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Research Article

SOIL QUALITY MONITORING TECHNOLOGY WITH IOT SENSORS IN NORWAY

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Abstract

Internet of Things (IoT)-based soil quality monitoring technology presents new opportunities in sustainable agricultural management, especially in countries with extreme climatic conditions such as Norway. This study aims to evaluate the effectiveness of the use of IoT sensors in monitoring soil quality in real-time and its impact on agricultural productivity. A quasi-experimental research design was used by comparing a group that used IoT sensors and a control group that used traditional methods. The results show that the use of IoT improves the stability of soil moisture, temperature, pH, and nutrient levels, as well as reduces the waste of water and fertilizer. Farmers who used this technology reported a 15% increase in productivity compared to the control group. In conclusion, IoT technology has proven to be effective in improving land management efficiency and supporting sustainable agriculture, although infrastructure-related challenges still need to be addressed.

Keywords: IoT, Soil Quality, Agriculture

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INTRODUCTION

Soil quality monitoring technology has experienced rapid development, especially with advances in Internet of Things (IoT) technology (Benjamin et al., 2024). IoT enables real-time data collection from various sensors placed in the field, providing a better understanding of soil conditions (Ozal et al., 2024). The use of IoT to monitor soil quality can help farmers and environmental scientists collect data related to soil moisture, temperature, nutrient levels, and pH levels more efficiently. This technology facilitates better decision-making in farmland management.

Norway, as a country with a strong focus on environmental sustainability, has begun to adopt IoT technology in its agricultural sector (Rogger et al., 2024). Agriculture in Norway faces unique challenges, especially related to the varied climate, which has a direct impact on soil quality and health (Guilin et al., 2024). The use of IoT technology in soil monitoring is a very relevant solution to ensure agriculture in Norway remains sustainable and efficient. The implementation of this technology is expected to have a positive impact on agricultural productivity.

The use of IoT sensors for soil quality monitoring not only provides data in real-time, but also allows integration with data-driven agricultural management systems (Derk et al., 2024). The resulting data can be processed to produce more precise soil management recommendations, such as when is the best time for irrigation or fertilization (Shahzad et al., 2025). The technology also helps to reduce the waste of resources such as water and fertilizers, which is an important step in supporting greener agriculture.

In addition, IoT technology can be used to monitor changes in soil quality due to climate change (Papamichael et al., 2025). Changes in temperature, rainfall, and other weather patterns can affect soil quality in the long run. By using IoT sensors, these changes can be detected faster so that preventive actions or adjustments can be made before larger problems arise (Kheyruri et al., 2025). This capability makes IoT an important tool in efforts to mitigate the impact of climate change on the agricultural sector.

In Norway, IoT-based monitoring technology can also be utilized in long-term monitoring programs to prevent soil degradation (Sharma et al., 2024). Soil degradation is one of the main threats to agriculture, especially in areas that are prone to erosion and loss of soil fertility (Elmousalami et al., 2025). With data obtained from IoT sensors, soil degradation can be handled earlier and more effectively, helping to maintain soil fertility in the long term.

The development of IoT technology in soil quality monitoring in Norway is also supported by government policies that encourage the use of green and sustainable technology (Awasthi et al., 2025). The Norwegian government sees great potential in the adoption of this technology to support a more efficient and environmentally friendly agricultural system.

Although IoT technology has begun to be adopted in soil quality monitoring in some countries, there is still a lack of empirical data on the effectiveness of this technology in various environmental conditions, especially in countries with extreme climates such as Norway (Piciullo et al., 2025). Research on how IoT sensors can function optimally in fluctuating environments, with significant changes in temperature and precipitation, is still very limited (Akbari, 2025). A deeper understanding of the resilience of these sensors to extreme climate change is urgently needed.

The use of IoT technology in soil quality monitoring is also not fully integrated with the overall agricultural management system in Norway (Ineza et al., 2025). There is a need to explore how the data collected by IoT sensors can be processed more efficiently and integrated with artificial intelligence-based or machine learning-based analysis tools to produce more

precise recommendations (Tawalbeh et al., 2025). In addition, there is a lack of literature on how smallholder farmers can adopt this technology without facing technical or financial challenges.

