A Bibliometric Analysis of Machine Learning Techniques for Predicting Crop Yield

Anuj Mehla, Sukhvinder Singh Deora

Department of Computer Science and Applications, Maharshi Dayanand University, Rohtak, India

Corresponding author: Sukhvinder Singh Deora, Email: sukhvinder.dcsa@mdurohtak.ac.in

Accurate crop yield prediction is paramount in agriculture to improve decision-making and resource allocation. It is a key part of precision agriculture, a sustainable farming approach that uses data and technology to improve crop yields while reducing environmental impact. Machine learning techniques have been extensively researched to enhance the accuracy of yield prediction. Athorough comprehension of the available literature on this topic is imperative. This study aims to categorize research, map relevant literature, and evaluate the progress made in yield prediction with machine learning over the last 13 years using bibliometric techniques. It analyzed the Scopus database for articles using search keywords Yield Prediction, Yield Estimation and Yield Forecasting with Machine Learning. It located 1177 pertinent articles, confirming the significance of machine learning in yield prediction. The Biblioshiny package analyzes the aggregated Scopus database, identifying current trends, challenges, and future research directions. The insights gained from this study can advance agricultural practices and contribute to sustainability efforts. Outcome: The study highlights the crucial role of machine learning in predicting crop yield accurately by using the Scopus database for finding articles, and the biblioshiny package of R is used to identify the current trends, challenges, and future research directions, which has the potential to transform precision agriculture by increasing crop yield and minimizing environmental impact.

Keywords: Yield Prediction, Yield Estimation, Systematic Mapping, Crop, Machine Learning.

in: *Advancements in Communication and Systems*. Ed. by Ashish Kumar Tripathi and Vivek Shrivastava. Computing and Intelligent Systems, SCRS, India., 2023, pp. 431–442. DOI: https://doi.org/10.56155/978-81-955020-7-3-38

1 Introduction

Crop yield prediction is crucial for farmers and policymakers as it helps them make informed decisions about crop planting, resource allocation, and market planning. Over the years, the field has evolved significantly due to advancements in computational capacity, data availability, and analytical techniques. The traditional yield prediction models reliled on statistical methods and domain-specific expertise, while the recent introduction of Machine Learning (ML) techniques has revolutionized the field [1]. ML models can analyze vast and varied datasets and identify patterns and correlations to generate predictive models encompassing crop growth and yield dynamics [2].

There are several ML algorithms used for crop yield prediction, and the final choice depends on the data characteristics and research objectives [3]. These algorithms [4–8] help manage complex relationships between input variables such as soil properties, weather patterns, crop management practices, and yield outcomes, improving prediction accuracy, and facilitating informed agricultural practices [9].

Despite the history of crop yield prediction, there is an urgent need for additional quantitative bibliometric analysis to fill the gaps and provide guidance for future research. Predicting crop yield is essential for smart farming, enabling optimal resource allocation, crop management, risks and uncertainty mitigation, identifying factors impacting crop growth, timely actions to address challenges, and planning harvest [10].

This investigation aims to establish the present-day cutting edge in implementing machine learning for agricultural yield forecasting and discern the trends in the field by leveraging the Scopus database and the Biblioshiny package of R language.

2 Literature review

In the past, the scientific impact of a publication was predominantly assessed based on the quantity of citations it garnered. It was commonly employed to evaluate the impact of research organizations, academic institutions, and the entire country [11]. The quantity of citations is a metric that measures the overall quality of research and its degree of influence [12].

Recently, there has been significant interest in applying machine learning techniques and methodologies to predict agricultural crop yields. While several studies have been conducted on this topic, no strctured bibliometric analysis of crop yield prediction using machine learning has not been conducted so far. This is particularly important and timely given the current global crises affecting food production, the environment, and biodiversity.

This literature review aims to present a thorough and inclusive overview of the current research on the utilization of machine learning methods in predicting crop yields. By analyzing numerous articles, distinct and significant themes have been identified.

1. Crop Yield Prediction Models: An important theme that has been identified pertains to investigating diverse machine learning models in the context of agricultural yield prediction. Traditional models, including Random Forest, Support Vector Machines, and Gradient Boosting, have been extensively used due to their interpretability and robust performance. Moreover, deep learning architectures such as Convolutional Neural Networks (CNNs) and Recurrent Neural networks (RNNs) have also shown promise in capturing complex patterns in agricultural data. Several studies have highlighted the importance of developing and implementing prediction models that accurately estimate crop yield. These models incorporate environmental conditions, soil characteristics, and historical yield data to predict crop yield [12]-[13].

