4CROP WEB APPLICATION FOR MONITORING RAIN-FED CROPS IN THE SAHEL

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ABSTRACT

Agro-geoinformation is the key information in the agricultural decision making and policy formulation process, especially in the countries where food security mainly depends on rain-fed crops production. It's the case of Sudano-Sahel zone where scarce economic resources hamper regular monitoring of crops development; a context that requires new approaches to detect crops risk zones during the agricultural season. The advances of Earth observation and sensing technologies, as well as geoprocessing web tools, enable new opportunities and challenges in applying agro-geoinformation to crop monitoring and assessment.

This paper presents the "4Crop" web application, an open source and interoperable solution for agricultural drought risk identification and forecasting in the Sahelian countries. The goal is the development of an operational tool that balances the lack of sufficient and timely acquisition of ground data using meteorological satellite open data sets. The whole web geoprocessing is based on the Crop Risk Zone (CRZ) model. The model performs a soil water balance to evaluate the satisfaction of crop water requirements in each phenological stage of the growing period. The model also provides a qualitative evaluation of the expected crop yields compared with the potential one, taking into account both water stress intensity and the phenological stage of crops.

The 4Crop web application currently running on Niger and Mali, and the outputs aim to identify installation and phenological phases of the main rain-fed crops (millet, sorghum, groundnut, cowpea) and to create crop risk zones images for each selected country.

The goal is to support Sudano-Sahel Early Warning Systems and any other local users in decision making and foster drought risk reduction and climate change resilience.

The proposed approach aims to encourage the integration and sharing of interoperable and open source solutions and thus contribute to the setting-up of distributed climate services in developing countries.

Keywords*:* agro-geoinformation, web application, geoprocessing, open source, climate services, Niger, Mali**.**

1. INTRODUCTION

Food security is still one of the major concerns that Sahelian populations have to face. In the Sahel, agriculture is primarily based on rainfed crops and it is often structurally inadequate to face the climatic variability. In general, low rainfall during the growing season can lead to crop yields decrease and, sometimes, to food crises (Sultan et al., 2005).

Crop yields may suffer significantly from either a late onset or early cessation of the rainy season, as well as from high frequency of damaging dry spells (Mugalavai et al., 2008). Therefore, the choice of the sowing date is of paramount importance for farmers. The ability to estimate effectively the onset of the season and potentially dangerous dry spells becomes therefore vital for planning rainfed agriculture practices aiming to minimize risks and maximize yields. Field observations in Mali, since 1983, show that when farmers use agro-meteorological information to plan the sowing date and to choose the varieties to be used, yields are higher compared to traditional choices (Hellmuth et al., 2007). As a consequence, reliable prediction of rainfall onset and duration is effective to reduce risk related to sowing date, planting practice and choice of varieties (Stewart, 1991).

In this context, advices to farmers are a fundamental component of prevention allowing a better adaptation of traditional crop calendar to climatic variability. Past experiences, in fact, show that agro-meteorological information can play a key role supporting food security, reducing the vulnerability of farmers, strengthening the rural production systems (Kleschenko et al., 2004) and that appropriated advices and agrometeorological information contributes in increasing crop productions.

In the Sudano-Sahel zone where scarce economic resources hamper regular monitoring of crops, the development of new approaches to detect crop risk zones during the agricultural season are required. The advances of Earth observation and sensing technologies, as well as geoprocessing web tools, enable new opportunities and challenges in applying agro-geoinformation to crop monitoring and assessment. As a matter of fact, in this Region web-based geoprocessing has not been yet fully explored for agricultural applications, whilst stand-alone applications and software are still widely used. The weak points of stand-alone solutions are time and effort required to install and manage the set-up, including the collection of geospatial data from a variety of sources, and pre-processing and analysing the data on local machines (Zhao et al., 2012). Indeed LDCs (Least Developed Countries) stand-alone applications, without continuous user support and updates, often makes the analysis and the application of geospatial data very expensive and time consuming.

The unavailability of timely meteorological data and the scarcity of funds for hardware and software maintenance, do not ensure near real-time drought monitoring on regular basis by National Early Warning Systems (EWSs) for food security. Moreover, the information and knowledge from geospatial data cannot be shared and integrated across organizations and communities.

The present work is focused on the development of a multipurpose, integrated crop monitoring web application, called 4Crop, which allows to monitor the impact of the drought stress on the main rain-fed agricultural production systems in the Sahel region.

2. METHODOLOGY

The web application, targeting Niger and Mali National Meteorological Services (NMSs), was implemented on a coherent Open Source web-based Spatial Data Infrastructure to treat all input and output data in an interoperable, platform-independent and uniform way.

