BBASR PUBLISHERS

Biological and Agricultural Sciences Research Journal
eISSN: 2959-653X; pISSN: 2959-6521
www.basrj.com
DOI: https://doi.org/10.54112/basrj.v2023i1.14
Biol. Agri. Sci. Res. J., Volume, **2***: 14*

BASRJ

Review Article

OPEN ACCESS

Check for updates

SATELLITES TO AGRICULTURAL FIELDS: THE ROLE OF REMOTE SENSING IN PRECISION AGRICULTURE

FAKHAR MI[1], *KHALID MN[2]

[1]Department of Land and Water Conservation Engineering, PMAS Arid Agricultural University, Rawalpindi 46000, Pakistan
[2]Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan

**Correspondence author email address:* noumankhalidpbg@gmail.com

(Received, 6th February 2023, Revised 10th July 2023, Published 15th July 2023)

Abstract: *Precision agriculture, driven by the growing demand for sustainable farming practices, relies heavily on technologies such as remote sensing. Despite its critical role, a comprehensive review of remote sensing within the context of precision agriculture remains sparse. This paper aims to bridge this gap by providing a thorough overview of remote sensing technologies, their applications, challenges, future trends, and potential impact on precision agriculture. Employing a literature review methodology, we analyzed key studies to comprehend precision agriculture's evolution and remote sensing technologies' significant role. Our examination encompassed various remote sensing applications, from crop health monitoring to yield estimation, soil mapping, irrigation management, and pest and disease detection. We also evaluated emerging trends and identified challenges such as the need for high-resolution data, atmospheric disturbances, and requisite technical expertise for effective data interpretation. Despite these challenges, the review underscores the transformative potential of remote sensing technologies in advancing precision agriculture. Future research should prioritize addressing these challenges and strive to make these technologies more accessible and affordable. Moreover, integrating remote sensing with artificial intelligence and machine learning in interdisciplinary research could further bolster the efficacy and potential of precision agriculture.*

[*Citation: Fakhar, MI., Khalid, M, N. (2023). Satellites to agricultural fields: the role of remote sensing in precision agriculture. Biol. Agri. Sci. Res. J.,* ***2023****:* ***14****. doi:* https://doi.org/10.54112/basrj.v2023i1.14]
Keywords: precision agriculture; remote sensing; irrigation management; sustainable farming

Introduction

Precision agriculture is a contemporary approach integrating advanced technologies into farming practices to maximize efficiency, productivity, and sustainability (Schimmelpfennig, 2016). The sector has witnessed a considerable shift from traditional farming methods to a more sophisticated approach known as precision farming or precision agriculture. Numerous technological advancements have facilitated this shift; remote sensing technology holds a significant role. Initially, agriculture was predominantly based on intuition and experience. Farmers had to make decisions relying on their inherent knowledge accumulated over generations. However, as societies evolved and the demand for agricultural products increased, there was a crucial need to increase productivity without compromising environmental sustainability (Tey & Brindal, 2012). Traditional farming practices often applied resources uniformly across fields, irrespective of the spatial and temporal needs of different crops. This one-size-fits-all approach led to wasted resources and caused significant environmental harm, including soil degradation and water pollution. To address these issues, precision agriculture came into being.

Precision agriculture is a farming management concept based on observing, measuring, and responding to inter and intra-field crop variability (Zhang & Kovacs, 2012). The fundamental principle is that variability exists within a field. Recognizing and addressing this variability can result in more efficient use of farming inputs, such as water, fertilizer, and pesticides, increasing crop productivity and decreasing environmental impact. This principle has led to various technologies and methodologies that help observe and quantify variability, such as GPS, yield monitors, variable rate technology, and, more importantly, remote sensing (Bongiovanni & Lowenberg-DeBoer, 2004). Remote sensing technology is a crucial component of precision agriculture, allowing farmers and agricultural professionals to collect data about their crops without physical contact. This data collection is facilitated by various sensors mounted on different platforms such as satellites, airplanes, or drones. These sensors can collect data in various forms, such as imagery, that can be processed and interpreted to provide valuable insights about the crop or the field (Li, Zhang, & Huang, 2014).