2 Machine Learning in Agriculture: Another key theme is machine learning algorithms, which have transformed the sector by enabling data-driven decision-making. These algorithms can precisely predict crop yields by utilizing environmental factors, historical data, and agronomic practices. The potential of machine learning in enhancing agricultural productivity and resource management has been underscored in numerous studies. Yield prediction has been accomplished with the aid of machine learning algorithms, including kernel Ridge, Lasso, Convolutional Neural Networks, and Long-Short Term Memory [3], [7], [14]- [15].

3 Climate Change: The impact of climate change on crop performance has emerged as a major concern, and researchers have acknowledged its adverse effects. As such, they have emphasized the importance of crop yield forecasting in advance to support policy decisions and mitigate potential risks. [17–20].

4 Integration of Remote Sensing: It has been discovered that remote sensing technologies, such as sensor platforms and satellite imagery, are indispensable for predicting crop yields [21–26]. Through the collection and analysis of massive amounts of data, these technologies enable precise forecasts and efficient nitrogen management.

5 Feature Engineering and Selection: The feature engineering process is paramount in augmenting machine learning models' prognostic capacities in predicting crop yield. Numerous studies have underscored the significance of discerning pertinent attributes, including historical yield data, meteorological parameters, and soil characteristics, to enhance models' precision. In order to identify crucial features, methodologies such as Principal Component Analysis (PCA), Recursive Feature Elimination (RFE), and Forward Feature Selection (FFS) have been implemented [8, 27–31].

3 Research Questions

The primary essential step to undertaking a systematic mapping study is establishing pertinent research questions (RQs). This particular study aims to comprehensively summarize prevailing practices in Crop Yield Prediction with Machine Learning while categorizing the qualitative outcomes of pre-existing research. To achieve this, this study has formulated the following set of RQs:

RQ1: What research has been conducted regarding using machine learning to predict crop yields?
RQ2: Which nation is leading in employing machine learning to forecast crop yields?
RQ3: How are studies distributed between academic journals and conferences?
RQ4: What is the extent of research in applying machine learning to predict crop yields?
RQ5: What academic disciplines presently dominate this field?

The current investigation necessitates access to various resources that provide insightful data on research and publications. Popular repositories such as Scopus, Web of Science, Scimago, and Google Scholar are generally recognized as some of the finest places to get this kind of data. Among these, Scopus is one of the most popular and extensively used databases.

This investigation focuses on literature published between 2011 and January 05, 2024. The collection's most frequently mentioned articles are shown in Table 1.

Table 1. Most cited articles on Predicting Crop Yield using machine learning

Focus of the paper	Journal Indexing	Total Citations
Machine learning applications in Agriculture comprehensive review [32]	MDPI, WOS	1340
Meta-review on remote sensing technology in agricultural applications [33]	MDPI, WOS	733
Review and analysis on machine for crop yield prediction and nitrogen	ELSEVIER	711

status estimation [34]		
Systematic literature review on predicting crop yield using machine learning algorithms [2]”	ELSEVIER	549
“Predicting soybean yield using a UAV data and deep learning [35]”	WOS, MDPI	433

4 Methodology

4.1 Search Criteria

The search criteria for this review include two parts: C1, which is a string with the keywords “Machine Learning” OR “Deep Learning” AND “Yield Prediction,” and C2, which is a string with related yield prediction keywords. The search criterion is “C1 OR C2,” with an example search being “Yield Prediction,” “Yield Estimating,” “Yield Forecasting,” and “Machine Learning,” or “Deep Learning.”

4.2 Criteria for Exclusion and Inclusion

Table 2 provides an outline of the criteria for inclusion and exclusion.

Table 2. Exclusion and Inclusion Criteria

Criteria for Inclusion	• The study discusses the application of machine learning to crop yield prediction; • Papers published between 2011 and January05, 2024; • Papers that are in Scopus; • Papers published in Computer Science, Agricultural and Biological Sciences, Engineering, Earth and Planetary Sciences, Decision Sciences, Environmental Science, Multidisciplinary, Business, Management & Accounting, and Mathematics.
Criteria for Exclusion	• The study is not a primary study, such as editorials, keynotes summaries, seminars, and tutorials; • The study is not written in English; • The study does not have an abstract; • The study has only an abstract; • Publications that have only summarized information;

5 Bibliometric Analysis and Result

Bibliometric analysis is a quantitative research technique used to identify patterns, relationships, and research trends within scientific publications related to crop yield prediction using machine learning techniques. The process includes analyzing pertinent keywords to determine publication trends and categories, followed by statistical analysis to examine subject areas, authors, citations, and affiliations. Common bibliometric analyses include citation, co-authorship, journal, and keyword analyses.