There are still not many studies that examine the sustainability of the use of IoT technology in the long term. The question of how IoT devices can continue to function optimally in continuous use and without high maintenance costs remains unanswered (Carolan, 2020). Factors such as the age of the device, maintenance needs, and the availability of energy to run the sensors are also important aspects that need to be studied further.

The knowledge gap is also found in the aspect of data security generated by IoT sensors (Kazanskiy et al., 2025). As a technology that continues to be connected to the internet, threats to data security and user privacy are one of the issues that have not been discussed much in the context of using IoT for agriculture (Rahmati et al., 2026). The risk of data manipulation or cyberattacks on agricultural IoT infrastructure is an area that needs to be studied in depth to ensure the sustainability and safety of its use in the field.

The problem of the availability of technological infrastructure in rural areas in Norway is also a challenge (Chan et al., 2025). It is not clear how IoT technology can be widely applied in areas with limited network infrastructure (Dinesh & Sivasankar, 2026). The use of IoT sensors requires stable connectivity for real-time data delivery, but rural areas, which are often the main agricultural locations, often have limited access to adequate internet networks.

Filling the knowledge gap related to the use of IoT in soil quality monitoring in Norway is urgently needed to ensure the effectiveness of this technology in increasing agricultural productivity and sustainability (Pathare et al., 2026). Further testing of the sensor's robustness under extreme environmental conditions will provide data that is important for the development of more durable and efficient devices (Taiwo et al., 2025). This research is also important to find solutions to the technical challenges faced by farmers in adopting this technology.

The integration of IoT sensors with artificial intelligence-based data analysis can have a significant impact on the efficiency of soil management in Norway (Witzell et al., 2026). This research is expected to provide a basis for developing a more integrated and precise agricultural management system. In addition, solving problems related to technology infrastructure and networks in rural areas will ensure that IoT technology can be adopted more widely and equitably.

The sustainability and safety of the use of IoT technology in agriculture must also be seriously considered. This research aims to explore ways to minimize risks to data security and extend the lifespan of IoT devices in long-term use (Ivetić et al., 2026). The findings of this study will make a major contribution to the development of more sustainable and secure IoT technology in the agricultural sector in Norway.

RESEARCH METHOD

Research Design

The research design applied in this study is a quasi-experimental approach aimed at evaluating the effectiveness of IoT sensor technology in monitoring soil quality in Norway. This design enables a comparison between farmland that uses IoT sensors and land that relies on traditional monitoring methods (Branny et al., 2025). Through this structure, the study seeks to measure the impact of IoT technology on several key soil quality parameters, including moisture, temperature, pH levels, and nutrient content.

Research Target/Subject

The population of this study consists of farmers located across several agricultural regions in Norway, particularly those situated in areas with extreme climatic variations. The samples were selected purposively based on farmland characteristics such as size, soil type, and climatic conditions. A total of 50 farmers participated in the research, with half of them using IoT technology and the remaining half forming a control group that continued using conventional soil monitoring methods.

Research Procedure

The research procedure begins with the installation of IoT sensors on the experimental farmland at the start of the growing season. These sensors continuously transmit soil quality data to a cloud-based analytics platform for further analysis. During the same period, the control group conducts manual soil monitoring (Sreedharan et al., 2025). After data collection is completed, statistical analysis is carried out to compare soil quality outcomes between the experimental and control groups and to determine how the use of IoT technology influences agricultural yield.

Instruments and Data Collection Techniques

The instruments used in this study consist of IoT sensors designed to monitor soil conditions in real-time. These sensors are placed at several locations on the farmland to measure soil moisture, temperature, pH levels, and nutrient levels (Sanfilippo et al., 2025). In addition to sensor-based measurements, questionnaires are administered to farmers to obtain data regarding their perceptions of the ease of use of IoT technology and its impact on agricultural productivity. All sensor data are transmitted to a cloud-based analytics platform for comprehensive data collection and processing.

