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Precision, Prediction and Protection: AI in Climate Smart Agriulture

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Abstract:

Agriculture, a key economic driver, faces challenges in meeting the demands of a growing global population with limited resources and climate instability. As a result, "Smart Farming" has grown in popularity, which employs cutting-edge artificial intelligence (AI) to support autonomous decision-making. This article explores how IoT, AI, ML, remote sensing, and VRT might alter agriculture. The research focuses on applying sophisticated algorithms to predict soil conditions, improve agricultural yield projections, diagnose water stress from sensor data, and identify plant diseases and weeds through image recognition, crop mapping, and AI-guided crop selection. To efficiently satisfy the world's food demands, this study envisions a sustainable agricultural future that mixes AI-driven initiatives with traditional methods.

Key words: Precision, Climate Smart Agriculture, Artificial Intelligence, Adaptation

Introduction:

Artificial Intelligence (AI) is anticipated to have a substantial potential for addressing climate change. Throughout the globe, agriculture is the most dynamic and ancient occupation (Kaur & Sidhu, 2020; Marco et al., 2021). Addressing climate change in agriculture is of paramount importance. In order to achieve optimal crop growth and livestock production, agriculture is intrinsically dependent on favorable climatic conditions, such as temperature, precipitation, and sunlight. Nevertheless, alterations in these conditions are being caused by climate change, resulting in heightened variability, extreme weather events, and long-term changes in temperature and rainfall patterns. Agricultural systems worldwide are confronted with substantial challenges and hazards as a result

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of these modifications (Marco et al., 2021; Subeesh & Mehta, 2021). Agriculture is the primary source of sustenance for the expanding global population. The disruption of crop yields, the reduction of water availability for irrigation, and the increase in the prevalence of parasites and diseases are all ways in which climate change poses a security threat to food (Krastanova et al., 2022). It is imperative to adjust agricultural practices to climate change in order to guarantee a stable and substantial food supply for both present and future generations (Vijayakumar & Balakrishnan, 2021).

There are millions of producers who depend on agricultural activities for their livelihoods. Events that are caused by climate change, including droughts, floods, and heatwaves, can have catastrophic consequences for agricultural incomes, livestock productivity, and crop yields. Addressing climate change in agriculture is crucial for the preservation of rural livelihoods, the reduction of poverty, and the promotion of sustainable rural development (Wang & Zhang, 2019).

The environment is inextricably linked to agriculture. Deforestation, soil degradation, water pollution, and greenhouse gas emissions are all exacerbated by unsustainable agricultural practices. We can promote sustainable land and resource management and mitigate the environmental impact of agriculture by implementing climate-smart agricultural practices, including precision farming, agroforestry, and conservation agriculture (Tielkiniena et al., 2020).

- AI-powered systems are capable of analysing images of crops to identify diseases, nutrient deficiencies, and insect infestations. AI can recognise visual patterns that are linked to crop health issues through the use of computer vision and machine learning algorithms. This allows producers to reduce crop losses and optimise resource utilisation by taking early action and implementing targeted treatments.
- In order to offer insights into soil conditions, weather patterns, and crop growth, AI algorithms analyse data from a variety of sources, such as sensors, drones, and satellites. This data enables producers to optimise productivity and minimise input waste by customising the application of pesticides, fertilisers, and irrigation to specific regions of a field (Kaur & Sidhu, 2020).
- In order to optimise feed formulation and feeding practices, AI can analyse data on animal nutrition, feed composition, and performance. AI algorithms can produce personalised feed plans by taking into account factors such as animal health,

growth stage, and nutrient requirements. This reduces the environmental impacts associated with animal husbandry, minimises waste, and improves feed efficiency.