5.1 Performance Analysis

Distribution of Publications and their Sources per Year: By conducting a meticulous keyword search in the Scopus database, 1,177 publications were extracted from 2011 to January05, 2024. The resulting data is further scrutinized to determine any trends in publication frequency, encompassing publications from journals and conferences. Table 3 demonstrates the publication count from 2011 to January05, 2024.

Table 3. No. of Publications from 2011-2023

Year	Number of Publications	Year	Number of Publications
2011	1	2018	25
2012	1	2019	66
2013	2	2020	123
2014	4	2021	194
2015	4	2022	313
2016	9	2023	408
2017	3	2024	24

Table 3 shows a significant increase in publications on crop yield prediction using machine learning since 2012. Remote sensing has been published in most articles in this field, and the adoption of computer-based technologies and funding of agricultural initiatives have led to a remarkable increase in publications.

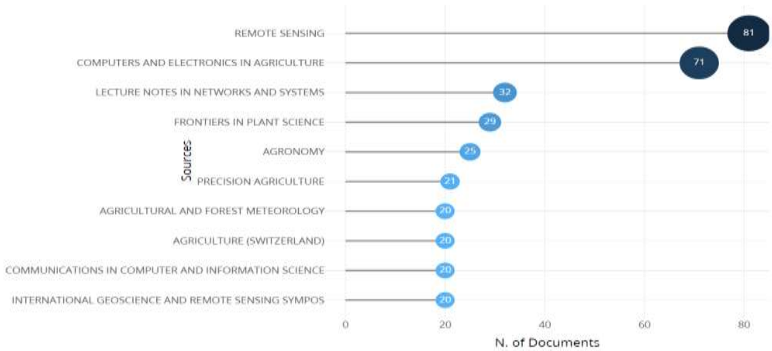

Figure 1. Top 10 Leading Journals

5.2 Most Influencing Journals

Various articles on yield prediction using Machine Learning can be found in academic literature. According to Scopus data from 2011 to 2024, Figure 1 lists the journals that have published the most studies on this topic. Agronomic and Computer Science research journals have been the most active in publishing scientific articles. “Remote Sensing” journal is a prominent source with fifty-two published articles focusing on remote sensing applications involving IoT, Machine Learning, Image Processing, and Remote Sensing techniques. Elsevier's "Computers and Electronics in Agriculture" journal has published forty-four articles on applying monitoring systems, software, computer science, and electronics to agricultural challenges. "Frontiers in Plant Science" has also contributed significantly to the discipline with eighteen published articles.

5.3 Most Influencing Articles

Table 4 lists the eight most influential articles on machine learning for crop yield prediction. They were ranked by global citation count, with “Machine learning in agriculture: A review” being the most cited. “Computer and Electronics in Agriculture” and “Remote Sensing Environment” also had significant impacts.

Table 4. Top Eight Leading Articles

References	Year	Local Citations	Global Citations	References	Year	Local Citations	Global Citations
[32]	2018	9	1340	[35]	2020	1	433
[33]	2020	0	733	[36]	2016	90	350
[34]	2018	132	711	[5]	2016	9	339
[2]	2020	2	549	[37]	2019	11	328

5.4 Details of the Keywords for the Advanced Search

Important keywords for conducting an advanced search on predicting crop yield using Machine Learning techniques include "Crop," "Machine Learning," "Crop Yield," "Forecasting," "Estimation," AND "Yield Prediction." These keywords are searched using "AND" and "OR" conditions in the Scopus database, resulting in a refined search from 2011 to January05, 2024. Figure 2 highlights a few important keywords related to Crop Yield Prediction.

5.5 Publication Type

The search was restricted to English publications, with only 3% in Chinese and Portuguese. The results are refined based on publication type. A total of690 articles, 369 conference papers, 52 Reviews, 26 Conference reviews, and 40 book chapters were found.

5.6 Analysis of Geographical Region-Based Publication Counts

Figure 3 shows the research contributions made by different countries in machine learning-based Crop Yield Prediction. India has the most significant influence with 213 articles, followed by the USA (131 articles) and China (119 articles). To obtain a more exhaustive understanding of researchers' academic affiliations and geographic distribution, kindly refer to Table 6.

