A Review of Agrometeorological Monitoring Tools and Methods Used in the West African Sahel

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Abstract

Agrometeorological monitoring in the Sahelian countries consists of collecting, processing, and analyzing various data and information that can affect the outcome of the agricultural season. It combines observational data from national meteorological, hydrological, agricultural extension, plant protection, and livestock breeding offices, as well as satellite data provided by the AGRHYMET Center. From May until the end of October, multidisciplinary working groups (MWGs) in each country publish dekadal and monthly bulletins. At the regional level in the AGRHYMET Center, data and information coming from the national components are combined with satellite data to elaborate regional syntheses that are published at different time steps. In these publications, the current situation is analyzed and compared with that of the previous period, the previous year, and the average. Forecasts of seasonal rainfall and crop yields, that are refined from month to month, are also given. Color maps illustrates the amounts of rainfall, sowing dates, crop water requirements, satisfaction indices, yield estimates, zones with particular pests, and the advance of the vegetation front. Hard copies and electronic versions of these publications are mailed to subscribers. They are also posted on the Center's website: www.agrhymet.ne.

Introduction

The creation of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) has played a major role in the development of agricultural meteorology in West Africa. Indeed, it is following the catastrophic droughts of the early 1970's that seven countries (Burkina Faso, Chad, The Gambia, Mali, Mauritania, Niger, and Senegal) decided to create the CILSS. They were joined later by Cape Verde and Guinea Bissau. The AGRHYMET Center, a specialized institution of the CILSS, was created in 1974 with the mission of training personnel, providing adequate technical equipment for the meteorological and hydrological stations networks, and setting up MWGs for the monitoring of the meteorological, hydrological, and crop and pasture conditions during the rainy season. The main task of these groups was to analyze the current situation and give advice to policy-makers (national authorities and their international partners) regarding the possible outcome of the rainy season, thus allowing them to take adequate measures to prevent massive human suffering and displacement.

The AGRHYMET Center still continues to support, financially and technically, the activities conducted. Indeed, the main objective of all the new methodological developments undertaken at the Center is to transfer them to member countries. This is done through workshops and long-term training sessions attended by the staff of the different technical offices. Those offices are also assisted with equipment to be used for data collection, transmission, storage, and analysis. All this is done by the operational units of the AGRHYMET Center, in collaboration with scientific partners such as African Center for

Meteorological Applications to Development (ACMAD), Centre de cooperation Internationale en Recherche Agronomique pour le Developpement (CIRAD), Food and Agriculture Organization (FAO), Food and Agriculture Organization-Famine Early Warning System Information Network (FEWS-NET), Institute de Recherche pour le Developpement (IRD), Institute of Biometeorology-National Research Council (IBIMET), U.S. Geological Survey (USGS), and World Meteorological Organization (WMO). Financial support for these activities is provided by Danish, French, Italian, and U.S. governmental cooperation agencies and other regional and international donors.

The objective of this paper is to give an overview of agrometeorological monitoring tools and methods that are used by the nine CILSS member countries in West Africa.

Seasonal Forecasting

The AGRHYMET Centre is a member of a consortium, along with the ACMAD and the Niger River Basin Authority (NBA), which issues forecasts for the July-August-September (JAS) cumulative rainfall, two to three months in advance, for the Economic Community of West African States (ECOWAS) member countries. These forecasts are based on outputs of ocean-atmosphere dynamic models coupled with outputs of national statistical models. Each year, scientists from all West and Central Africa countries delineate zones for which forecasts are made separately. For each of theses zones, the seasonal forecast gives the probabilities of the JAS rainfall (Figure 1), or maximum river flow, within the lowest, middle, or top third of the available time series, usually the last 30-year standard normal period (www.acmad.ne).

