The Application of Machine Learning in Agriculture Sustainability: A Review

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***Abstract*— The major challenge arises from social issues such as overpopulation and the competition over food resources and groundwater overused poses the main threat to food security. Sustainable development is becoming increasingly important in the agricultural sector, considering the environmental pressures from climate change, soil management, crop yield management, water consumption, and irrigation management, as well as disease management. This paper presents the finding of the literature review analysis to establish the modern evidence regarding the application of Machine Learning in Agriculture Sustainability. Published papers are reviewed within the period from 2018 to 2022. Advanced computer algorithm techniques have been learned and explored to improvise the challenges faced by agriculture sector, to ensure the efficiency of yields and sustainability, and to increase the level of quality of agriculture products in society generally. Meanwhile, the methods of Machine Learning have also been deeply explored recently to develop advanced techniques for agriculture to increase data-driven decision-making for farmers.**

Keywords*— *agriculture sustainability; climate management; crop management; disease management; irrigation management; machine-learning; soil management

1. Introduction

Agriculture activities remains as an essential element in maintaining human activities to ensure production quality; moreover, it also plays an important role as the backbone of the economic growth and contributing to the country's GDP despite of the COVID-19 pandemic [1]. Meanwhile, the world's population is expected to reach over 10 billion by 2050 [2]. The lack of knowledge on the current agriculture condition is one of the major issues from sowing to harvesting [3]. Upon the rapid population growth and urbanization, United Nations (UN) claims that the world will be facing food shortage crisis if the agriculture sector fails to produce doubled by 2050. Taking into consideration of not just providing food, but also contain high nutritious in food production, insufficient arable land- agriculture, climate crisis, quality of the soil, and the groundwater consumption. Knowing that agriculture heavily depends on climate, it will possibly affect the yield production without proper planning and scheduling on sowing to harvesting [4]. Nevertheless, irrigated agriculture continues to consume up to 70% of the groundwater used globally and it has contributed to the global environmental issues- groundwater overused [5]. It is not an easy task to meet the growing food supply demands even with the increased production in agriculture [6]. The usage of Machine Learning will be helpful for agricultural sustainability as it helps to predict and manage the crop productivity with the optimal season to sow and harvest through the analyzation on soil properties of weather

forecast and historical crop performance; thus, reducing water and fertilizer consumption as well as enhancing crop yields production. Consequently, it reduces the usage of natural ecosystems and ensures that the food production is sufficient to meet the ever-growing population. Hence, it is critical to analyses agricultural practices in the aim of proposing innovative approaches to sustain and enhance agricultural sustainability to support the growing population.

2. Materials and Methods

The systematic literature review (SLR) is adopted with three-staged methodology comprising of pre-operational stage, operational stage, and post-operational stage. The review protocol was defined to emphasize the application of Machine Learning algorithms in Agricultural Sustainability; more specifically on increasing the efficiency of agricultural sustainability. Firstly, research questions are identified to address the objective summary for this literature review study:

- RQ1- To what extent that the adoption of Machine Learning algorithm influenced agriculture sustainability?
- RQ2- Which Machine Learning algorithm performed better?
- RQ3- Which factors have been discussed in the literature for agriculture sustainability using Machine Learning?

The study for scientific articles is broken down into selected keywords such as machine learning algorithms, agriculture sustainability, soil management, irrigation management, crop yield management, climate changes, and disease management were used. Published research papers are reviewed within the period from 2018 to 2022. In addition, the review was conducted through the search strategy of digital journal databases such as IEEE, Science Direct, Taylor and Francis, Springer Link, MDPI, Emerald, and Research Gate. The main search string which includes the keywords of "machine learning" OR "artificial intelligence" AND "agricultural sustainability" AND "soil management" AND "irrigation management" OR "water

management" AND "yield management" OR "yield prediction" AND "climate changes" OR "climate crisis" AND "disease management". At a next stage, the selection criteria of the journals are based on the publication of English and availability of the full-text edition. Journal papers that are limited to view are excluded as it does not provide a full-text publication to readers.

3. Results and Discussion

Agriculture requires a great deal of decision-making and uncertainties. Ranging from events related to mother nature and environmental issues to the matter of supply and demand; meanwhile, farmers must deal with all these uneasiness. Considering the practice of agriculture activities is broad, this literature reviews the study on soil management, water consumption and irrigation management, crop yield management, weather crisis and disease management.