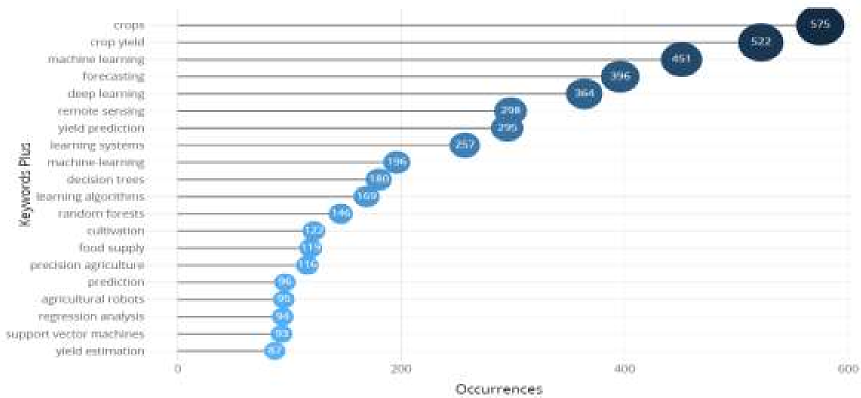

Figure 2. Top 20 Keywords per Document

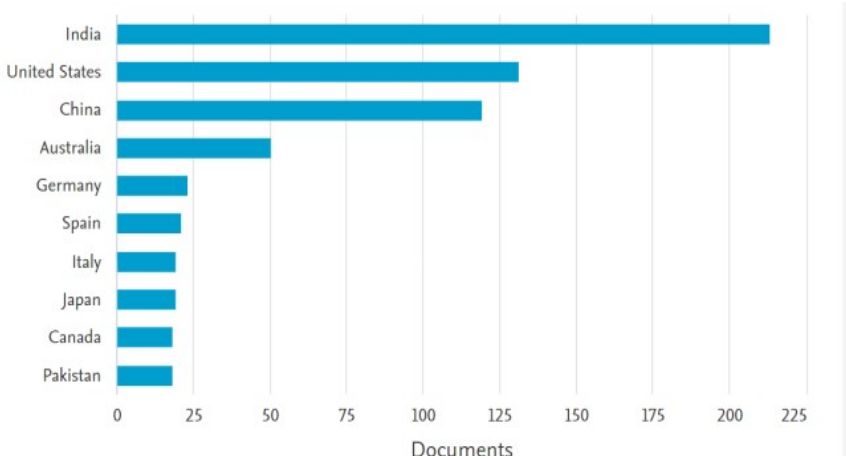

Figure 3. Top 10 Countries per Documents

This research investigates authors' countries and academic affiliations regarding Machine Learning techniques to forecast crop yields. Table 6 shows "China Agricultural University" as the leading contributor with 111 articles, followed closely by " LOWA STATE UNIVERSITY" and NANJING AGRICULTURAL University" with 64 and 61 articles. Notably, universities in the United States, such as "LOWA State University" and the "University of Florida," produced 31publications each.

Table 5 showcases their academic contributions.

Table 5. Top 10 Relevant Affiliations

Rank	Affiliation	Articles	Rank	Affiliation	Articles
1.	CHINA AGRICULTURAL UNIVERSITY	111	6.	SOUTH CHINA AGRICULTURAL UNIVERSITY	45
2.	IOWA STATE UNIVERSITY	64	7.	ZHEJIANG UNIVERSITY	40
3.	NANJING AGRICULTURAL UNIVERSITY	61	8.	WUHAN UNIVERSITY	38
4.	BEIJING	54	9.	UNIVERSITY OF CALIFORNIA	31
5.	BEIJING NORMAL UNIVERSITY	53	10.	UNIVERSITY OF FLORIDA	31

Furthermore, Figure 4 depicts the nations of origin and corresponding authors of published works. This figure also looks at the number of articles and how they are distributed across single countries (SCP), multiple countries (MCP), and the fraction of publications that involve multiple countries. The top three contributors are India, China, and the United States, with 83, 72, and 40 publications, respectively. India leads the way with 76 Single-Country Publications (SCP) and 7 Multi-Country Publications(MCP), followed by China (49 SCP and 23 MCP) and the United States (33 SCP and 7 MCP).

5.7 Analysis of Publications Counts for Each Author

The field of crop yield prediction through machine learning techniques has been dominated by notable authors. According to data, 2,227 authors have contributed to this field of study. Zhang Z holds the highest position with 26 articles, followed by LIH and ZHANG Y with 17 articles each. Among all authors, Dimitrios Moshou[32] emerges as the most influential, with 1393 citations. In terms of average citations, Dimitrios Moshou maintains the lead with an average of 661.5 citations, followed by Liakos KG and Busato P with 547 average citations each, albeit for a small number of articles. The top ten prolific researchers in yield prediction using machine learning have contributed to 16.93% of all publications and generated 2,856 citations. It is important to note that these statistics were derived from data retrieved from the Scopus database. Table 6 also depicts the top 10 Author Contributors based on the published articles and total count.