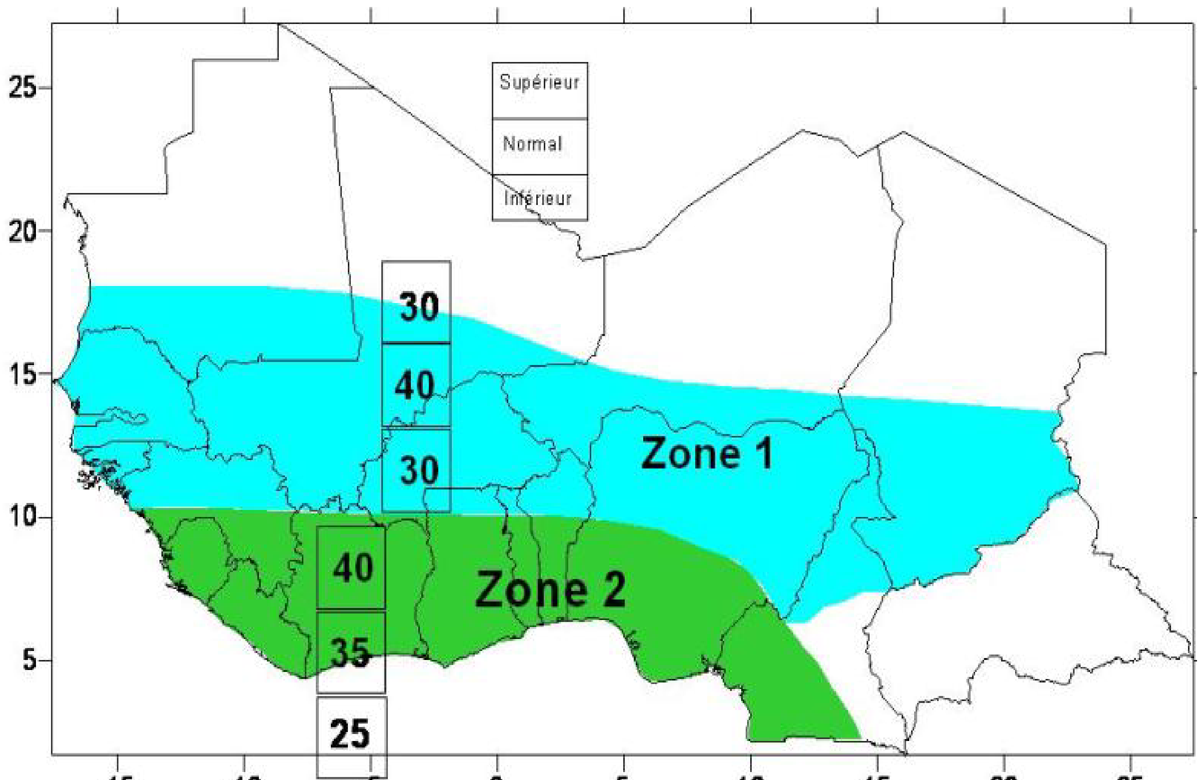

Figure 1. Seasonal forecast for the year 2003 July-August-September cumulative rainfall. Source ACMAD.

Monitoring the Cropping Season and Determining Risk Zones

Most of the information generated by the AGRHYMET Center and its national components is addressed to policy makers at the government or international aid agency level. Several indicators are used throughout the rainy season to assess crop and livestock conditions and issue advisories or warnings, if necessary, to decision makers at different levels. Indicators include decadal and cumulative rainfall amounts, surface water levels and flows, estimated starting dates of the season, simulated crop satisfaction indices, status of natural vegetation, crop pests and diseases status, crops and overall biomass yield estimations, among others.

Rainfall

The analysis of the rainfall situation consists of mapping the cumulative dekadal and seasonal amounts observed throughout the Sahel and commenting on them with regards to the average or the previous year. Rainfall data can come from the regular raingauge networks of member countries and/or estimates made using meteorological satellite (METEOSAT) infrared images. Particular attention is paid to zones with exceptional events, such as those with prolonged dry spells or flooding.

Surface waters

Surface waters are monitored using data collected and transmitted by the national hydrological offices. Water levels and river flows are analyzed and inter-annual comparisons are made (Figure 2).