The 4Crop client/server architecture has been implemented using open source tools and OGC (Open Geospatial Consortium) standards in order to guarantee the web application sustainability and the implementation of customized geospatial functions required by the end users.

The whole web geoprocessing is based on the Crop Risk Zone (CRZ) model (Vignaroli et al., 2016) that performs a soil water balance to evaluate the satisfaction of crop water requirements in each phenological stage during the growing period. The model is initialized by a rain threshold (10, 15 or 20 mm); this threshold depends on the crop calendar and the varieties traditionally used by farmers in different agro-ecological zones (Bacci et al., 2009). To best adapt simulation to the real behaviour of various cropping systems, the CRZ model allows users to customize some parameters: crop types and varieties, sowing conditions (rain threshold and start of simulation period) and extent of analysis area. So far the model has been tested on the following four crops: pearl millet (85 days and 130 days), cowpea (75 days), groundnut (100 days and 140 days), sorghum (110 days). The model data input can be summarized as follows:

- Gridded daily Cumulated Rainfall Estimate Images;
- Gridded daily Cumulated Precipitation Forecast (0 - 240 h);

- Gridded average daily potential evapotranspiration (PET) (from MOD16 Global Terrestrial Evapotranspiration Data Set);
- Average start of growing season (computed on the last 10 years);
- Average end of growing season (computed on the last 10 years);
- Gridded soil water storage capacity (from FAO Harmonized World Soil Database);
- Phenological phase lengths and crop coefficient Kc (FAO, 1998) for each simulated crop.

Due to the lack of a dense weather station network in Africa and the availability and consistency of long-term rainfall data for the Sahel Region, open satellite-derived datasets have been used to provide the CRZ model with the input data required for analysis. NCEP/NOAA Global Forecast System (GFS) is the reference data source for precipitation forecast images at 0.25° resolution; the Climate Prediction Center (CPC) Rainfall Estimator supplies daily Rainfall Estimates (RFE) at 0.1° resolution and EUMETSAT Earth Observation Portal makes available historical series of Multi-Sensor Precipitation Estimate (MPE) at 3 km resolution. For such reason, in the system architecture, chains for automatic data downloading (figure 1) ensure a continuous update of each data set, while specific procedures and services have been built up and integrated into the 4Crop environment to handle CRZ model input data flow.

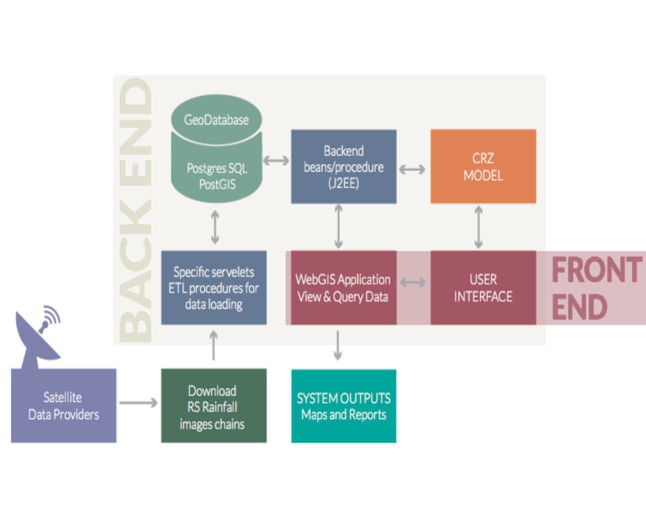

Figure 1. 4Crop System Architecture

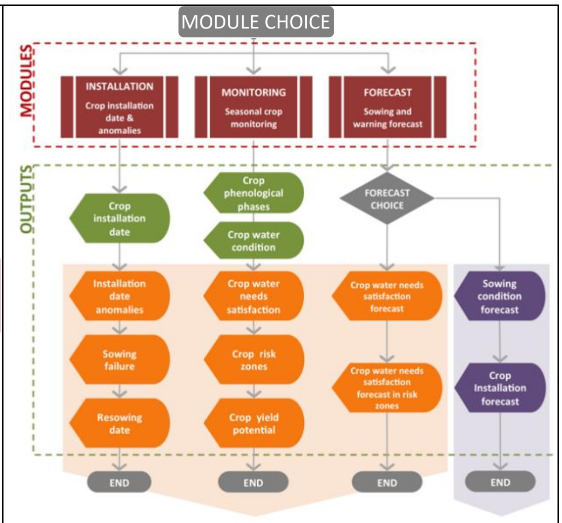

Figure 2. CRZ model flow chart

The CRZ model is composed of three modules of analysis (figure 2). The first two modules use rainfall estimate images as input data and operate in diagnostic mode. The third module employs precipitation forecast images and it works in predictive mode.