The introduction of satellite-based remote sensing was a game-changer in precision agriculture. Satellites provide vast, consistent, and high-quality data, offering an unparalleled ability to monitor and manage agricultural practices on a global scale (Chen et al., 2021). Coupled with other remote sensing technologies such as drones or UAVs, satellites have brought about a new era of advanced precision agriculture, making it possible to monitor crop health, predict yield, manage irrigation, nd detect pests and diseases more efficiently and comprehensively (Wolfert et al., 2017). Despite its potential, remote sensing technology is not without challenges. Technical difficulties, cost considerations, data handling, and privacy concerns are some of the issues that need to be addressed for the technology to reach its full potential in precision agriculture. This review aims to present a detailed examination of the role of remote sensing technology in precision agriculture. The discussion will begin with an exploration of the evolution of precision agriculture, followed by an analysis of different types of remote sensing technologies, their applications, and case studies showcasing their use in the real world. The review will also explore future trends in remote sensing technology and the challenges faced in their application to precision agriculture.

Brief History and Evolution of Precision Agriculture

Precision agriculture, also known as site-specific crop management or satellite farming, has significantly evolved over the past few decades, paralleling technological advancements. To fully appreciate its current state, it is essential to understand its historical development. Precision agriculture emerged in the early 1980s in the United States due to technological developments in GPS and GIS (Geographical Information Systems). At its inception, precision agriculture was primarily focused on spatial variability within agricultural fields, recognizing that traditional, uniform management of these fields was neither efficient nor sustainable (Bongiovanni & Lowenberg-DeBoer, 2004). During the 1980s, the U.S. government's launch of GPS satellites significantly advanced the possibilities for precision agriculture. GPS technology provided an efficient, reliable means of locating positions in the field, a game-changer for farmers (Schimmelpfennig & Ebel, 2011). Farmers could now collect spatially varied data, which led to adopting variable rate technology (VRT), allowing differential applications of inputs like fertilizers and pesticides based on specific field conditions.

By the 1990s, GPS technology in agriculture had become more widespread. Yield monitors, another significant development in precision agriculture, were combined with GPS receivers on harvesters to map yield variations across fields. This combination allowed farmers to visualize and understand the variability within their fields, enabling them to make more informed decisions about resource application (Whelan & Taylor, 2013). The late 1990s and early 2000s saw the rise of remote sensing technologies as integral components of precision agriculture. These technologies, including satellite and aerial imagery, gave farmers a new perspective on their fields. Remote sensing enables monitoring crop health, detecting pest and disease infestations, and managing irrigation more effectively (Li et al., 2014). In recent years, the proliferation of Internet of Things (IoT) technology has revolutionized precision agriculture. IoT has enabled real-time monitoring and decision-making, integrating various data sources, such as soil sensors, weather stations, and machinery, into a centralized system for more efficient management (Wolfert et al., 2017). Today, advancements in machine learning and artificial intelligence are paving the way for the next stage in the evolution of precision agriculture. These technologies promise to enhance further the ability to analyze and interpret data collected from fields, leading to even more precise management practices (Kamilaris et al., 2017).

Evolution of Precision Agriculture

The journey toward precision agriculture is an evolutionary process influenced by technological advancements and our understanding of natural ecosystems. Based on experience and intuition, traditional agriculture saw a radical transformation with the introduction of mechanization in the early 20th century. However, the real precursor to precision agriculture was the Green Revolution in the 1950s and 1960s, which introduced high-yield crops and modern farming practices, significantly increasing global agricultural production (Pingali, 2012). Despite its successes, the Green Revolution's approach was a one-size-fits-all, treating all fields as homogeneous units. However, fields are inherently heterogeneous, with soil properties, moisture levels, and nutrient content variations. This realization led to the development of site-specific crop management in the late 1980s, which is considered the birth of precision agriculture (McBratney et al., 2005). Precision agriculture took off with the advent of the Global Positioning System (GPS) in the 1990s. GPS technology enabled accurate mapping of field variations, allowing farmers to apply inputs more effectively and reduce waste. Simultaneously, yield monitors were developed, enabling the farmers to measure yield variations across fields (Blackmore et al., 2003). In the 2000s, Variable Rate Technology (VRT) emerged, enabling farmers to apply different rates of inputs in other parts of the field based on the data collected from GPS and yield monitors. Integrating Geographic Information Systems (GIS) into precision agriculture has allowed for the collection, storage, analysis, and display of geographically referenced information, further enhancing the precision of agricultural practices (Sørensen et al., 2010).