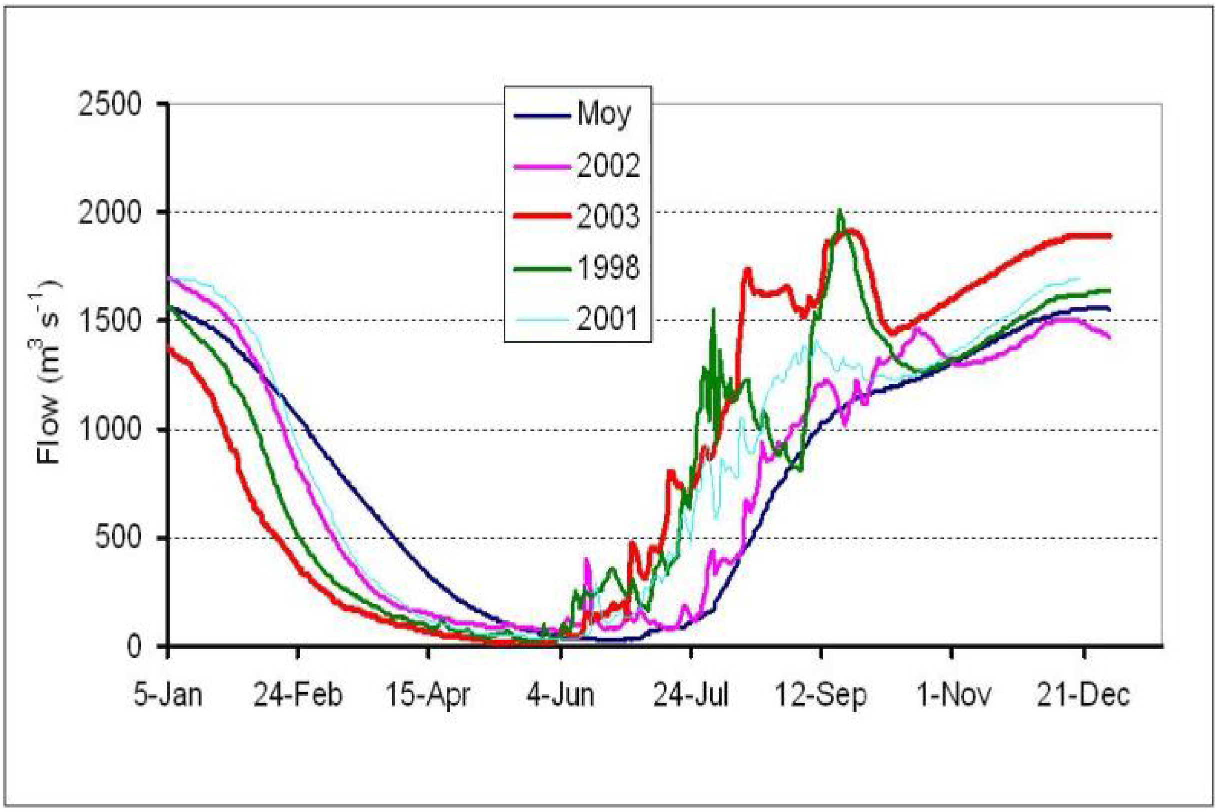

Figure 2. Evolution of Niger River flow in 2003 at Niamey, Niger.

Start of the Season

Two models, based on slightly different methods, are used at the AGRHYMET Center to determine the start of the season. The first method, based on soil water balance simulation, is implemented using the diagnostic hydrique des cultures (DHC) model (Girard, et al., 1994; Bourneuf, et al., 1996). This model uses as input data the daily rainfall from the regular network of CILSS member countries or rainfall estimates from METEOSAT infrared images, the average dekadal values of potential evapotranspiration (PET), and the soil potential water storage above the wilting point in the first meter layer. The starting date of the rainy season, called "successful sowing date" is determined by giving a threshold of available soil moisture (10 millimeters [mm]) in the soil top layer (15 centimeters [cm]) to be reached starting from the 1st of April, and a 20-day period during which the crop water requirements satisfaction index should not fall below 50 percent (Figure 3). The "successful sowing date" may or may not be the same as the "first sowing date," which just satisfies the first condition.