- AI has the potential to enhance disease surveillance and outbreak prediction in animal husbandry. AI algorithms can predict disease outbreaks and identify patterns by analysing data from a variety of sources, such as veterinary records, environmental factors, and animal health indicators. Farmers can minimise the spread of diseases and reduce economic losses by implementing control strategies through early detection and proactive measures.
- AI can assist in environmental monitoring, which includes the assessment of soil health, the monitoring of water quality, and the monitoring of biodiversity. In order to identify environmental hazards and optimise resource utilisation, AI algorithms analyse data from sensors and other sources. This encourages the conservation of natural resources, reduces the environmental impact, and promotes sustainable cultivation practices (Kurgat et al., 2020).
- AI-powered data analytics tools aid producers in making well-informed decisions. Artificial intelligence algorithms analyse substantial quantities of data, including historical records, meteorological data, and market trends, in order to generate actionable insights. In an effort to enhance productivity and profitability, this enables producers to optimise planting schedules, manage inventory, predict market demand, and make data-driven decisions (Veroustraete, 2015). In both agriculture and animal husbandry, it is imperative to mitigate climate risks and establish resilience. There are numerous applications of artificial intelligence (AI) that contribute to these objectives. The following are the primary applications of AI in agriculture and animal husbandry to reduce climate risks and enhance resilience:
- Satellite imagery, real-time weather data, and historical climate data are analysed by AI algorithms to create climate models and forecast future climate patterns. These forecasts assist farmers and animal producers in anticipating and preparing for climate-related hazards, including disease epidemics, temperature fluctuations, and extreme weather events. The integration of AI-generated climate forecasts enables stakeholders to make informed decisions regarding animal welfare, management practices, and adaptation strategies.

- AI technologies facilitate the surveillance and management of livestock by analysing data obtained from sensors, cameras, and wearable devices. Detected and analysed by machine learning algorithms are environmental conditions, health indicators, and behaviour patterns. Additionally, this facilitates the early identification of abnormal behaviour, distress signals, or maladies in animals. The prompt identification of such issues can result in the implementation of appropriate measures to prevent the spread of diseases, ensure animal welfare, and mitigate risks.
- Artificial intelligence algorithms optimise feed formulation and feeding practices by analysing data on animal nutrition, feed composition, and performance. AI is capable of producing personalised feed programs by taking into account factors such as animal health, growth stage, and nutrient requirements. This optimises feed efficacy, minimises waste, and mitigates the environmental consequences of animal farming. It is possible to reduce greenhouse gas emissions from livestock and encourage sustainable resource utilisation through the implementation of optimised nutrient management.
- AI is instrumental in the development of climate-resilient livestock through breeding programs. AI algorithms can identify genetic markers associated with desirable characteristics, such as heat tolerance, disease resistance, or feed efficiency, by analysing genetic data, environmental conditions, and performance records. This knowledge helps in selective breeding, which increases the resilience of animal populations to climate-related stresses and reduces their susceptibility to climate hazards.
- AI technologies have the potential to create early warning systems for climate-related hazards by integrating real-time data on animal health, climate, and weather. AI algorithms can offer farmers and livestock producers timely alerts and recommendations by analysing these data streams. This enables them to mitigate risks and reduce losses by adjusting management practices, sheltering animals, or instituting biosecurity protocols.
- Artificial intelligence-powered decision support systems offer real-time insights and recommendations to farmers and animal producers. Artificial intelligence algorithms facilitate the development of well-informed decisions regarding climate risks and resilience-building strategies by incorporating data from a variety of sources, such as weather forecasts,

environmental sensors, and animal health records. Included in this are suggestions regarding resource allocation, risk mitigation strategies, and adaptive management practices.

- AI plays a role in the surveillance and management of diseases in the animal husbandry industry. AI algorithms can predict disease outbreaks and identify patterns by analysing data on disease prevalence, environmental factors, and animal health indicators. The spread and impact of diseases on animal populations are reduced by early detection, which enables prompt response and targeted interventions, such as vaccination, quarantine, or treatment.

Different crop growth models and their major purpose:

1. **ELCROS (Netherlands):**
   - First crop growth simulator.
   - Simulate crop growth rate as a function of soil, air temperature, photosynthesis, respiration, and transpiration rate.
2. **GOSSYM (USA):**
   - Simulate cotton crop dynamics, growth, and yield.
   - Requires plant population information, irrigation, nitrogen fertilizer information, soil hydraulic properties, weather data.
3. **BACROS (Netherlands):**
   - Basic crop growth simulator with simple soil water balance model.
   - Simulates crop growth during the growing season with hourly time steps.
   - Requires maximum leaf photosynthesis rate, weather data (mainly maximum and minimum temperature, relative humidity), latitude, start and duration of the vegetative growth period, the width of leaves.
4. **PAPRAN (Netherlands):**
   - Estimates water and nitrogen balance for plant growth and seed production, biological and economic effects on crop and pasture management system.
   - Mainly applicable for a field of annual pasture or a small-grain crop growing in a semi-arid environment.
   - Mainly performs plants growth, N uptake, soil water balance.
5. **SUGROS (Netherlands):**
   - Simulates both potential and water-limited growth of a crop, i.e., its dry matter accumulation, CO2 accumulation (in terms of photosynthesis) under adequate and rainfed supply of water and

nutrients in a pest, disease, and weed-free environment under the prevailing weather conditions.