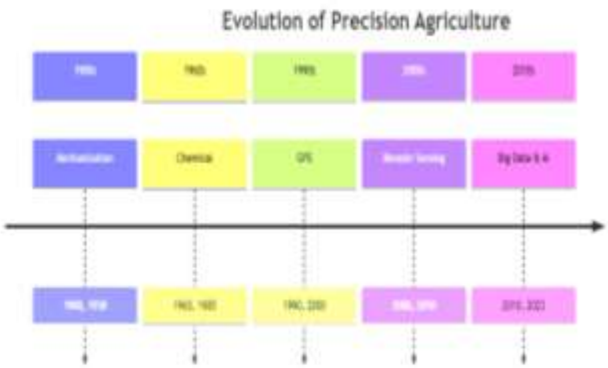

Figure 1 The timeline of the evolution of precision agriculture

Remote Sensing Technologies

While numerous technologies have influenced precision agriculture's evolution, remote sensing has had a significant impact. Remote sensing involves collecting information about an object or area without directly contacting it. It has a wide range of applications in agriculture, such as monitoring crop health, yield prediction, and irrigation management. Remote sensing technologies can be classified into two types: active and passive. Active remote sensors emit radiation and measure the reflected signal, while passive sensors measure natural radiation emitted or reflected by the object or area of interest (Thenkabail et al., 2011). The first generation of remote sensing technology in agriculture primarily used aerial photography. In the late 20th century, satellites became the primary remote sensing platform. Satellite remote sensing offers several advantages, such as extensive coverage, frequent revisits, and various spectral bands, making it ideal for large-scale agricultural monitoring (Tucker & Maxwell, 2017).

However, satellite remote sensing has limitations, such as lower spatial resolution and sensitivity to atmospheric conditions. To overcome these, Unmanned Aerial Vehicles (UAVs), or drones, have been introduced in recent years. Drones can capture high-resolution imagery at low altitudes, enabling detailed monitoring of individual plants (Zhang & Kovacs, 2012). With the advancement of technology, multispectral and hyperspectral imaging have emerged. Multispectral imaging captures images in specific, broad bands of the electromagnetic spectrum, while hyperspectral imaging captures images in many very narrow bands. These technologies allow for a more detailed and accurate assessment of crop health, nutrient status, and other critical parameters (Mulla, 2013).

Remote Sensing Technologies

Remote sensing, in its broadest sense, involves collecting data about an object or area without making direct contact. This technique has been fundamental to the advancements in precision agriculture due to its ability to monitor vast expanses of agricultural land efficiently and effectively (Mulla, 2013). There are two primary types of remote sensing technologies: active and passive. Active remote sensing involves sending a pulse of energy and then measuring the returned signal. This approach is commonly used in radar and LiDAR (Light Detection and Ranging) technologies. passive remote sensing involves recording the natural energy reflected or emitted from the surface. Most satellite and airborne sensors fall into this category, including multispectral and hyperspectral sensors (Thenkabail, 2015).

Active Remote Sensing

Active remote sensing systems generate their source of energy. Radar (Radio Detection and Ranging) is one of the most common forms of active remote sensing. It emits radio waves and measures the time delay for the signal to bounce back after hitting the target. This delay is then converted into a distance, thereby allowing the construction of a three-dimensional representation of the object or area (England & Viscarra Rossel, 2018). LiDAR is another active remote sensing technology that uses light energy as a pulsed laser to measure variable distances to the Earth. This technology can generate precise, three-dimensional information about the shape of the Earth and its surface characteristics, making it useful for topographic and elevation mapping in agricultural landscapes (Maltamo et al., 2014).

Passive Remote Sensing

Passive remote sensing systems rely on the natural radiation emitted or reflected from an observed surface. These systems are commonly used in precision agriculture and include multispectral and hyperspectral sensors. Multispectral sensors measure specific electromagnetic spectrum bands, generally falling within the visible and near-infrared regions. They are used extensively in precision agriculture for crop health monitoring, yield prediction, and pest and disease detection (Mulla, 2013). Hyperspectral sensors, on the other hand, measure hundreds of narrow, contiguous spectral bands throughout the electromagnetic spectrum's visible, near-infrared, and short-wave infrared portions. These sensors provide a more detailed scene image and can identify different materials based on their spectral signatures (Thenkabail, 2015).