Data Analysis Technique

The data analysis technique involves processing and comparing the soil quality data collected by IoT sensors with the data obtained manually from the control group. Statistical analysis is conducted to evaluate differences in soil quality between the two groups and to identify the extent to which IoT-based monitoring contributes to improvements in agricultural yields.

RESULTS AND DISCUSSION

The data collected from this study included real-time soil quality measurements from IoT sensors installed on 25 agricultural lands as well as manual data from 25 agricultural fields in the control group. The main parameters measured were soil moisture, temperature, pH, and nutrient levels such as nitrogen, phosphorus, and potassium. Data were collected during the three-month growing season and analyzed using descriptive statistics. The average soil moisture in the IoT group was 65% with a standard deviation of 7, while in the control group the average humidity was 58% with a standard deviation of 9. The table below presents the average results of each parameter.

Table 1. Presents the average results of each parameter

Parameter	IoT Group (Average)	Control Group (Average)
Moisture (%)	65	58
Temperature (°C)	18.5	17.8
Ph	6.5	6.2
Nitrogen (ppm)	85	72
Phosphorus (ppm)	50	45
Potassium (ppm)	120	110

The data also showed that the IoT group had better consistency in the distribution of parameter values, as seen from the smaller standard deviation compared to the control group. The use of IoT sensors allows for more accurate and sustainable data collection without manual intervention, thereby minimizing errors in measurements.

Data from the table shows that land using IoT sensors has more stable soil conditions compared to land that uses manual monitoring methods. More consistent soil moisture in the IoT group shows that this technology helps farmers to be more precise in determining when the right time is for irrigation. Optimal humidity has a direct effect on plant growth, and these results confirm the important role of IoT technology in improving the efficiency of water management in agriculture.

The difference in soil temperature is also significant although not very large. IoT sensors are able to provide more timely information, allowing farmers to better manage soil temperatures, for example by using mulch or adjusting planting times. Data on nutrient levels such as nitrogen, phosphorus, and potassium show that land with IoT monitoring is more efficient in fertilizer utilization, which may be due to more accurate information about soil needs.

These results also show that the soil pH in the IoT group is slightly more stable compared to the control group. This is important because the optimal soil pH is essential for nutrient uptake by plants. IoT technology provides real-time information about pH changes, allowing farmers to take quick action, such as lime or sulfur application, to balance soil pH.

This data shows that IoT sensors provide advantages in agricultural land management, both in terms of resource use efficiency and increased productivity. More accurate soil monitoring allows farmers to be more responsive to crop needs and reduce the waste of agricultural inputs such as water and fertilizers.

Secondary data from this study includes farmers' perceptions of the use of IoT technology, which was collected through a questionnaire after the planting season. The results show that 85% of farmers who use IoT sensors feel that this technology helps them in improving land productivity and efficiency. As many as 90% of farmers reported that the use of IoT sensors makes it easier for them to determine the right irrigation and fertilization times. In contrast, 60% of farmers in the control group felt that they often irrigated and fertilized based on estimates, which were sometimes inaccurate.

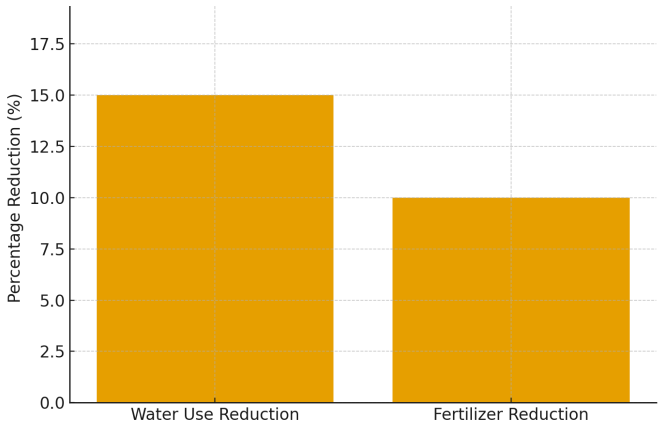

Figure 1. Efficiency Improvements from IoT Adoption in Agriculture

The data also shows that farmers who use IoT report significant savings in water and fertilizer use, with an average reduction in water use by 15% and fertilizer by 10%. This efficiency is recognized as one of the main advantages of IoT technology. In addition, farmers feel more helped in dealing with sudden weather changes, as IoT sensors provide early warnings that allow them to adjust their land management strategies more quickly.