6. **SOYGROW (USA):**
   - Growth simulation model for soybean for decision making on irrigation and pest management
   - Components of the model are the vegetative and reproductive development of legume crop, accumulation, and depletion of N pools
7. **PNUTGROW (USA):**
   - Simulates groundnut yield and dynamically responds to daily weather inputs (temperature, rainfall, and radiation) and to pest and soil-water deficit stresses.
   - It considers crop-carbon balance, nitrogen balance, and water balance at the process level.
8. **CERES-maize (USA):**
   - Simulates maize growth and development, yield variability, N uptake
   - Later, it has added as a module in DSSAT
9. **WOFOST (Netherlands):**
   - Simulates crop growth by means of the ecophysiological process like growth, phenological development and light interception, CO_2-assimilation, root growth, transpiration, respiration partitioning of assimilates to the various organs, and dry matter, formation with 1-day time step.
   - Can depict three different levels of crop production namely potential, water-limited, and nutrient-limited production.
10. **EPIC (USA):**
   - Simulates crop growth as expressions of soil productivity with a wide range of erosion damage.
   - Also simulates leaf interception to solar radiation, conversion to biomass, root growth, plant water, and nutrient uptake.
   - Model components include weather, hydrology, sedimentation, crop growth, soil temperature, tillage, nutrient cycling, plant environmental control.
11. **DAISY**
   - Simulate soil-plant water atmospheric dynamics, heat and solute balance in and crop production
   - This model includes a number of main modules namely a hydrological model including a sub-model for soil water dynamics,

a soil nitrogen model including a sub-model for soil organic matter dynamics, a crop model including a sub-model for water and nitrogen uptake, and a soil temperature model.

12. DSSAT

- Simulate crop growth, development, yield as a function of soil-plant-atmosphere-management relationships.
- It includes several crop modules
- Require daily weather data, soil surface and profile information, and detailed crop management, genetic information
- It has been used for a wide range of applications at different spatial and temporal scales.

13. CROPSYST

- Analyze management practices for water and nitrogen.
- Multi crop, multiyear and daily time step-based crop growth simulation model.
- Simulates the soil water budget, crop yield, crop phenology, crop canopy and root growth, soil-plant nitrogen budget, biomass production, residue production and decomposition, soil erosion by water, and fate and transport of pesticide.
- It consists of a crop growth simulator, GIS cooperator, weather generator, and watershed model.

14. TOMGROW

- Quantify the effect of temperature, CO2 concentration, and light on the tomato growth process.
- Mainly used for greenhouse conditions.

15. ALMANAC

- Simulates crop growth, canopy light interception, water use, biomass accumulation, partitioning of biomass into the grain, nutrient uptake, and growth constraints such as water, temperature, and nutrient stress.
- Weather, tillage, soil, and crop parameter are essential inputs. This model has an automated weather generator subroutine that can be used in case of unavailability of weather data.
- ALMANAC supports multi-species interactions mediated by light.

16. CROPWAT (ITALY):

- Calculate crop evapotranspiration by FAO Penman-Monteith Method
- • Mainly used for irrigation scheduling

17. ORYZA

- Predict rice growth, the yield for irrigated systems

- It can quantify the water stress, soil temperature, root dynamic growth, irrigation combination, GHG emissions, root water uptake, Organic fertilizer to soil C and N dynamics, transformation, N mass, and diffusion uptake.
- Also able to depict the climatic and abiotic stresses to yield, daily max and min temperature change to growth.

18. WTGROWS (INDIA):

- Estimates wheat yield and growth for tropical and subtropical wheat regions in India.
- Simulates dally dry matter production as a function of radiation and temperature, and water and nitrogen availability.
- It consists of a cropping module, water balance module for water uptake, and nitrogen balance module for uptake and distribution of N.

19. HERMES (GERMANY):

- Simulates crop water and nitrogen dynamics
- The model considers the main processes of nitrogen mineralization, denitrification, wSimulates the effects of weather, soils, management, and major pests on crop growth, yield, soil carbon,
- nitrogen and water, yield loss, and greenhouse gas emissions
- • Process of InfoCrop involved crop growth and development, crop weather, crop pest interactions, soil
- water, nitrogen balance, and organic carbon dynamicsater, and nitrogen movement, plant growth, and water as well as nitrogen uptake by plants.
- Applicable in data-limited condition

20. APSIM (AUSTRALIA):

- Simulates biophysical process in farming systems.
- Consists plant, soil, animals' climate, and management modules, and those modules have a diverse range of trees, crops and pastures, soil water balance, transformations of N and P, erosion, and a full range of management controls.