Platforms for Remote Sensing

Remote sensing technologies can be deployed on various platforms, offering distinct advantages and limitations. Satellites, for instance, provide a broad coverage area and consistent, repeat data collection, but their data may be influenced by cloud cover, and the temporal resolution can be limited (Chen et al., 2021). Aircraft offer higher spatial resolution and can be used flexibly, but they are costlier and subject to flight regulations (Sullivan, 2010). Unmanned aerial vehicles (UAVs), or drones, have emerged as powerful tools for precision agriculture. They can fly at lower altitudes and slower speeds than manned aircraft, allowing for high-resolution imagery. Their lower cost and increasing ease of use make them accessible to individual farmers (Zhang & Kovacs, 2012).

Table 1: Comparison of Different Remote Sensing Technologies

Technology	Type	Advantages	Limitations
Radar	Active	Can operate in all weather and lighting conditions	Complex data processing
LiDAR	Active	Highly accurate 3D mapping	Costly, complex data analysis
Multispectral Sensors	Passive	Broad applications in agriculture	Limited spectral resolution
Hyperspectral Sensors	Passive	High spectral resolution	Complex data analysis, high data volume
Satellites	Platform	Broad, consistent coverage	Affected by cloud cover, limited temporal resolution
Aircraft	Platform	High spatial resolution, flexible use	Higher cost, subject to flight regulations
Drones	Platform	High-resolution imagery, accessible and affordable	Limited flight duration, weather-dependent

(Adapted from Mulla, 2013; Sullivan, 2010; Zhang & Kovacs, 2012)

Applications of Remote Sensing in Precision Agriculture

Remote sensing has a broad spectrum of applications in precision agriculture. Using various remote sensing techniques, stakeholders can gain invaluable insight into various aspects of agricultural practice, including crop health monitoring, yield estimation and prediction, soil mapping, irrigation management, and pest and disease detection.

Crop Health Monitoring

One of the primary applications of remote sensing in precision agriculture is crop health monitoring. Using multispectral or hyperspectral sensors, farmers and agronomists can obtain timely and accurate information on the health status of crops over large areas (Li et al., 2014). Vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), are frequently used to infer crop health by measuring the density and vigor of plant growth. The NDVI is particularly sensitive to the amount of chlorophyll in plant leaves, indicating the presence of stressors like drought, disease, or nutrient deficiency before they become visually apparent (Pôças et al., 2019).

Yield Estimation and Prediction

Remote sensing also offers the potential for predicting crop yield before harvest. Remote sensors can detect patterns of photosynthetic activity, crop development, and stressors that directly relate to final yield outcomes (Lobell & Asner, 2003). The analysis of remote sensing data, combined with crop growth models and machine learning algorithms, can be used to develop yield prediction models. These models can provide farmers with essential information to make informed decisions about harvest strategies, market planning, and resource allocation (Basso et al., 2013).

Soil Mapping

The ability to map soil properties is another critical application of remote sensing in precision agriculture. Soil properties such as texture, moisture, and organic matter content can profoundly influence crop productivity and the efficiency of agricultural inputs (Lobell et al., 2003). Multispectral and hyperspectral remote sensing can measure specific soil properties, while radar and LiDAR can provide information on surface roughness and structure. When these data are combined with geostatistical techniques, high-resolution soil maps can guide decision-making in the field (Vasques et al., 2008).

Irrigation Management

Managing irrigation effectively is critical to successful farming, and remote sensing technology offers significant potential. Farmers can detect crop water stress by measuring the canopy temperature by using thermal remote sensing. Higher temperatures indicate that a plant is undergoing water stress and closing its stomata to prevent water loss, which reduces its cooling through transpiration (Taghvaeian, 2015). Using this data, farmers can implement precision irrigation strategies that only apply water where it is needed, reducing water usage, saving costs, and improving crop productivity (Khan et al., 2015).

Pest and Disease Detection

Detecting pests and diseases early can save a significant portion of a crop that would otherwise be lost. Remote sensing technologies can identify the spectral signatures of certain diseases and insect infestations, often before they become apparent to the human eye (Mahlein, 2016). For instance, multispectral and hyperspectral imagery can identify changes in plant reflectance due to pest or disease damage. This early detection can trigger timely intervention, mitigating crop loss and maintaining high crop productivity (Mahlein, 2016).

