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Agricultural Research and Food Security under Climate Change: The Place of Machine Learning Models.

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ABSTRACT

Climate change is now an essential topic of research globally, this cannot be unconnected with its effect on health, food productions, and the feature of human existence on the planet earth. The challenges from the climatic changes in the form of new diseases, shortages of rain, low yield, increasing heat, and variations in weather conditions have constituted major setback to agricultural activities and food production, thereby creating several uncertainties which threaten food security. Several researches are ongoing to develop strategies and technologies to cope with these challenges; most of those works combine Machine Learning Algorithms (MLAs), available data and advances in technology to develop models and apps that tackle various aspects of agricultural practices in other to boost food production. This paper presents a number of machine learning approaches to some of these research areas in agriculture and how Nigeria as a nation can benefit from the partnership of Machine Learning experts and those from Agriculture to improve food production in the Country.

Keywords — Climate change, food production, machine learning, food security

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1. INTRODUCTION

One of the primary concerns and need of every human is food. Food takes a large portion of household income in many countries, especially the developing countries where some are up to 54% of the household income and budget [1]. The central place food occupies in human life is further shown by the investments being made by both national governments and international organizations in agriculture [2]. the primary means of ensuring access to food is by direct cultivation of crops or proper intervention in the form of importation when necessary [3].

For agriculture to thrive, environmental conditions must be fovourable and in right proportion. However, climatic variations and the attendant shortage of rain, drought, increasing temperature, and emergence of new diseases have made agricultural activities very challenging and expose nations to food insecurity and hunger [4]. Nonetheless to ensure continuation of human existence on this planet, researches must be carried out to study these new developments that confront the scientific world. The focus of those researches is to find solutions to various environmental changes that adversely affect food production and to develop methods for plants to cope.

These researches are complex and costly to embark upon if they are to be carried out directly, this is not unconnected with the fact that climate change itself is complex to study; responses of various plants to these changes are also complex. However, machine learning algorithms provide nonlinear tools to model these complex systems and study them in other to solve them cheaply. Machine learning has emerged as an efficient way to address many of the challenges that are facing agricultural practice of the 21st century [5]. It has become a tool for developing crop models [6], weather forecast models, diseases control model, food security model, soil model, yield prediction models and a host of other complex models that have improved food production and security.

This paper presents a number of machine learning approaches to some of these research areas in agriculture and how Nigeria as a nation can benefit from the partnership of machine learning experts and those from Agriculture to improve food production in the Country. This paper is divided into introduction, climate change and food production issues, food security issues in Nigeria, machine learning model, specific machine learning applications in agriculture and food security and conclusion.

2. CLIMATE CHANGE AND FOOD PRODUCTION ISSUES

Agriculture remains the major economic backbone that climate change will affect in Africa with subsequent food crisis and hunger which may follow. Although many uncertainties remain in the regional projections of climatic changes – particularly in the tropics; however, there are projected changes in water resources, natural and agricultural ecosystems, and increase in temperature [7], with drought, floods, and other associated natural hazards. Aside the direct impact of climate change to agricultural activities, Nigeria faces the problem of climate-induced resource-conflict in the form of farmer/headers conflicts [8][9]. [10] made claims (which were substantiated by [11] and [12] that climate change has reduced the vegetation in several states in northern Nigeria below 10%, as against 25% ecological cover recommended by the United Nations Development Programme (UNEP) to support the herders, the consequence of which is the competitions for access to water and vegetation by farmers/headers.

The indirect result of farmer header conflict is reduction in food production and eventual food crisis for the country. [13], made case for strong connection between changing climatic condition, conflicts and continue reduction in food production. As the climate change hit harder in Sub-Sahara Africa and more negative environmental changes occur; there will be more conflict which may affect the availability of land. In the final analysis, there will be food crisis and hunger if proper plans are not made.

Africa depends so much on rain-fed agriculture which is projected to have a decline of 50% by 2020 through reduction in the length and quality of the growing season [8]. The reduction of the rain and the length of the growing season will have several impacts on yield and provision of the necessary food for the nation. Some crops which normally need long months of rain may eventual become very difficult to grow, thereby causing over-dependent on some other crops. This over-dependent will cause malnutrition and other health complications.