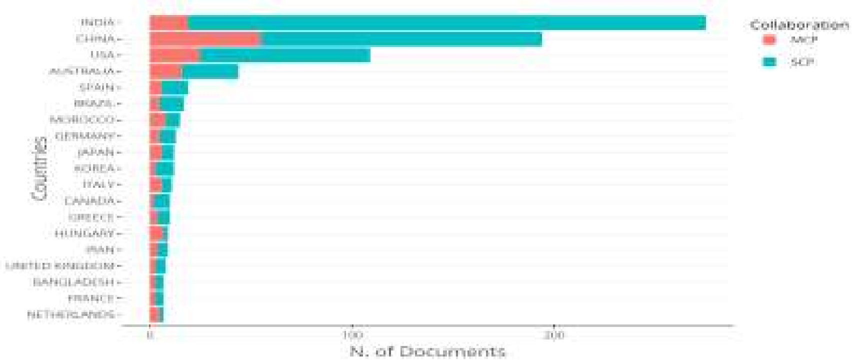

Figure 4. Corresponding author's countries and their publications

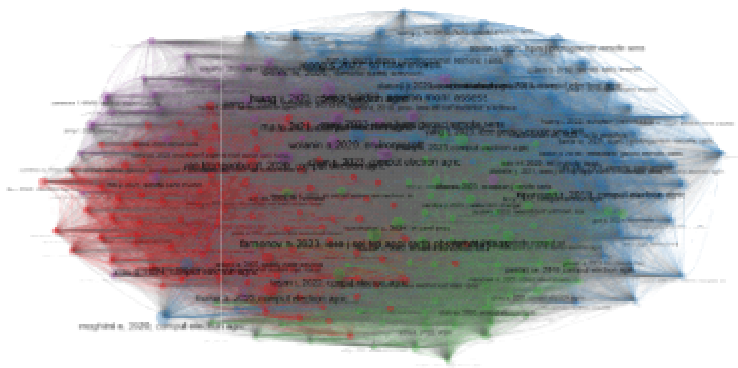

Figure 5. Networking mapping of bibliometric coupling analysis

Table 6. Top contributing authors based on the published articles

Authors	Articles	TC	H_index	TC/Articles	Authors	Articles	TC	H_index	TC/Articles
ZHANG Z	26	700	15	35	LI Z	13	440	8	48.88889
LI H	17	204	8	15.69231	WANG X	13	357	3	39.66667
ZHANG Y	17	327	8	29.72727	ZHANG X	13	298	7	37.25
MA Y	16	261	7	26.1	ZHU Y	13	83	5	10.375
WANG L	16	145	5	16.11111	CHEN Z	12	41	4	5.125

5.8 Bibliographic Coupling Analysis

Bibliographic coupling is a technique that helps explore potential advancements in a specific field by identifying similarities between two papers through their shared references. This study analyzed 65 papers across five clusters focusing on machine learning and remote sensing for crop monitoring, yield prediction, and precision agriculture using a Biblioshiny package of R programming for bibliographic coupling.

The first cluster focuses on machine learning and remote sensing for crop monitoring and yield estimation. Figure 5 highlights it with red bubbles. This cluster highlights the use of advanced machine learning techniques [38], [39] [40] for accurate mapping of end-of-season wheat yields and precise estimations of soybean cereal yield [41].

The second cluster is comprised of 16 articles on machine learning and remote sensing to predict crop yield. These studies identify significant correlations between input variables and crop yields using machine learning algorithms like random forest (RF), support vector machines (SVM), and neural networks (NN) have been used along with historical data about weather conditions, crop types, soil characteristics, and other relevant factors to identify significant correlations between input variables and crop yields [42–44].

Cluster 3compares 14 articles on "Machine Learning Techniques for Crop Yield Prediction." These articles offer valuable insights into optimizing agricultural processes, resource allocation, and risk management in crop production [37,45–48] [49–51].

The fourth cluster includes ten articles on predicting crop yields and practicing precision agriculture within machine learning. The studies showcase phenological variables' efficacy in improving predictive accuracy [52], and some studies have developed a workflow for large-scale crop yield forecasting that combines crop modeling principles with machine learning.
The fifth and final cluster comprises four articles focusing on the diverse applications of machine learning techniques within the agricultural industry, explicitly predicting crop yield and detecting produce fruit in agricultural settings [53].