Flowchart: Using Remote Sensing in Precision Agriculture

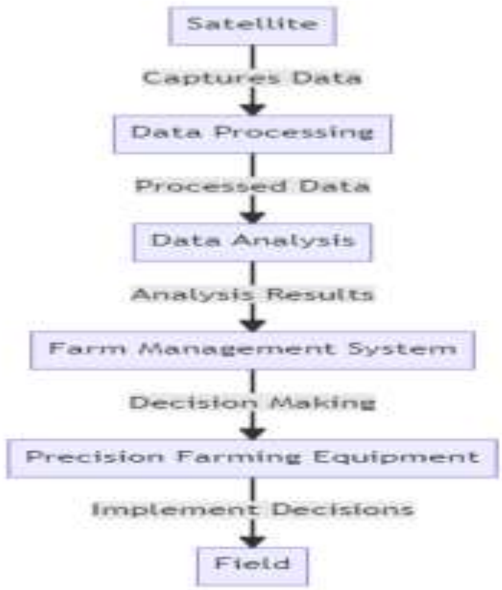

Figure 2 Process of using remote sensing in precision agriculture.

Future Trends in Remote Sensing for Precision Agriculture

The development and integration of emerging technologies in remote sensing hold immense promise for the future of precision agriculture. This section discusses the emerging technologies in remote sensing and their potential applications and impacts.

Emerging Technologies in Remote Sensing

Hyperspectral Imaging: Hyperspectral imaging collects and processes information from the electromagnetic spectrum, allowing for more detailed observation and characterization of crops and soils (Thenkabail, 2015). This technology could enable farmers to detect subtle physiological changes in plants indicative of stress conditions, such as nutrient deficiency, drought stress, or pest and disease infestation. Thermal Imaging: Thermal imaging uses infrared radiation to measure temperature differences, providing valuable information about plant water stress and irrigation needs (Taghvaeian, 2015). As water scarcity continues to be a major global issue, the use of thermal imaging in precision agriculture will likely increase. LiDAR (Light Detection and Ranging): LiDAR, an active remote sensing system that uses laser light, has been gaining attention in precision agriculture. It provides detailed crop height and structure information, which is useful for biomass estimation and crop health monitoring (Maltamo et al., 2014). Machine Learning and AI: Machine learning algorithms and AI are becoming increasingly important in interpreting and applying remote sensing data. Advanced machine learning techniques, such as deep learning, can handle large and complex datasets, making them especially useful in handling the big data generated by remote sensing (Kussul et al., 2017).

Future Applications and Potential Impact

Remote sensing, coupled with these emerging technologies, can revolutionize the agriculture industry. Farmers could harness these technologies for real-time monitoring of crop health, intelligent irrigation systems that conserve water, and early-warning systems for disease and pest infestation. Moreover, machine learning algorithms can be trained to predict crop yields based on remote sensing data, which could significantly impact food supply chain management. These technologies could also aid in sustainable farming practices, which is essential considering the pressing need for environmental conservation and increased food production to feed a growing global population (Zhang et al., 2019).

Challenges and Limitations

While remote sensing technologies offer many benefits to precision agriculture, they are not without their challenges and limitations.

Technical and Practical Challenges in Implementing Remote Sensing

One of the major technical challenges is the need for spatially and temporally high-resolution data. Remote sensing platforms like satellites often provide data at larger spatial and temporal scales, which might not be suitable for managing small agricultural plots (Gebbers & Adamchuk, 2010). On the other hand, while drones can provide data at a very high spatial resolution, they may face restrictions due to weather conditions and aviation regulations (Mulla, 2013). Furthermore, the quality and accuracy of remote sensing data heavily depend on atmospheric and weather conditions at the time of data acquisition. Cloud cover, dust, and other atmospheric disturbances can distort the data (Verrelst, Camps-Valls, Muñoz-Marí, Rivera, & Veroustraete, 2015). Another technical challenge is the requirement of advanced expertise and technical knowledge to interpret and use the data generated by remote sensing technologies effectively. This might be a barrier for farmers and stakeholders with limited technical knowledge (Tey & Brindal, 2012).

Limitations of Current Technologies

Current remote sensing technologies also have their limitations. For instance, while hyperspectral imaging provides a wealth of data, it can also result in high data redundancy and increased complexity in data processing and interpretation (Thenkabail, 2015).

Although powerful in irrigation management, thermal imaging depends on weather conditions and might not provide reliable information under cloudy or humid conditions (Taghvaeian, 2015).

Even though machine learning techniques can provide powerful tools for analyzing remote sensing data, they require a large amount of high-quality training data, and the results can be difficult to interpret (Kussul, Lavreniuk, Skakun, & Shelestov, 2017).