21. ROTASK (NETHERLAND):

- Simulates dynamically cropping and tillage system and evaluates crop rotation strategies on farms
- This crop growth model is based on light use efficiency for direct conversion of intercepted radiation into dry matter.

- It enables the user to perform all kinds of management practices on field level which are common in temperate cropping and tillage systems.

22. STICS (FRANCE):

- Simulates crop water and nitrogen balance and biomass accumulation over one crop cycle to several crop cycles by using daily climatic data, soil, crop phenological, and management data (like mulching, etc.).
- Can simulate root front, root density, canopy water transfer, soil surface status.
- Adaptable to various crops and can simulate various soil-climate conditions.
- It incorporates a simplex algorithm for parameter optimization.
- It can able to consider the functioning of agricultural drainage systems in 3D.

23. GLAM (UK):

- Process-based large area model to simulate the impact of climate on crop yield, yield gap as a function of daily weather data, soil hydrologic data, and planting date information.
- Lesser data requirement.
- The spatial scale can be similar to the climate model grid scale.

24. InfoCrop (INDIA):

- Simulates the effects of weather, soils, management, and major pests on crop growth, yield, soil carbon, nitrogen and water, yield loss, and greenhouse gas emissions.
- Process of InfoCrop involved crop growth and development, crop weather, crop pest interactions, soil water, nitrogen balance, and organic carbon dynamics.

25. AquaCrop (ITALY):

- Simulates yield response to water of mainly herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production.
- Simulates yields for single field scale (point simulations) without any spatial heterogeneity and for single growth cycles.
- Majorly uses for irrigation scheduling, crop management practices, and yield response to climate change.
- Compute only vertical incoming (rainfall, irrigation) and outgoing (Evaporation, transpiration, deep percolation) fluxes.

26. MONICA (GERMANY):

- Process-based 1-dimensional simulation model to see the impact of climate and management impact on crop yields and environmental variables mainly in central Europe.
- Predict crop growth, evapotranspiration, nitrate leaching, carbon dynamics.

27. SIMDualKc (PORTUGAL):

- Computes evapotranspiration using dual crop coefficients (Kc) approach, also separately computes soil evaporation and crop transpiration using root zone soil-water balance.
- Able to compute total available water, total evaporable water, and readily evaporable water by considering soil hydrologic characteristics.

28. ARMOSA (ITALY):

- A micrometeorological model that can simulate crop growth, carbon, and nitrogen balance under different pedoclimatic conditions.
- It simulates the energy balance, allowing the evapotranspiration estimation by using global radiation and temperature.
- Performed the soil water balance.

29. Web InfoCrop -Wheat (INDIA):

- Estimate crop growth, yield, water, nitrogen dynamics, and global warming potential for wheat.
- Simulate the growth of wheat on a daily basis using inputs of weather, soil, variety, and management practices.

30. MANIHOT (USA, Colombia):

- Able to represent indeterminate growth of and development of Cassava that is devoid of critical phenological stages, incorporated in DSSAT 4.7 version.
- It also includes new water stress factor based on the soil water content instead of the ratio between potential and actual transpiration and which affects the germination, leaf size, leaf appearance, branching, and biomass increase.

Conclusion:

In agriculture and animal husbandry, these applications of AI demonstrate its potential to improve sustainability, productivity, and efficiency. In the end, farmers can contribute to more sustainable and resilient agricultural practices by optimizing resource utilization, improving decision-making, and mitigating risks through the use of AI technologies. Climate-Smart Agriculture endeavors to establish a sustainable and resilient agricultural system that can simultaneously adapt to and mitigate the effects of climate change. By adopting the principles and objectives of CSA, agricultural communities can improve productivity, establish resilience, decrease greenhouse gas emissions, and contribute to sustainable development objectives.

One key application of AI in climate-smart agriculture is precision farming. AI-driven tools, such as remote sensing and satellite imagery, can accurately monitor crop health and identify areas requiring specific interventions. This enables targeted irrigation, fertilization, and pest control, minimizing the use of resources and reducing environmental impact. AI also plays a crucial role in climate modeling and prediction. Machine learning algorithms can analyze historical climate data and identify patterns, allowing for the creation of accurate climate models. These models can help farmers anticipate climate-related risks, such as droughts or floods, and take proactive measures to adapt their farming practices accordingly.

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