- Soil is the basic and main contribution to the successfulness in agriculture, and it contains the source of nutrients, and stores water for the proper growth of crops and development. The amount of available water determines the crop yield. A proper understanding and knowledge on soil conditions can improve soil management.
- Agriculture production also critically depends on the water consumption for the growth in crop production; agricultural sector fails to survive without water. An appropriate water consumption and irrigation management help to conserve the aquatic ecosystem.
- Crop yield management plays an important role during the harvesting season. It acts as a source of food and raw materials to the community and increases the rate of employment globally. The output of the crop yield productions is thought to contribute significantly to the overall economy of a country. Services like agricultural business plan, agricultural marketing, and after-sales service have also been part of the crop production in the 21st century. Thus, the opportunity to improvise the future crop development is significant.
- Climate changes can affect the potential increase in the crop yields production and eventually attack the food security at the level of locally, regionally, and even globally.
- Plant disease acts as a threat in agriculture and has a negative impact on the quantity and quality of crop production. This has resulted as a struggle for the agriculture sector to support the growing population due to the post-harvest disease on crops

I. SOIL MANAGEMENT

Issues regarding soil management is an essential attribute in agriculture. Inappropriate soil management will possibly cause crop failure and degraded yield condition [7]. Moreover, the moisture level of soil has a significant impact on the crop yield variability [8]. A good knowledge on the different soil types and conditions may enhance crop yields and reserve the natural soil resources, with the adoption of agriculture operations and practices. This section of the review highlights the research method which corresponds with the agriculture soil management, with the assistance of Machine Learning.

In the paper of [9] performed two Machine Learning methods, i.e., least squares- support vector machines (LS-SVM) and the Cubist, on 140 fresh Luvisol soil samples. The finding of the study showed that the Machine Learning methods have proved not only solving non-linear issues but successfully outperformed the prediction on different soil types. Subsequently, paper of [10] used Crop Selection Method (CSM) to solve several factors such as seasonal problems to adapt a desired crop cultivation in an appropriate location and to maximize the yield production. The model accuracy from the prediction of soil helps to provide an overview of the efficiency of soil management practices for farmers. In the work of [11], the Neural Network approach was used as a prediction of six different properties such as soil features, characterized as clay, sand and silt; based on Digital Elevation Model (DEM) with the combination of hydrographic parameters of soil maps to predict the moisture level of soils. The author of [12] used the Fuzzy Modelling approach to provide farmer decision-making and recommendation based on the ongoing pattern of the soil content data, that consists of the three variables: Temperature, Humidity and Precipitation, Light and Wind; and four output value: Healthy crop, Mild crop disease, Moderate crop disease, and Severe crop disease. The author of [13] employed Classification and Regression trees, Random Forest Regression, and Boosted Regression Trees to predict the soil moisture nearby a river valley in corresponds with the weather and climate condition. Hence, these explained algorithms have the highest influence on the prediction result on soil moisture level.

II. WATER CONSUMPTION AND IRRIGATION MANAGEMENT

According to The World Bank Data, agricultural production uses 70 percent of groundwater, on average globally [14]. This indicates that water consumption should be used wisely to conserve the freshwater ecosystem. Irrigation scheduling and management shows a significant impact on the quality and quantity of crops. Moreover, it helps to control the supply of water to provide moisture to crops for growth [15]. Subsequently, poor designed irrigation system leads to water waste of natural resources, as a result in releasing toxic chemical to the soil hence reducing the crop yield productions [16]. Conventional irrigation system is commonly practiced among farmers which they need to follow up with the modernized technique using Artificial Intelligence (AI); it benefits the crop with a controlled water input [17]. Hence, an effective irrigation system promotes a systematic balance on the long-term sustainability of climate, hydrologic cycle, and agronomical cycle [8].

In the paper of [18] used Machine Learning in irrigation management in predicting the soil moisture, soil temperature and weather forecast to minimize the water usage in irrigation. The Machine Learning model is applied to extract information to generate a precision decision rules in a sustainable irrigation action [19]. In paper [20], used the Neural Network technique to determine the amount of water to be used based on input layer: the stages of the individual's crop growth or based on the types of crops in different environmental and evapotranspiration. Paper [21] employed results obtained from time series prediction as an application of Neural Network, to observe the rainfall, average temperature, movement of winds and cloud situation; through the usage of rainfall, farmers can minimize the water consumption during irrigation process [22].

III. CROP YIELD MANAGEMENT

Crop yield management begins with the preparation of soils, sowing of seeds, seedling, fertilizing, irrigation, harvesting and storage [23]. It is practiced in agriculture activities to enhance the growth of crops. Machine Learning in forecasting models is highly used to boost the crop yield production [24]. The accuracy of a crop yield prediction could benefit the farmers to have better decision-making on the type of crops to grow and the suitable time to sow and harvest their crops [25].

The paper of [26] introduced the Machine Learning method of Kernel Density Estimation (KDE) in offering a data-driven decision-making using historical parameters on weather conditions, property of soils for seed variety selection decision on a targeted agriculture practice. The research has a 9 percent contribution to optimize the result on yield. The research conducted by a group of researchers performed a yield forecast model through Machine Learning on pre-season forecasting to have a yield management decision-making on the crop or genetic selection and ideal time to harvest [27]. Meanwhile reference [28], worked on a review to study on the estimation of nitrogen level in soil using Machine Learning as they believed that the properties of soil are important in crop yield management. This paper has concluded that the Machine Learning techniques can help to determine any crop disease issues, improve on crop management, and resolve the cost- effectiveness and labor in the agricultural sector. A paper published by [8] reviewed the application of Machine Learning in the crop management and yield prediction. The system used in Machine Learning (KDE) to detect occluded branches even with the inconspicuous foliage. The aim of the system is to provide an automating shaking vision to reduce labor requirement during harvesting. Additionally, Cisterna et al, performed the Machine Learning methods (KDE) in Precision Crop Management, based on the historical parameters to manage the crop input and supply chain, to optimize the profitability and the reduction of environment contamination will be achieved [29].