Future Research Directions for each Cluster

Cluster 1: Prioritize the development of remote sensing technologies, engage in advanced fusion techniques, develop a novel machine learning algorithm, and integrate environmental factors into remote sensing and crop models.
Cluster 2: Integrate data from various sources, fine-tune machine learning algorithms, optimize algorithm parameters and architecture, and explore advanced remote sensing technologies.
Cluster 3: Develop automated methods for extracting useful features from various data sources and optimizing input variables for the model. Explore ensemble methods that leverage the strengths of different algorithms.
Cluster 4: Incorporate comprehensive and real-time data, fine-tune model parameters and hyperparameters, and customize models for different crop types and regions.
Cluster 5: Refine and enhance deep learning methods, optimize machine learning techniques, and achieve the automation of fruit counting by refining and expanding machine vision techniques in different agricultural contexts.

6 Limitations of the Study

This Bibliometric analysis has certain limitations:

1 Exclusive use of Scopus database only.
2 Focus on only English-language articles and limited data from only ten subjects.

These limitations highlight the need for additional research using a wider variety of databases, languages, sources, and periods to understand the topic entirely.

7 Conclusion

This research paper analyzes1, 177 articles on machine learning for crop yield prediction. The study identified key research topics, authors, institutions, and leading countries. Most publications on this topic in Computer Science, Engineering, Environmental Science, and Earth and Planetary Sciences came from China, India, and the USA. Cultivation, deep learning, and remote sensing were the most popular topics. The findings revealed that ZHANG Z was the most productive author, while Dimitrios Moshou was the most influential. Liakos K's research was identified as the most influential article through citation analysis. Five significant clusters were also identified, providing a valuable guide for researchers and decision-makers using machine-learning techniques to predict crop yield. By mapping out each cluster, this comprehensive research is a valuable resource for future investigations and progress in this vital study area.

References

[1] Jhajharia K, Mathur P, Jain S, Nijhawan S. Crop Yield Prediction using Machine Learning and Deep Learning Techniques. Procedia Comput Sci. 2023;218.

[2] van Klompenburg T, Kassahun A, Catal C. Crop yield prediction using machine learning: A systematic literature review. Vol. 177, Computers and Electronics in Agriculture. 2020.

[3] Mehla A, Deora SS. Use of Machine Learning and IoT in Agriculture. In: EAI/Springer t

[4] Sellam V, Poovammal E. Prediction of crop yield using regression analysis. Indian J Sci Technol. 2016;9(38).

[5] Jeong JH, Resop JP, Mueller ND, Fleisher DH, Yun K, Butler EE, Timlin J. Dennis, Shim Kyo-Moon, Gerber James S., Reddy Vangimalla R. Random forests for global and regional crop yield predictions. PLoS One. 2016;11(6).

[6] Thanh Noi P, Kappas M. Comparison of Random Forest, k-Nearest Neighbor, and Support Vector Machine Classifiers for Land Cover Classification Using Sentinel-2 Imagery. Sensors (Basel). 2017;18(1).

[7] Kaul M, Hill RL, Walthall C. Artificial neural networks for corn and soybean yield prediction. Agric Syst. 2005;85(1).

[8] Mehla A, Deora SS, Dalal S. Improving Crop Yield Prediction Models with Optimization-Based Feature Selection and Filtering Approaches. Indian J Sci Technol [Internet]. 2024 Jan 4;16(47):4512–24. Available from: https://indjst.org/articles/improving-crop-yield-prediction-models-with-optimization-based-feature-selection-and-filtering-approaches

[9] Sridhara S, Manoj KN, Gopakkali P, Kashyap GR, Das B, Singh KK, Srivastava AK. Evaluation of machine learning approaches for prediction of pigeon pea yield based on weather parameters in India. Int J Biometeorol. 2023;67(1).

[10] Moysiadis V, Sarigiannidis P, Vitsas V, Khelifi A. Smart Farming in Europe. Vol. 39, Computer Science Review. 2021.

[11] Safer MA, Tang R. The Psychology of Referencing in Psychology Journal Articles. Vol. 4, Source: Perspectives on Psychological Science. 2009.

[12] Anderson MH. How can we know what we think until we see what we said?: A citation and citation context analysis of Karl Weick's the social psychology of organizing. Organization Studies. 2006;27(11).