Table 2: Summary of Challenges and Potential Solutions

Challenges	Potential Solutions
Need for high-resolution data	Development and use of drones, miniaturized satellites

Atmospheric disturbances	Advanced data correction algorithms
Need for technical expertise	Training and support for farmers, development of user-friendly software
Data redundancy in hyperspectral imaging	Use of feature selection and extraction methods
Dependence of thermal imaging on weather conditions	Complementary use of other data sources
Requirement of large data sets for machine learning	Use of transfer learning, data augmentation

Conclusion

Precision agriculture has seen remarkable advancement due to the integration of remote sensing technologies. This evolution has been fueled by the demand for sustainable agricultural practices that increase yield and efficiency while reducing environmental impacts. This review has examined precision agriculture's development, emphasizing remote sensing's role in this transformation. The study explored various remote sensing technologies, including their types (active vs. passive), platforms (satellites, drones, etc.), and a comparison of their benefits and drawbacks. The applications of remote sensing in precision agriculture are vast, encompassing crop health monitoring, yield estimation and prediction, soil mapping, irrigation management, and pest and disease detection. These applications underscore the critical role of remote sensing in revolutionizing agricultural practices, enabling timely decision-making based on accurate and data-driven insights.

The future of precision agriculture hinged on emerging technologies like hyperspectral imaging, thermal imaging, LiDAR, machine learning, and AI, paints a promising picture. However, these advancements do not come without challenges. Among the notable issues are high-resolution data needs, atmospheric disturbances, technical expertise, data redundancy, and weather-dependent inaccuracies. Solutions such as developing more sophisticated drones, advanced data correction algorithms, user-friendly software, and data augmentation techniques are potential paths to overcoming these obstacles.

Precision agriculture is heading towards unprecedented advancement, with remote sensing technologies at its helm. As the technologies evolve, their affordability and accessibility are expected to improve, allowing for broader adoption and further democratization of precision farming practices. Further research is warranted to mitigate the challenges identified in this review. Particularly, there is a need for more user-friendly systems to assist farmers in interpreting and applying remote sensing data effectively. Also, strategies to handle the massive data sets generated by these technologies should be developed, possibly by integrating cloud computing and advanced data analytics.

In conclusion, remote sensing has already revolutionized precision agriculture and will continue to do so. The path forward requires continued research, technological advancements, and close collaboration among farmers, researchers, technologists, and policy-makers.

Declarations

Conflict of interest

The authors have no conflict of interest.

Data Availability statement

All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Funding

Not applicable

References

Basso, B., Cammarano, D., & Carfagna, E. (2013). Review of Crop Yield Forecasting Methods and Early Warning Systems. In First Meeting of the Scientific Advisory Committee of the Global Strategy to improve Agricultural and Rural Statistics, FAO Headquarters.

Bongiovanni, R., & Lowenberg-DeBoer, J. (2004). Precision agriculture and sustainability. Precision Agriculture, 5(4), 359-387. https://doi.org/10.1023/B:PRAG.0000040806.39604.aa

Gebbers, R., & Adamchuk, V. I. (2010). Precision Agriculture and Food Security. Science, 327(5967), 828-831. https://doi.org/10.1126/science.1183899

Chen, H., Lan, Y., Fritz, B. K., Hoffmann, W. C., & Liu, S. (2021). Review of agricultural spraying technologies for plant protection using unmanned aerial vehicle (UAV). International Journal of Agricultural and Biological Engineering, 14(1), 38-49. DOI: 10.25165/j.ijabe.20211401.5714

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2017). A review on the practice of big data analysis in agriculture. Computers and Electronics in Agriculture, 143, 23-37. https://doi.org/10.1016/j.compag.2017.09.037

Khan, S. I., Khaliq, A., & Prabhakar, M. (2015). Remote Sensing and Geographical Information System Application in Irrigation Water Management. Journal of Applied and Natural Science, 7(2), 658-666. https://doi.org/10.3390/w10050608

Kussul, N., Lavreniuk, M., Skakun, S., & Shelestov, A. (2017). Deep Learning Classification of Land Cover and Crop Types Using Remote Sensing Data. IEEE Geoscience and Remote Sensing Letters, 14(5), 778-782. https://doi.org/10.1109/LGRS.2017.2681128

Li, L., Zhang, Q., & Huang, D. (2014). A review of imaging techniques for plant phenotyping. Sensors, 14(11), 20078-20111. https://doi.org/10.3390/s141120078