IV. CLIMATE CHANGES

The crop production and growth phase mainly depend on the weather predictions. Climate change has been shown to affect agricultural productivity and food security globally; however, different countries and regions face the significant impact differently [30]. The climate change phenomenon such as natural disaster has a huge impact on the agriculture productivity and profitability, hence influencing the decision- making on crop selection, and time of crop cycle [31]. Eventually, rain can possibly postpone the irrigation process and it helps to prevent water waste in the ecosystem.

Reference [32] implemented a method using Machine Learning approach to predict the preparedness of climate change in Southeast Asia. The goal of the study is to precautionary alert the regional farmers to have an informed decision to reduce potential loss on crops. In this review carried out by the author [33], the Neural Network Method was used as a process of supervised and unsupervised learning to predict using different weather parameters. Paper [34] has proposed four Machine Learning algorithm: Random Forest, Neural Network, Decision Trees, and Linear Regression to predict the weather forecast through the temperature, evapotranspiration, and the velocity and direction of wind; based on a specific location. The results showed that Random Forest and Decision Trees has a better performance in predicting all weather conditions, while Linear Regression obtained the maximum errors. In the framework of [35], mentioned that Random Forest is a well- known method applied in forecasting the rainfall models, as it can handle big data to avoid overfitting variables. Additionally, the paper of [36], critically discussed the application of Machine Learning model on weather prediction. Therefore, the result showed that Random Forest has the highest accuracy rate on R-Square 0.97 Random Forest consists of the highest prediction rate on predicting weather conditions.

V. DISEASE MANAGEMENT

Among other issues as equally important, crop disease constitutes a significant concern in agriculture to farmers. It has reported that plant disease has caused losses in crop yield; even though spray pesticides have been widely used for plant disease control, but it has certainly had side effects to the environment such as contamination of groundwater, soils, and ecosystems of the wildlife [37]. According to Ngozi, the factors that will incubate diseases to attack plants can be based on properties of soil, genetic and climate fluctuation. To prevent and control these diseases in agriculture, farmers need to adopt the modern application of Machine Learning to minimize losses in crops [23].

Paper [38] mentioned that the assistance of Artificial Intelligence and Machine Learning help to identify the area that obtained the highest risk in the spread of diseases in plants. Paper [39] used Residual Neural Network based model to address the plant diseases in different crops; the research has achieved a 97.36 percent of accuracy rate in evaluating the Residual Neural Network model. In the work of [40], the Neural Network was used as a detection of early stripe rust on wheat. As a result, the detection of the disease outbreak contains 95 percent accuracy rate. The author of Nettleton et al, has used two Machine Learning methods (M5Rules and LSTM) to predict the plant disease. The results have proved that the chosen Machine Learning methods has provide a significant early warning signs to anticipate plant diseases with the following input of air temperature, humidity, and wetness of leaf [41]. Additionally, this research of [42], critically performed using Long Short-Term Memory (LSTM) to treat problems on cotton diseases and pest's occurrence. The study aimed to use LSTM against other Machine Learning methods such as KNN, and Random Forest to predict Bollworm disease. The prediction of occurrence was used upon the discovery of bollworm diseases are more likely to occurred in the influence of temperature, humidity, and rain. The results have proven that the outperformed model is LSTM. In the work of [43], employed the Machine Learning (KNN, Decision Tree and Naïve Bayes) to approach disease detection on crops. The result of the study showed that Decision Tree has an accuracy rate of over 97 percent.

4. **Conclusions**

The growth of agricultural productivity needs to hit at least 70 percent by 2050 to satisfy human needs. Facing the rapid population growth and high demand on food supply, the

agricultural sector cannot depend on the traditional method [44]. The application of the advanced technological solution has shown to be a great innovation idea to increase the efficiency of farming. Efficiency is an important attribute in the agriculture production, it focuses on the essential requirements on agricultural production such as water conservation through regulating and controlling the irrigation functions. However, a poor irrigation management will certainly influence the soil, quality and quantity of crop, and the weather predictions to predict the storage release management. The pre-production phase and production phase have a correlation factor of ecological conditions and yield productivity. Therefore, the application of Machine Learning provides a high productivity in the crop growth stages for sowing, seedling, irrigation, fertilizing, and harvesting; hence business organizations in agriculture sector will have a data-driven decision-making when Machine Learning are adopted.

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