3. FOOD SECURITY ISSUES IN NIGERIA

Food is an essential part of every society as continuation of human existence depends greatly upon it. However, sufficient availability of it for the entire population continues to be a major challenge to Nigeria as a nation. According to [15] and [3], hunger rate in Sub-Saharan Africa is so severe that one out of every three persons is malnourished. Nigeria is a nation where the severe nature of food insecurity results in large importation of domestic food due insufficient internal production [1]. The statistics of food challenge in Nigeria has it that 79% and 71% house-holds in rural and urban areas of the country are food insecure [15], therefore, there is need to confront food production if the nation must achieve her economic goals.

For effective policy formulation, planning, and intervention, it is crucial to provide accurate and current assessments of food security status and vulnerable of families. Face-to-face interviews are the standard method for gathering these data. However, these methods are costly, time-consuming, and, in some places, impossible to carry out because due negative prevailing circumstances. Since primary data are not always available, researchers have started to look into machine learning algorithms with secondary data to predict food security[16]–[22]. This method provides an inexpensive and accurate means to estimate certain parameters and extract vital information from data

4. MACHINE LEARNING MODEL

Machine learning models are mathematical models developed to study the behaviour of a complex system [23]. They are mostly applied to nonlinear system for which intuitive analytical solutions may not be suitable or readily available. A typical example of such models contains several variables that represent the characteristics of the modeled system. To carry out experimental simulation, input data are supplied to the model and the result of their effects on the system is observed from the output result. Such models are common in weather and rainfall modeling [24], conflict studies [25], and several other fields.

Machine learning models are developed using Machine Learning Algorithms (MLAs). These algorithms are designed or developed with capacity to learn from data [26][27]. Learning process in machine learning model is divided into two steps: training and testing. In training process, samples in training data are taken as input in which features are learned by learning algorithm or learner and build the learning model. In the testing process, learning model uses numerical or rule-based inference engine to make prediction. Tagged data are the output of learning model which give the final prediction or classified data.

MLAs are generally supervised or unsupervised learning. Common MLAs include Artificial Neural Networks, Genetic Algorithm, Fuzzy Cognitive Maps, Hebbian Learning Algorithms, Support Vector Machine, and a host of others. Detailed review of machine learning algorithms can be found in [28] and [27]. International Maize and Wheat Improvement Centre (CIMMYT), whose research is dedicated to developing improved maize and wheat seed, highlighted simulation models as important tools for deriving breeding goals and alternative farming practices. The models allow estimating the extent to which climate change and policy decisions can affect crop productivity and food security [29][30]. Recent developments aim at being able to better represent extreme climate changes or to better understand crops in rotations. The enormous progress in information technologies also offers novel opportunities for models that explain the causal links between these variables.

5. SPECIFIC MACHINE LEARNING APPLICATIONS IN AGRICULTURE AND FOOD SECURITY

- **Climate Modelling**: climatic studies and understanding are vital issues for successful agricultural activities. Projections of future climatic conditions of a nation are used to carry out researches to prepare for the future and to handle various future challenges and uncertainties [31] that may be obvious from the simulations. But for Nigeria situation, there is no single model for this nation upon which future projection and researches can be made [32]. United States Institute for Peace noted that the current models for studying the Nigeria climate were developed by intergovernmental panel on climate change (IPPC) to study either global or West African climate [32]. However, with the complex nature of Nigeria ecosystem which extends six major vegetation zones and soils, there are several variations in weather patterns which vary across the different zones and altitudes; which some is said to be between 3,000 feet to less than 10 feet above sea level [33]. No single generic model or adaptation scheme could reasonably apply to the whole country [32]. With the power of Machine Learning which handles complex data and systems, there is a need to develop Nigeria climate models which will help both the scientist and the policymakers study future climatic changes and prepare the nation for posterity.

- **Handling Plant Disease:** one major challenge for food production is plant diseases, about 20-40% of crop losses result from diseases and weeds [34]. Machine learning can help scientists and farmers to detect or identify diseased plants and treat them before large loses result. [34], reported the use of Machine Learning model (Deep Learning) to analyse 14 crops which are susceptible to 26 diseases. When the model was tested with images of 50,000 crops, it was able to correctly diagnose 99.35% of them. Developing mobile App with this level of accuracy will aid the farmers to detect diseased plants even in the absence of extension workers and take necessary actions to reduce damage the farmers may be experiencing [35].