- **Installation module** provides an overview of the dates of successful seeding, showing areas where sowing failures may have occurred due to water stress. Zones where a crop was installed later than normal - because of the late onset of the rainy season or due to a first sowing failure - are also highlighted.
- **Monitoring module** performs a diagnostic of crop condition after its installation. The algorithm assesses the water requirements satisfaction and shows the areas where a water stress happened. The model also provides an estimate of the potential crop yield as a consequence of the water stress intensity and the phenological stage in which the stress occurred.
- **Forecast module** is composed of two sub-routines. The first, Sowing Forecast, provides outputs on the occurrence of favourable conditions for sowing and the subsequent crop installation. The second, called Warning Forecast, performs a prognosis on the possible occurrence of a water stress situation for crops already sown crops.

The UI (User Interface) has been implemented to allow users in initializing of analysis modules and to manage model outputs (viewing and saving or download data).

2.1 Open Source geoprocessing tools for CRZ model implementation

The CRZ model was developed using PL/pgSQL - SQL Procedural Language for PostgreSQL database system and PostGIS library built-in PostgreSQL. Each CRZ module is composed of a main PL/pgSQL function, performing initialization processes, and an iteration of functions for crop simulation processes. The CRZ modules work on input vector and raster data stored previously in the GeoDataBase. For example, in the "Installation module" the initialization processes set the parameters defined by the user (e.g. crop type, season length, country name) and extract the input data from GeoDB (e.g. daily RFE, daily PET images, season end and average sowing date images). All raster input images are clipped with the country's boundaries, so time and resource consuming are optimized for the following processing phases. Within the installation module the iteration of functions generates module outputs (e.g. crop installation, sowing failures, etc.). The ST_MapAlgebra, as call-back function, performs pixel-by-pixel operations over raster images defined by the CRZ model algorithm.
At the end of the iteration cycles of each module, the main PL/PgSQL function stores the results in the GeoDB with all metadata information related to the model run.
Finally a JAX-WS, using the PostGIS predefined functions, publishes classified output images on 4Crop web Interface.

2.2 "4Crop" WebGIS application user requirements

During web applications development phase user requirements were defined through a User Consultation Process (UCP) involving the technical staff of Niger and Mali National Meteorological Services. The operators/users were interviewed in order to understand their specific needs in terms of usage, information products (maps and reports), and also to assess the usability needs in view of their previous experience with the CRZ model stand-alone software. The interviews allowed to better focus on user requirements, particularly for UI development. The UI prototype was shared with the users to obtain their feedback and further suggestions. In order to avoid any language barrier, which could prevent a wider use of the web application, 4Crop is available in French, the official language of the target countries (figures 3).
4Crop system has been conceived as a multipurpose tool (figure 4) in order to meet the needs of different categories of stakeholders, from farmers to political decision makers.

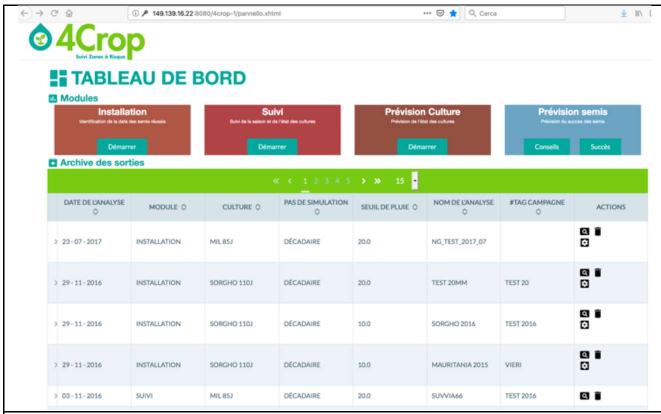

Figure 3. 4CROP User Interface

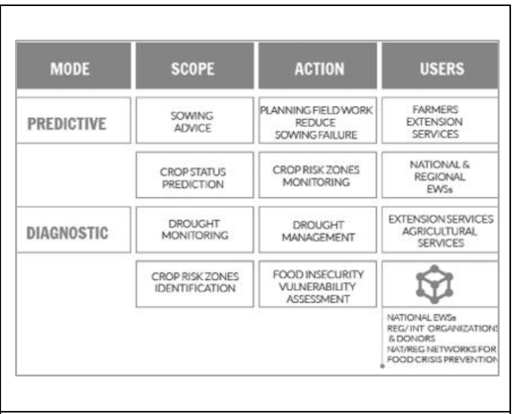

Figure 4. Multipurpose Tools

3. RESULTS

At present 4Crop is directly available by defined users' profiles (personnel staff of NMSs of Niger and Mali) throughout a login procedure (http://149.139.16.22:8080/4crop-1/).
4Crop aims to localize potential crop risk zones, allowing an early evaluation of potentially involved production systems and population. Indeed, 4Crop aims to intercept agricultural drought phenomena