[13] Iniyan S, Akhil Varma V, Teja Naidu C. Crop yield prediction using machine learning techniques. Advances in Engineering Software. 2023;175.

[14] Bondre DA, Mahagaonkar S. PREDICTION OF CROP YIELD AND FERTILIZER RECOMMENDATION USING MACHINE LEARNING ALGORITHMS. International Journal of Engineering Applied Sciences and Technology. 2019;04(05).

[15] Nejad SMM, Abbasi-Moghadam D, Sharifi A, Farmonov N, Amankulova K, Laszlz M. Multispectral Crop Yield Prediction Using 3D-Convolutional Neural Networks and Attention Convolutional LSTM Approaches. IEEE J Sel Top Appl Earth Obs Remote Sens. 2023;16.

[16] Panda SS, Ames DP, Panigrahi S. Application of vegetation indices for agricultural crop yield prediction using neural network techniques. Remote Sens (Basel). 2010;2(3).

[17] Hansen JW, Challinor A, Ines A, Wheeler T, Moron V. Translating climate forecasts into agricultural terms: Advances and challenges. Clim Res. 2006;33(1).

[18] Palosuo T, Kersebaum KC, Angulo C, Hlavinka P, Moriondo M, Olesen JE, Patil RH, Ruget F, Rumbaur C, Takac J, Trnka M, Bindi M, Caldag B, Ewert F, Ferrise R, Mirschel W, Saylan L, Siska B, Rotter R. Simulation of winter wheat yield and its variability in different climates of Europe: A comparison of eight crop growth models. European Journal of Agronomy. 2011;35(3).

[19] Clark S. Organic farming and climate change: The need for innovation. Sustainability (Switzerland). 2020 Sep 1;12(17).

[20] Cai Y, Guan K, Lobell D, Potgieter AB, Wang S, Peng J, Xu T, Asseng S, Zhang Y, You L, Peng B. Integrating satellite and climate data to predict wheat yield in Australia using machine learning approaches. Agric For Meteorol. 2019;274.

[21] Ines AVM, Das NN, Hansen JW, Njoku EG. Assimilation of remotely sensed soil moisture and vegetation with a crop simulation model for maize yield prediction. Remote Sens Environ. 2013;138.

[22] Johnson DM. An assessment of pre- and within-season remotely sensed variables for forecasting corn and soybean yields in the United States. Remote Sens Environ. 2014;141.

[23] Sishodia RP, Ray RL, Singh SK. Applications of remote sensing in precision agriculture: A review. Remote Sens (Basel). 2020;12(19).

[24] Wang J, Gao X, Huang K, Yuan Y, Wang A, Dong L, Zhao X. A remote sensing-based method for high-resolution crop water footprint quantification in an irrigation district with complex planting structure. J Hydrol (Amst). 2023;617.

[25] Prasad AK, Chai L, Singh RP, Kafatos M. Crop yield estimation model for Iowa using remote sensing and surface parameters. International Journal of Applied Earth Observation and Geoinformation. 2006;8(1).

[26] Lobell DB, Asner GP, Ortiz-Monasterio JI, Benning TL. Remote sensing of regional crop production in the Yaqui Valley, Mexico: Estimates and uncertainties. Agric Ecosyst Environ. 2003;94(2).

[27] Maya Gopal PS, Bhargavi R. Selection of important features for optimizing crop yield prediction. International Journal of Agricultural and Environmental Information Systems. 2019;10(3).

[28] Jeon H, Oh S. Hybrid-recursive feature elimination for efficient feature selection. Applied Sciences (Switzerland). 2020;10(9).

[29] Whitmire CD, Vance JM, Rasheed HK, Missaoui A, Rasheed KM, Maier FW. Using Machine Learning and Feature Selection for Alfalfa Yield Prediction. AI. 2021;2(1).

[30] Suruliandi A, Mariammal G, Raja SP. Crop prediction based on soil and environmental characteristics using feature selection techniques. Math Comput Model Dyn Syst. 2021;27(1).

[31] Fei S, Li L, Han Z, Chen Z, Xiao Y. Combining novel feature selection strategy and hyperspectral vegetation indices to predict crop yield. Plant Methods. 2022;18(1).

[32] Liakos KG, Busato P, Moshou D, Pearson S, Bochtis D. Machine learning in agriculture: A review. Vol. 18, Sensors (Switzerland). MDPI AG; 2018.

[33] Weiss M, Jacob F, Duveiller G. Remote sensing for agricultural applications: A meta-review. Remote Sens Environ. 2020;236.