- **Intelligent weeding and fertiliser application**: There is a general move towards SMART or Precision Agriculture, to evolve new methods that increase yield while minimizing chemical inputs such as fertilizers, herbicides, and pesticides that affect the environment, and soul microorganisms [36]. A solution to this is the implementation of machine learning algorithms on some intelligent machines which can selectively fertilise and weed at the same time. One of such application is reported by [37], where Machine Learning model was implemented on

a physical machine to identify each sprout as a lettuce or a weed. Once found, it sprays a strong fertilizer to kill the weed and fertilize the lettuce in one go, this technology can reduce farmers' use of chemicals by 90%. In Nigeria where fertiliser is mostly scarce and high use of chemicals that damage the soil, the use of Machine learning can reduce further damage to the environment, reduce fertiliser usage and increase yield.

- **Predicting crop yield**: Prediction of crop yield is very vital for proper planning in other to avoid troubles of national food crisis when crop failure occurs, but this is very challenging in an environment of uncertainty and lack of data [37]. In Nigeria, a lot of what is obtained is from self report from the farmers, which is said to have high level of error. Data from Satellite images can be combined with machine leaning algorithms to model crop yield [37], these models have capacity to predict yield without ground survey and have proven to be useful in proper planning. [38], applied Artificial Neural Network to predict the crop yield based on certain climatic conditions like rainfall, temperature and the result was encouraging. Development of such model can be useful in avoiding malnutrition and over dependence on few crops when certain crop are predicted to fail. The country can plan proper course of action or necessary intervention.

- **Crop stress and drought resistance studies**: One key area that climate change affects the plants is the shortage of water, drought and other negative environmental changes which cause biotic and abiotic stress [6]. If there is need for such research anywhere in the world, then it will be more in Nigeria. With the reality of changing pattern of rain in **Sub-Saharan Africa who rely greatly on rain-fed agriculture, there is need to study different plants ability to cope with drought so that necessary drought-resistant breeds can be developed. However, some studies claimed that it's very difficult to understand the coping strategy without high level model. Machine learning strength was demonstrated by** [39] who used machine learning algorithms to study different stress condition which certain crops may experience under different climatic conditions. With large volumes of genome-scale gene expression data machine learning computational techniques, they were able to study complex nature of the stress response in plant and examine in depth the overlap between abiotic and biotic stress responses. The benefit of this research will help Nigeria to prepare new breeds and drought-resistant seeds for future projected climatic changes in the region.

- **Soil property prediction**: Nigeria is large and the vegetation and soil property varies greatly across different vegetation zones of the country. Carrying out direct field studies of various zones and place will be an enormous task which may cost so many resources. A wonderful approach to such research is the use of diffuse reflectance infrared spectroscopy to collect remote data from a particular environment, from such data, high level machine learning models are developed which quickly gives the characteristic of the soil [40]. Inexpensive soil characterization allows large, data-sparse regions to plan sustainable agricultural development and manage local natural resources [40].

- **Modelling household food need:** The required amount of food as population grows is vital issue in food security of any nation. It helps in proper planning of the necessary intervention. Such models are complex with several multidimensional variables [41]. It forecasts household food need by using data on the subject of food and building Machine learning model. [41], applied Artificial Neural Network (ANN) to data from the Egyptian ministry of agriculture to predict household food insecurity, likewise, experts from machine learning and agricultural area can partner with necessary agencies of government to develop machine leaning models to forecast required food to feed the nation or necessary intervention in the form of import and other important variables. The information from such models will be vital in planning.

Figure 1 below is a brief conceptual framework of how machine learning can improve food production under climate change. With the available data being used to develop either research or forecasting models and apps, there will be better future climate forecasts which will improve crop yield, improve food intervention planning and reduce crop loss to diseases.