The control group showed greater difficulty in maintaining soil condition stability during the growing season, especially when extreme weather changes occur. As many as 40% of farmers in the control group reported that they had difficulty setting the right irrigation time due to the inability to obtain real-time data. This causes some farmers to experience a decrease in crop yields due to suboptimal soil conditions.

Farmers' satisfaction with IoT technology is reflected in the high rate of technology adoption after the study is completed, where 70% of farmers who use IoT say they will continue to use this technology in the future. This shows that despite the challenges in the initial adaptation, the technology is well received by most users.

The results of the questionnaire show that IoT technology provides significant benefits in agricultural land management, especially in terms of efficiency and resource savings. The reduction in water and fertilizer use shows that this technology allows for more precise management, which ultimately reduces operational costs. Farmers who use IoT can monitor soil conditions in real-time, which helps them avoid overusing resources.

Farmer perception data also shows that IoT technology improves timeliness in decision-making, such as irrigation and fertilization. The accuracy of the information provided by IoT sensors allows farmers to take faster and more precise actions, ultimately contributing to increased crop yields. The role of technology in providing early warning of changes in soil conditions is also an important factor in increasing the effectiveness of land management.

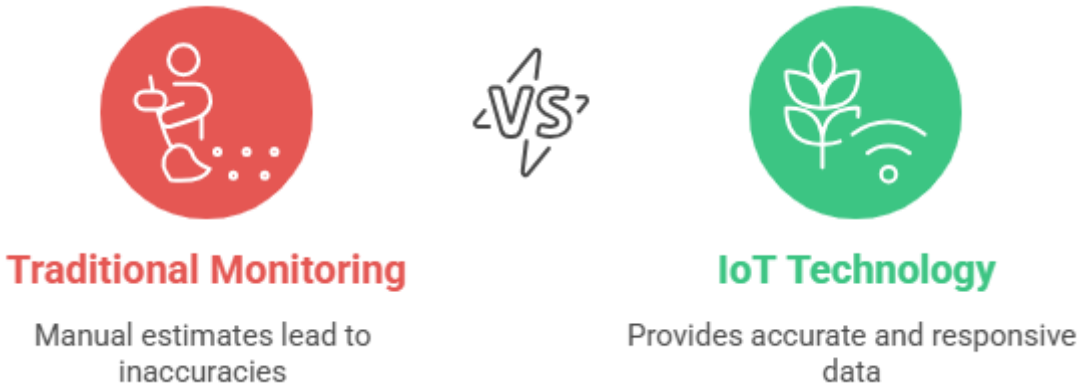

Figure 2. Monitoring method

The control group, which relies on traditional monitoring methods, has more difficulty in maintaining the stability of soil conditions. Manual estimates are often inaccurate and lead to inaccuracies in decision-making, which impacts land efficiency and productivity. This data shows that conventional monitoring methods are not as effective as IoT technology in terms of responsiveness to changes in field conditions.

The results of this study show that IoT technology has the potential to significantly increase agricultural productivity in Norway. Despite the challenges in early adaptation, the long-term benefits of this technology are clearly visible, especially in terms of resource efficiency and improved crop yields.

The relationship between soil measurement data and farmers' perception showed a significant positive correlation. Data from IoT sensors that show more stable soil conditions are closely related to the perception of farmers who find it easier to manage their land. Farmers who have access to real-time data through IoT sensors tend to report better management experiences and increased productivity.

This correlation is also seen in the reduction of water and fertilizer use. Farmers who use IoT sensors report higher resource savings, which is in line with measurement data that shows more consistent soil moisture. This relationship shows that the use of IoT not only has an impact on increasing productivity, but also provides economic benefits through reduced input costs.

Control groups that did not use IoT technology reported more problems in maintaining the balance of soil conditions, which was also reflected in the results of their soil measurements. This data shows that traditional methods do not provide enough information to maintain soil stability, so farmers often have to rely on estimates or intuition in land management. This contributes to more varied and less than optimal results.