starting from the crops installation, detecting seeding delays and failures, and analysing the crop water balance during the cropping season. The model can simulate most widespread crops and varieties in the Sahel: pearl millet, sorghum, cowpea and groundnut.
The models have an overall tendency to postpone the sowing dates with an overall accuracy within a range between +/- 10 days.

The model results can be affected by rainfall estimated images used as input. RFE images which initialize 4Crop model, despite the lower spatial resolution, seem to better represent the rainfall patterns compared to the Meteosat Second Generation (MSG) images. This behaviour is more evident in the agricultural areas with a late installation of the monsoon circulation and a short duration of the rainy season.

Regarding the estimated potential yields, validation was performed on yield of millet and sorghum with respect to the data of the agricultural statistics of Mali at third administrative level (Cercles). The validation results have shown that the degree of accuracy of the estimates improves when the model is applied on homogeneous agro-ecological zones, rather than on the whole agricultural area of the country. Tests performed on sorghum using two different starting dates of sowing, early for the southern agricultural zone and delayed for the north, have marked values of overall accuracy significantly higher (0.75%) than those obtained with a single one (0.50%). At the same time, the double simulation has allowed to reduce the number of false negatives with an important increase of all the accuracy indexes.

The results of output validation process demonstrate that the 4Crop model performances in simulating the real field situations mainly depend from choice of the initialization parameters.

4Crop has been conceived to work over extended areas (until entire Sahel region) where there are different climatic and agronomic conditions. For this reason, it would be appropriate to perform analysis on areas which have homogeneous characteristics as regards the production systems (type of crops and most used varieties, the growing season length, rainy season period installation, etc.).

4. Discussion

A further element to consider in order to ensure an appropriate exploitation of 4Crop outputs is the understanding of the potential and limitations of the system. The validation process has shown how the analysed outcomes are influenced by the characteristics of the images of rainfall estimate. The setting of the start date of growing cycle and the choice of the useful rainy threshold useful for sowing are also essential for a right simulation of crops behaviour. The evaluation activities during the agricultural season necessarily require the involvement and participation of the final beneficiaries, in particular the NMSs. Their knowledge of different production systems and of the strategies adopted by farmers is fundamental for a rigorous evaluation of products and outcomes provided by 4Crop. Finally, Open Source solutions adopted in developing 4Crop System can make an important contribution to capacity building of local Institutions, which are the main actors in planning and implementation of prevention and response policies to potential food crises. Indeed, the 4Crop approach is meant to encourage the integration and sharing of interoperable and open source solutions among national and international stakeholders.

5. Conclusions

In developing countries, the development of climate services has been often hampered by the lack of strong national institutions, particularly weather services. Consequently, the setting up of interinstitutional alliances and collaborations involving research, national and international institutions are showing beginning results.

In this sense, 4Crop perspective is to contribute to the setting-up of distributed climate services, allowing stakeholders at different level to access and share information products through web services and standard protocols. Accessibility and availability, re-use and re-distribution of scientific products are recognized to be the prerequisite to build climate services worldwide based on the paradigm of Open Data Policies that should encourage the use of a trans disciplinary approach and collaboration to build products and services tailored on users' needs.

The 4Crop study case in Mali and Niger, aims to evaluate impacts due to drought stress during the whole crop growth cycle, providing farmers with information in order to implement appropriate and timely response strategies that minimize risk exposure to food security (Vignaroli et al., 2016).

The Spatial Data Infrastructure is designed to manage further agrometeorological products and services derived from advances in research in applied meteorology and climatology. The use of open source tools and standardized interoperable web services ensure sustainability in the development and deployment of web applications with geo-referenced data and customized territorial analysis that could be connected to other interoperable climate services. Indeed, the development of climate services that provide products tailored to different users implies the capability of using multiple data sources and mastering of competencies, which are not always available in national meteorological services.

Moreover, the whole infrastructure framework code is open source and can be shared to foster cooperation among software and interface designers, experts, practitioners, and researchers.

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