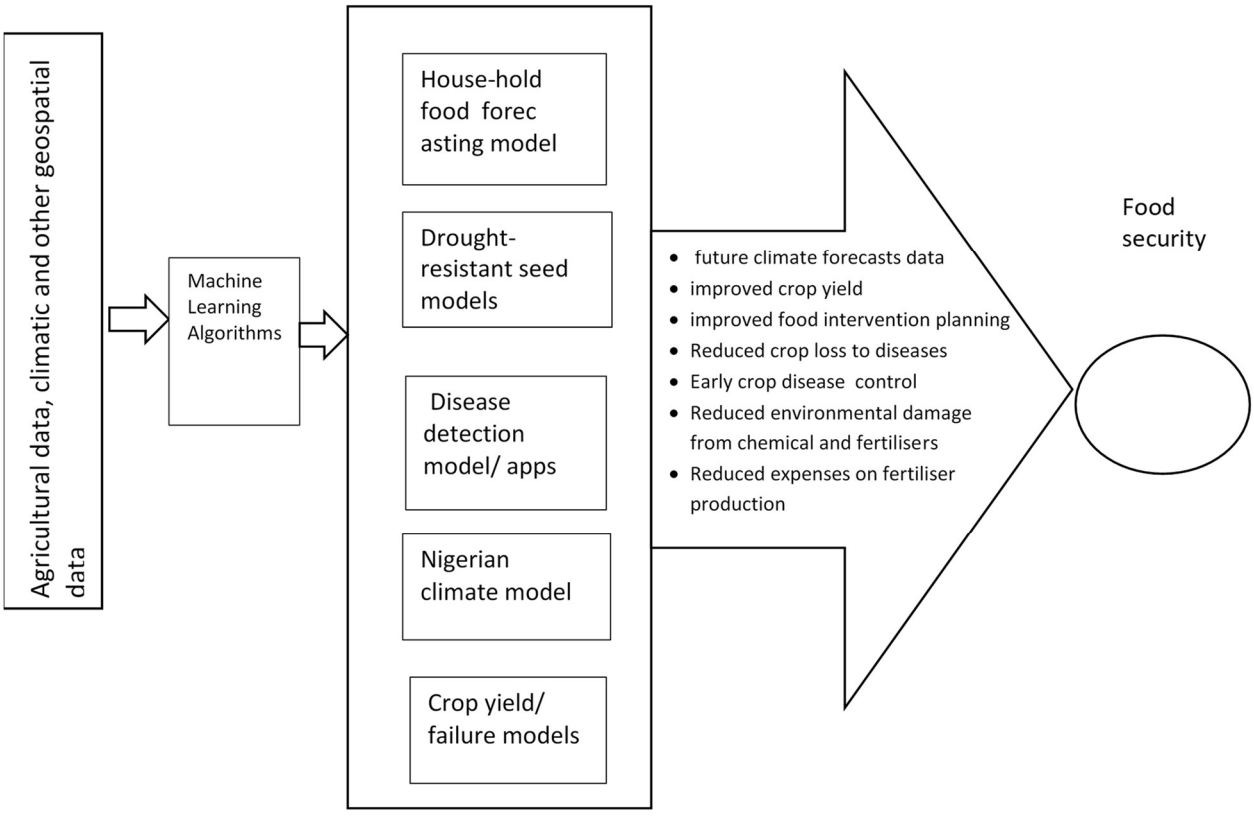

Figure 1: A Conceptual Framework of How Machine Learning Can Improve Food Production

5.1 Challenges of the machine learning applications to the Nigerian food security problem

There are always challenges to application of machine learning in solving problems in various fields, but firstly is the availability of data. Machine learning models are developed from huge data of the system being modeled and train until their level of accuracy is acceptable. Nigerian case is a challenge where many of the data available are either incomplete, or are too sparse [42].

Example, developing a machine learning model to predict pest outbreak will require data about the pattern of migration for a number of years, also developing an accurate crop yield model will require data of crop yield model for a good number of years, however, as earlier stated, any of such data are either not available or available with gaps or error. Another close challenge to the availability of data is its accessibility. While we have some government agencies that generate huge data from the satellite images of direct field survey, their accessibility are a huge issue. Data for research are quite often very difficult to access, making some of these interesting solutions if carried out a frustrating effort.

Another drawback to the progress in machine learning application in agriculture in Nigeria is lack of collaboration among experts from different fields. The experts from the computing field, statistics and other field where machine learning are deeply studied have not formed strong research alliance with those in agriculture and environmental studies to develop powerful and reliable models which will give agriculture a boost in the country.

6. CONCLUSION

Challenges of climate change are multidimensional and directly impact agriculture seriously; tackling them requires high level researches which are very challenging and costly. Without confronting those challenges, the country risks national food crisis and hunger. Therefore, there is serious need for partnership across various fields to tackle the issue of food security from different angles by bringing different skills together to further a research that will improve food production. This may require coming together of machine learning experts, climatologists, and experts from agricultural fields in other to developed models that will give understanding of some of the complex issues in climate change studies and crop production.

This paper presented various areas in which machine leaning algorithms come handy to help handle such problems and do hope that adoption of some of these research areas will bring solution to some challenges in agricultural and proper planning for food security in Nigeria.

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