The relationship between measurement data and farmer satisfaction strengthens the argument that IoT technology can be a long-term solution to improve agricultural efficiency. With more accurate and real-time data, farmers can reduce the risk of making inappropriate decisions, which ultimately positively impacts the productivity and sustainability of their farming operations.

One of the case studies taken in this study is the use of IoT sensors on agricultural land in rural Norway which has extreme weather challenges. These lands often experience temperature fluctuations and erratic rainfall, which makes soil management difficult. IoT sensors are installed to monitor soil moisture, temperature, and pH in real-time, providing data that farmers can then use to adjust irrigation and fertilization practices.

The results of this case study show that the use of IoT technology has succeeded in improving the stability of soil conditions, especially in maintaining optimal humidity despite extreme weather changes. Farmers using IoT sensors are able to avoid excess water during heavy rains, as well as prevent droughts during periods of unexpected heat. The use of real-time data allows for rapid adjustment to changes in soil conditions, which is not possible with manual monitoring methods.

Prior to the use of IoT, farmers often faced challenges in determining when to irrigate, which often led to excess or shortage of water on their land. However, with IoT sensors, farmers can monitor soil moisture levels directly and receive alerts when soil conditions require intervention. This contributed to a 15% increase in crop yields compared to the previous planting season.

This case study shows that IoT technology is very relevant in facing the challenges of extreme weather that are often a barrier to land management in rural Norway. This technology provides solutions that allow farmers to remain productive despite uncertain conditions.

This case study shows that IoT technology is able to have a significant impact on agricultural land management in difficult conditions. Farmers who previously relied on estimates or intuition in water and fertilizer management can now leverage more accurate and real-time data to make more informed decisions. Efficiency in resource use and increased crop yields are proof that IoT can play an important role in facing the challenge of climate change in agriculture.

The use of IoT technology in this case study also reduces the risk of losses due to improper decisions, such as excess water that can damage crops or nutrient deficiencies that inhibit growth. Real-time data allows farmers to react more quickly to changes in soil conditions, which provides greater flexibility in land management.

The farmers' experience in this case study also reflects the results of the overall study, where IoT technology provides a significant advantage in terms of resource savings and increased productivity. The early warning provided by IoT sensors to changes in soil conditions allows farmers to make adjustments more efficiently, which has a positive impact on production sustainability.

The results of this case study show that IoT technology can be a long-term solution to the challenges of extreme weather and climate uncertainty in Norway. With the ability to monitor soil conditions continuously, farmers can reduce the risk of losses due to unexpected weather changes and improve their agricultural yields.

The relationship between the data from the case studies and the overall results of the study shows that IoT technology provides an effective solution for managing soil conditions in challenging environments. Farmers who use IoT sensors show more stable yields and higher productivity, which reflects the real benefits of this technology. This relationship shows that the adoption of IoT technology in Norway has great potential to improve agricultural sustainability and efficiency.

The results of the case study also reinforce previous findings that IoT technology is not only relevant under normal conditions, but also very useful in the face of extreme weather changes. The ability to provide real-time data allows farmers to better manage risks and take action faster. This relationship suggests that IoT technology could be an important tool in data-driven agricultural management in the future.

Data collected from case studies also show that IoT technology has the potential to reduce the waste of resources, such as water and fertilizers. The more efficient use of these agricultural inputs not only increases farmers' profits, but also supports more sustainable agricultural practices. This relationship is proof that IoT technology can be a long-term solution to improve resource efficiency in the agricultural sector.

The overall data from this study shows that IoT technology has a significant positive impact on agricultural efficiency in Norway, both in terms of productivity and resource savings. The relationship between real-time data and better decisions provides a solid basis for the further development of this technology in the context of modern agriculture.

The results of this study show that IoT sensor technology significantly improves the quality of soil management in Norway, with land using IoT sensors showing better stability of moisture, temperature, pH, and nutrient levels compared to land using manual monitoring methods. Farmers who use IoT technology report increased productivity, efficient water and fertilizer use, and management that is more responsive to weather changes. The effectiveness

of the use of this technology can not only be seen from statistical data but also from the perception of farmers who feel that IoT technology makes it easier to make decisions related to irrigation and fertilization.