Lobell, D. B., Asner, G. P., Ortiz-Monasterio, J. I., & Benning, T. L. (2003). Remote sensing of regional crop production in the Yaqui Valley, Mexico: estimates and uncertainties. Agriculture, Ecosystems & Environment, 94(2), 205-220. https://doi.org/10.1016/S0167-8809(02)00021-X

Mahlein, A. K. (2016). Plant Disease Detection by Imaging Sensors – Parallels and Specific Demands for Precision Agriculture and Plant Phenotyping. Plant Disease, 100(2), 241-251. https://doi.org/10.1094/PDIS-03-15-0340-FE

Maltamo, M., Næsset, E., & Vauhkonen, J. (2014). Forestry Applications of Airborne Laser Scanning: Concepts and Case Studies. Managing Forest Ecosystems, 27. https://doi.org/10.1007/978-94-017-8663-8

England, J. R., & Viscarra Rossel, R. A. (2018). Proximal sensing for soil carbon accounting. Soil, 4(2), 101-122. https://doi.org/10.5194/soil-4-101-2018

Mulla, D. (2013). Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. Biosystems Engineering, 114(4), 358-371. https://doi.org/10.1016/j.biosystemseng.2012.08.009

Pôças, I., Gonçalves, P., & Pereira, L. S. (2019). NDVI from Landsat 8 Vegetation Continuous Fields: A New Approach to Normalize NDVI for the Estimation of Biophysical Parameters in Mediterranean Pear Orchards. Remote Sensing, 11(23), 2777.

Schimmelpfennig, D. (2016). Farm Profits and Adoption of Precision Agriculture. Economic Research Report, (217), 1-40. http://dx.doi.org/10.22004/ag.econ.249773

Schimmelpfennig, D., & Ebel, R. (2011). On the doorstep of the information age: Recent adoption of precision agriculture. USDA-ERS Economic Information Bulletin, 80. https://ssrn.com/abstract=2692052

Sullivan, D. G. (2010). Hyperspectral Imaging with a Helicopter Platform: Early Detection of Plant Stress. In P. Thenkabail, J. G. Lyon, & A. Huete (Eds.), Hyperspectral Remote Sensing of Vegetation (pp. 541-562). CRC Press.

Taghvaeian, S. (2015). Remote Sensing of Evapotranspiration: Theories, Models, and Applications. In Water Conservation in the 21st Century (pp. 71-98). Springer.

Tey, Y. S., & Brindal, M. (2012). Factors influencing the adoption of precision agricultural technologies: a review for policy implications. Precision agriculture, 13(6), 713-730. https://doi.org/10.1007/s11119-012-9273-6

Thenkabail, P. S. (2015). Remote Sensing Handbook - Three Volume Set: Land Resources Monitoring, Modeling, and Mapping with Remote Sensing. CRC Press. https://scholar.google.com/scholar_lookup?title=Remote+Sensing+Handbook-Three+Volume+Set&author=Thenkabail,+P.&publication_year=2018

Vasques, G. M., Grunwald, S., & Sickman, J. O. (2008). Comparison of Multivariate Methods for Inferential Modeling of Soil Carbon Using Visible/Near-Infrared Spectra. Geoderma, 146(1-2), 14-25. https://doi.org/10.1016/j.geoderma.2008.04.007

Verrelst, J., Camps-Valls, G., Muñoz-Marí, J., Rivera, J. P., & Veroustraete, F. (2015). Optical remote sensing and the retrieval of terrestrial vegetation bio-geophysical properties – A review. ISPRS Journal of Photogrammetry and Remote Sensing, 108, 273-290. https://doi.org/10.1016/j.isprsjprs.2015.05.005

Whelan, B., & Taylor, J. (2013). Precision Agriculture for Grain Production Systems. CSIRO Publishing. https://doi.org/10.1071/9780643107489

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming – A review. Agricultural Systems, 153, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

Zhang, N., & Kovacs, J. M. (2012). The application of small unmanned aerial systems for precision agriculture: a review. Precision agriculture, 13(6), 693-712. https://doi.org/10.1007/s11119-012-9274-5

Zhang, Z., Jayachandran, K., & Grunwald, S. (2019). Soil Information Derived from Visible/Infrared and Passive Microwave Remote Sensing: Status and Perspectives. Earth Science Reviews, 190, 420-436.