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AgGlob: Toolset for Cropping Systems Modeling and Simulation

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1. Introduction

This notice introduces a comprehensive toolset designed for the modeling and simulation of cropping systems. With increasing pressures on agricultural systems due to population growth, climate change, and resource constraints, it has become essential to develop advanced tools that help researchers, farmers, and policymakers optimize crop management strategies. This toolset offers capabilities to model complex interactions within cropping systems, predict outcomes under various conditions, and simulate different scenarios to aid in decision-making.

2. Objectives of the Toolset

The primary objectives of the toolset are:

1. **Scenario Analysis:** Enable the exploration of different climate, soil, and management scenarios to understand their impacts on crop yield, resource use, and sustainability.
 2. **System Integration:** Facilitate the integration of various components of cropping systems (e.g., soil, water, weather, and crop physiology) for comprehensive system analysis.
 3. **Support for Decision-Making:** Provide stakeholders with insights on the best cropping practices based on simulations and data-driven models.
 4. **Automate modelling and simulation tasks by processing pipelines (or modelling chains):** processing pipelines refer to a structured sequence of computational stages that automate the flow of data and tasks required to simulate agricultural processes. These pipelines typically consist of multiple steps, including data acquisition (e.g., weather, soil, and crop data), pre-processing (data cleaning and transformation), model execution (crop growth, water, and nutrient dynamics simulation), and post-processing (result analysis and visualization). By organizing these steps into a pipeline, users can efficiently manage and automate complex workflows, such as running simulations for different cropping scenarios, assessing environmental impacts, or optimizing resource use. Processing pipelines ensure that large-scale simulations are performed consistently, reproducibly, and with minimal manual intervention.
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3. Toolset Components

The toolset is composed of the following models, each designed to address a specific aspect of cropping system simulation:

3.1 Crop Growth Models

These models simulate crop growth and development stages based on environmental conditions such as temperature, solar radiation, and water availability. The crop growth model integrates physiological processes such as photosynthesis, transpiration, and nutrient uptake, providing accurate predictions of crop performance. In AgGlob, we use mainly STICS (Brisson et al. 2003, Brisson et al. 2008) developed by INRAE agronomists.

- **Input parameters:** Climate data (temperature, rainfall, solar radiation, wind), soil properties, crop management practices.
- **Outputs:** Biomass accumulation, crop yield, phenology stages, water and nutrient use.

3.2 Soil-Water Balance Models

They simulate water movement through the soil profile, accounting for infiltration, evaporation, plant uptake, and drainage. It helps assess the availability of water to crops and the risk of water stress or excess water. In AgGlob, we use mainly STICS developed by the INRAE agronomists.

- **Input parameters:** Soil texture, porosity, field capacity, climate data.
- **Outputs:** Soil moisture levels, water availability to crops, irrigation requirements.

3.3 Nutrient Management Models

They evaluate nutrient cycling and availability within the cropping system. It tracks nutrient inputs (fertilization), losses (leaching, volatilization), and crop nutrient uptake, allowing for the optimization of fertilization strategies. In AgGlob, we use mainly STICS developed by the INRAE agronomists.

- **Input parameters:** Fertilizer type and application rates, soil nutrient content, crop requirements.
- **Output:** Nutrient uptake, soil nutrient balance, potential nutrient losses. Information on the dynamics of the carbon and nitrogen cycles.

3.4 Decision rule based model Models

A decision-rule-based model for cropping system management is a framework that uses predefined rules to drive decision-making processes in agricultural systems. These rules are typically derived from expert knowledge, historical data, or experimental results, and they guide actions such as irrigation, fertilization, pest control, and crop rotation. The model interprets environmental inputs (e.g., soil moisture, weather conditions, crop growth stages) and applies decision rules to determine the optimal management practices at each stage of the cropping cycle. The primary purpose of such models is to automate and optimize crop management, ensuring that resources are used efficiently and sustainably while maximizing crop yields and minimizing risks, such as water stress or nutrient deficiencies. This approach allows for more precise, data-driven decision-making tailored to specific conditions in the cropping system.

4. Simulation Capabilities

The toolset allows users to run simulations that provide valuable insights into various aspects of cropping systems. The simulation process involves:

1. **Data Input:** Users input site-specific data, including weather conditions, soil properties, crop types, and management practices.
2. **Scenario Definition:** Users define different scenarios, such as changing irrigation levels, applying different fertilization strategies, or simulating the effects of climate change.
3. **Model Execution:** The toolset runs the models based on the input data and selected scenarios, simulating system behavior over time. AgGlob enables also multi-simulation in High-Performance Computing (HPC). This refers to the simultaneous execution of multiple simulations, often with varying parameters or initial conditions, across a distributed computing environment. This approach leverages the power of HPC systems to run numerous simulations in parallel, allowing for faster exploration of complex scenarios, sensitivity analyses, or optimization tasks that would be computationally prohibitive on a single machine. By distributing the computational workload across multiple processors or nodes, HPC multi-simulation significantly reduces the time needed to obtain results, facilitating large-scale data analysis and decision-making.
4. **Result Analysis:** The outputs of the simulations are displayed in graphical and tabular formats. Users can analyze the results to identify optimal practices or predict risks.

5. Applications of the Toolset

The toolset can be applied to a wide range of research and practical applications, including:

- **Climate Change Impact Studies and mitigation studies:** Simulating how future climate scenarios will affect crop yields and resource use. Simulating of how new agriculture practices can contribute to mitigating climate change. (Nendel et al. 2023, Launay et al. 2023, Debaeke et al. 2021)
- **Development of Agroecology practices and Sustainable Agriculture:** Optimizing resource use (water, nutrients) to ensure environmental sustainability while maximizing yields. (Willaume et al. 2024)
- **Risk Management:** Assessing the risks associated for example, with extreme weather events, and determining appropriate mitigation strategies. (Nendel et al. 2023)

6. User Interface and Accessibility

The toolset features an interface based on R environment, accessible to researchers with different levels of expertise, all the different components of AgGlob are available on github.

7. Future Developments

To stay current with evolving agricultural challenges, the toolset will undergo continuous updates, including:

- **Incorporation of New Crops:** Expanding the database to include a wider range of crops and varieties.
 - **Advanced Climate data:** Integration of data climate models for more accurate predictions of weather and its effects on cropping systems.
 - **Advanced Soil data at different scales (France, Europe, World)**
 - **Machine Learning Integration:** Leveraging artificial intelligence to improve model accuracy and predictive capabilities. (example: Corrales et al. 2021)
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8. Conclusion

The presented toolset provides a powerful and versatile toolset for the modeling and simulation of cropping systems. It offers valuable insights into crop growth, resource management, and risk mitigation, making it an essential tool for researchers aiming to improve agricultural productivity and sustainability. By enabling scenario analysis and supporting decision-making processes, the toolset contributes to the development of more resilient and efficient cropping systems.

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