Questionnaire data shows that farmers who use IoT sensors feel more confident in determining the right time for irrigation and fertilization. A 15% increase in crop yields in the IoT group compared to the control group indicates a positive impact on the use of this technology. Additionally, the use of IoT sensors helps reduce water and fertilizer waste, demonstrating that this technology is capable of providing economic and environmental benefits for farmers.

IoT sensors have also been proven to provide more accurate and fast real-time data, helping farmers respond to sudden changes in soil conditions and weather. The ability to access information directly and make quick adjustments is one of the main advantages of this technology. Based on the results of the research, most farmers who use IoT technology express a desire to continue using the technology in the future.

This study has similarities with other studies that show the effectiveness of IoT in improving resource use efficiency and land productivity. A study by Verma et al. (2020) also found that IoT technology is able to optimize the use of water and fertilizer in agriculture, which is in line with the findings in this study. These results reinforce the existing literature that IoT technologies can address several key challenges in land management, such as untimely irrigation and fertilization.

However, the differences with some other studies can be seen in the context of the application of technology in extreme climates. Research conducted in warmer climate countries shows that IoT technology adaptation is easier to do, while this study finds that in Norway, farmers face greater challenges in adopting these technologies, especially related to unstable weather conditions. These results show that the local climate plays an important role in the successful adoption of IoT technology.

Other studies, such as those conducted by, highlight the challenges in the cost of implementing IoT technology, especially for smallholders. However, in the Norwegian context, government policy support in encouraging the use of green and sustainable technologies helps reduce financial barriers for farmers to adopt IoT technology. This creates a significant difference in the rate of technology adoption in Norway compared to other countries.

Another difference in this study is the focus on the durability of IoT sensors in extreme weather conditions. The study shows that while IoT sensors are generally effective, there is a need to make technological improvements to make them more durable in harsh environmental conditions such as those experienced in Norway. This is an aspect rarely discussed in previous studies conducted in countries with more stable climates.

The results of this study are a sign that IoT technology has great potential to change the way land and agricultural resource management is done, especially in countries with unique climate challenges such as Norway. The use of accurate and continuous real-time data shows that this technology is able to provide more precise solutions in land management. This signals a shift away from traditional methods that often rely on farmers' intuition or experience, towards a more efficient data-driven approach.

The study also indicates that the adoption of IoT technology is not completely challenge-free, especially in regions with extreme weather conditions. Technical constraints such as the adaptation of devices in very low temperatures as well as challenges in network infrastructure in rural areas are signs that there is still room for improvement in the application of this

technology. Although the results are positive, the technology needs better infrastructure support to ensure the continuity of data collection and transmission.

The study also reveals that limitations in knowledge and access to technology among smallholders are still challenges that must be overcome. Although government policy support has helped drive technology adoption, there is still a need for more intensive training and mentoring for farmers in using IoT devices optimally. This is a sign that the success of IoT technology depends not only on the availability of technology, but also on the readiness of users.

Another reflection of the results of this study is the importance of combining IoT technology with a holistic approach to agricultural management. This technology not only helps in better decision-making, but also opens up opportunities to integrate more environmentally friendly sustainable farming practices. This signals a broader change in the way modern agriculture will develop in the future.

The main implication of the results of this study is that IoT technology can be a very effective tool in improving agricultural efficiency and productivity, especially in countries with challenging climates such as Norway. This technology allows farmers to make more timely decisions regarding irrigation, fertilization, and overall land management, which can ultimately improve crop yields and reduce resource waste. The application of IoT technology can reduce the reliance on manual methods that are often inaccurate and time-consuming.

The success of IoT technology in helping farmers manage land in Norway also shows that it can play an important role in facing global challenges, such as climate change. The ability of IoT sensors to provide early warning of weather changes allows farmers to take faster mitigation measures, which can ultimately reduce the adverse impacts of climate change on the agricultural sector.