[34] Chlingaryan A, Sukkarieh S, Whelan B. Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: A review. Vol. 151, Computers and Electronics in Agriculture. 2018.

[35] Maimaitijiang M, Sagan V, Sidike P, Hartling S, Esposito F, Fritschi FB. Soybean yield prediction from UAV using multimodal data fusion and deep learning. Remote Sens Environ. 2020;237.

[36] Pantazi XE, Moshou D, Alexandridis T, Whetton RL, Mouazen AM. Wheat yield prediction using machine learning and advanced sensing techniques. Comput Electron Agric. 2016;121.

[37] Khaki S, Wang L. Crop yield prediction using deep neural networks. Front Plant Sci. 2019;10.

[38] Bose P, Kasabov NK, Bruzzone L, Hartono RN. Spiking Neural Networks for Crop Yield Estimation Based on Spatiotemporal Analysis of Image Time Series. IEEE Transactions on Geoscience and Remote Sensing. 2016;54(11).

[39] Crane-Droesch A. Machine learning methods for crop yield prediction and climate change impact assessment in agriculture. Environmental Research Letters. 2018;13(11).

[40] Feng L, Zhang Z, Ma Y, Du Q, Williams P, Drewry J, Luck B. Alfalfa yield prediction using UAV-based hyperspectral imagery and ensemble learning. Remote Sens (Basel). 2020;12(12).

[41] Fu Z, Jiang J, Gao Y, Krienke B, Wang M, Zhong K, Cao Q, Tian Y, Zhu Y, Cao W, Liu X. Wheat growth monitoring and yield estimation based on multi-rotor unmanned aerial vehicle. Remote Sens (Basel). 2020;12(3).

[42] Brinkhoff J, Robson AJ. Block-level macadamia yield forecasting using spatio-temporal datasets. Agric For Meteorol. 2021;303.

[43] Cao J, Zhang Z, Luo Y, Zhang L, Zhang J, Li Z, Tao F. Wheat yield predictions at a county and field scale with deep learning, machine learning, and google earth engine. European Journal of Agronomy. 2021;123.

[44] Cao J, Zhang Z, Tao F, Zhang L, Luo Y, Zhang J, Han Jm Xie J. Integrating Multi-Source Data for Rice Yield Prediction across China using Machine Learning and Deep Learning Approaches. Agric For Meteorol. 2021;297.

[45] Abbas F, Afzaal H, Farooque AA, Tang S. Crop yield prediction through proximal sensing and machine learning algorithms. Agronomy. 2020;10(7).

[46] Gandhi N, Petkar O, Armstrong LJ, Tripathy AK. Rice crop yield prediction in India using support vector machines. In: 2016 13th International Joint Conference on Computer Science and Software Engineering, JCSSE 2016. 2016.

[47] Gonzalez-Sanchez A, Frausto-Solis J, Ojeda-Bustamante W. Predictive ability of machine learning methods for massive crop yield prediction. Spanish Journal of Agricultural Research. 2014;12(2).

[48] Johnson MD, Hsieh WW, Cannon AJ, Davidson A, Bédard F. Crop yield forecasting on the Canadian Prairies by remotely sensed vegetation indices and machine learning methods. Agric For Meteorol. 2016;218–219.

[49] Kouadio L, Deo RC, Byrareddy V, Adamowski JF, Mushtaq S, Phuong Nguyen V. Artificial intelligence approach for the prediction of Robusta coffee yield using soil fertility properties. Comput Electron Agric. 2018;155.

[50] Maya Gopal PS, Bhargavi R. A novel eapproach for efficient crop yield prediction. Comput Electron Agric. 2019;165.

[51] Maya Gopal PS, Bhargavi R. Performance Evaluation of Best Feature Subsets for Crop Yield Prediction Using Machine Learning Algorithms. Applied Artificial Intelligence. 2019;33(7).

[52] Marques Ramos AP, Prado Osco L, Elis Garcia Furuya D, Nunes Gonçalves W, Cordeiro Santana D, Pereira Ribeiro Teodoro L, Antonio da Silva Junior C, Fernando Capristo-Silva G, Li J, Rojo Baio F H, Marcato Junio J, Eduardo Teodoro P, Pistori H. A random forest ranking approach to predict yield in maize with uav-based vegetation spectral indices. Comput Electron Agric. 2020;178.

[53] Gené-Mola J, Vilaplana V, Rosell-Polo JR, Morros JR, Ruiz-Hidalgo J, Gregorio E. Multi-modal deep learning for Fuji apple detection using RGB-D cameras and their radiometric capabilities. Comput Electron Agric. 2019;162.