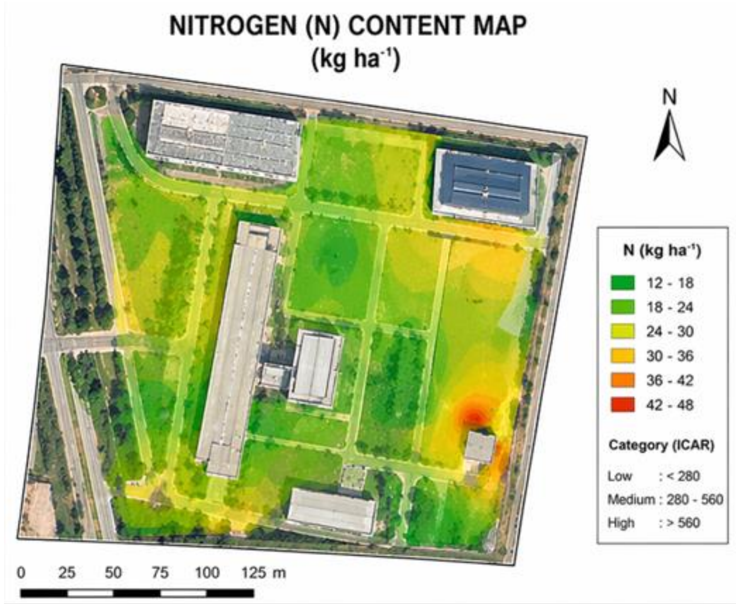

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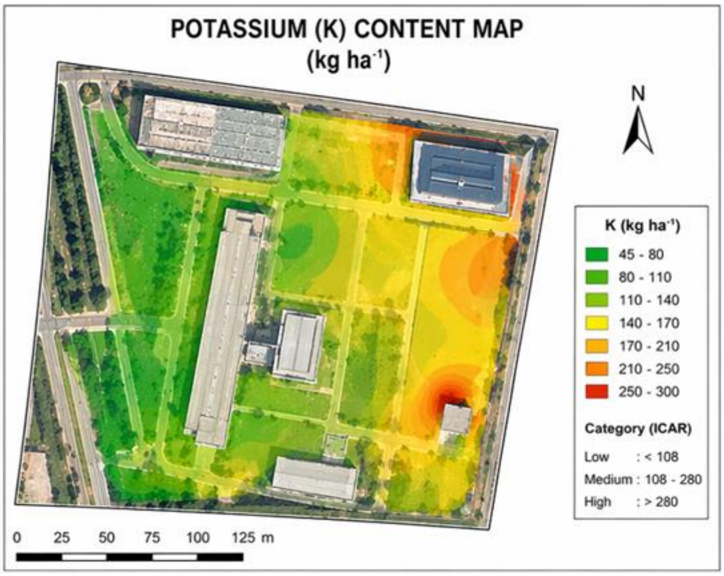

4. CONCLUSION

The present study demonstrates the effectiveness of spatial soil nutrient analysis for evaluating nitrogen, phosphorus, and potassium distribution across heterogeneous land use zones. The results clearly indicate a widespread **nitrogen deficiency across all sampling locations**, confirming that nitrogen is the most limiting nutrient in the study area.

In contrast, phosphorus and potassium levels exhibited moderate spatial variability, with some areas showing sufficient or high concentrations. This suggests that blanket fertilizer application is not suitable for the study area, and nutrient management should instead be tailored based on spatial variability.

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The findings highlight the importance of precision agriculture techniques, including IoT-based sensing and spatial mapping, for improving fertilizer efficiency and soil health management. Implementing site-specific nitrogen fertilization strategies is strongly recommended to enhance soil productivity and ensure sustainable land management practices.

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