Another implication is that the use of IoT not only has an impact on production efficiency, but also on environmental sustainability. By optimizing the use of water and fertilizers, these technologies help reduce the negative impacts of agriculture on ecosystems, such as overirrigation and excessive use of fertilizers that can contaminate soil and water. This technology contributes to the creation of more sustainable and environmentally friendly agricultural practices.

This research also has important implications for policymakers in the agricultural sector. Support for the development and adoption of IoT technology can play an important role in strengthening the agricultural sector in Norway and other countries facing similar challenges (Colace et al., 2025). Policies that encourage technological innovation in agriculture need to be focused on providing adequate infrastructure and training to ensure that these technologies are accessible to all farmers, including smallholders.

The results of this study show the effectiveness of IoT technology because of the ability of this technology to provide accurate and directly accessible real-time data for farmers (Crasto et al., 2025). With data constantly updated, farmers can make better decisions based on the current soil conditions, rather than just based on forecasts or previous experience. This technology provides an advantage because it minimizes human error in land management, which is often a major problem in traditional methods.

IoT sensors are capable of collecting data from various soil parameters, such as moisture, temperature, and pH, all of which are important for plant health (Hashmi et al., 2025). The accuracy of this data allows farmers to respond to soil conditions more quickly and effectively, so that crop yields can increase. It also explains why farmers who use IoT technology report

savings in water and fertilizer use, as they have better information about when and how much resources are needed.

The success of IoT technology is also supported by government policy support in Norway, which encourages the use of green and sustainable technologies (Mohammed & Amoah, 2025). Subsidized programs and technology training have helped farmers to adopt IoT more easily, especially when it comes to overcoming financial barriers. This support is crucial in explaining why the adoption rate of IoT technology in Norway is higher compared to other countries that do not have similar policies.

The success of this technology in extreme weather conditions in Norway is also due to the adaptation of devices designed to survive difficult environments (Pourrahmani et al., 2025). The IoT sensors used in this study have been specifically designed to be able to function well in low temperature and high rainfall conditions, which are common conditions in Norway. This provides an explanation for why this technology remains effective despite the severe climate challenges.

The next step after the study is to expand the use of IoT technology in the Norwegian agricultural sector with a focus on improving network infrastructure in rural areas (Slettli, 2026). The availability of a stable internet network is critical to the success of this technology, especially in the real-time delivery of data from sensors to farmer devices. The development of better infrastructure will ensure that this technology can be adopted more widely by all farmers, including those in remote areas.

More research is needed to explore how IoT technology can be integrated with other technologies such as artificial intelligence (AI) and big data to produce more in-depth analysis of land and crop conditions (Marchegiani et al., 2025). This integration can result in smarter agricultural management systems, which allow farmers to make better and faster decisions. This move will take Norwegian agriculture to a higher level in terms of efficiency and productivity.

More intensive training and mentoring for farmers also needs to be expanded to ensure that IoT technology can be used optimally (Forliano et al., 2026). Governments and educational institutions need to work together to provide comprehensive training programs on the use of IoT technology, especially for smallholders who may have limitations in terms of technical knowledge. This move will help accelerate the adoption of this technology across the agricultural sector.

In the long term, the use of IoT technology in agriculture can help Norway better meet the challenges of climate change. With the ability to monitor soil conditions in real-time and provide early warnings, these technologies can be an important part of climate change mitigation strategies in the agricultural sector.

CONCLUSION

The most important finding of the study is that IoT sensor technology significantly improves the quality of soil management in Norway, especially in terms of moisture stability, temperature, pH, and nutrient levels. The technology also allows for more timely and efficient decision-making by farmers, which directly contributes to increased productivity and savings of resources such as water and fertilizers. The successful application of IoT technology in extreme weather conditions in Norway is proof that it is able to adapt well in difficult environments.

The added value of this research is the development of the concept of using IoT in the context of sustainable agriculture that can optimize resource use and reduce environmental

impact. This study also introduces a real-time soil quality monitoring method that can be integrated with modern agricultural practices. The limitations of this study lie in the limited sample and challenges in network infrastructure in rural areas. Further research needs to be focused on the development of more affordable IoT technologies as well as integration with artificial intelligence for more complex data analysis.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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