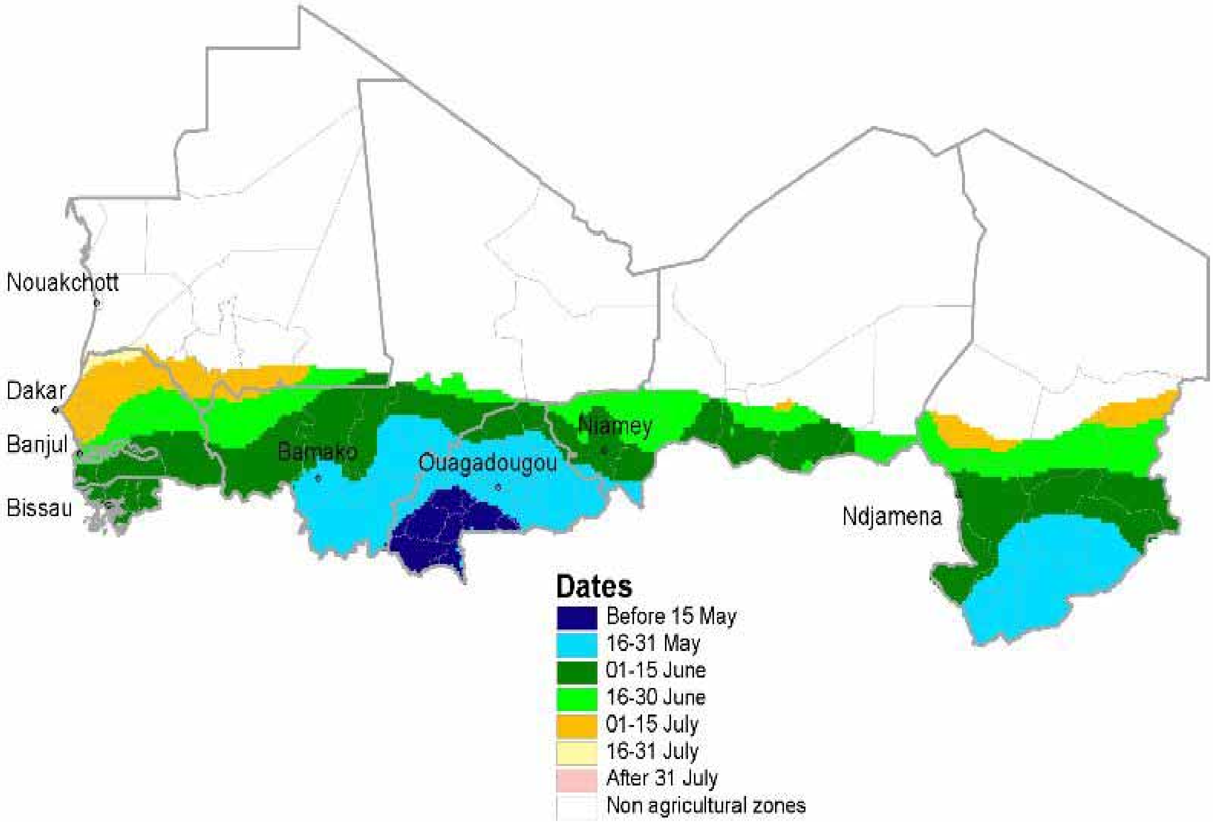

Figure 3. Year 2003 "successful" sowing dates. Source DHC.

The second method, implemented with the Zones A Risque (ZAR) model, determines the start of the season based on a rainfall threshold of 20 mm followed by a dry spell of no more than 20 days in the next 30 days using dekadal METEOSAT derived rainfall estimates (AGRHYMET, 2002). In addition, the ZAR model gives areas of "failed sowings," the potential duration of the season based on a fixed average ending date (Figure 4), and other information related to the starting date.

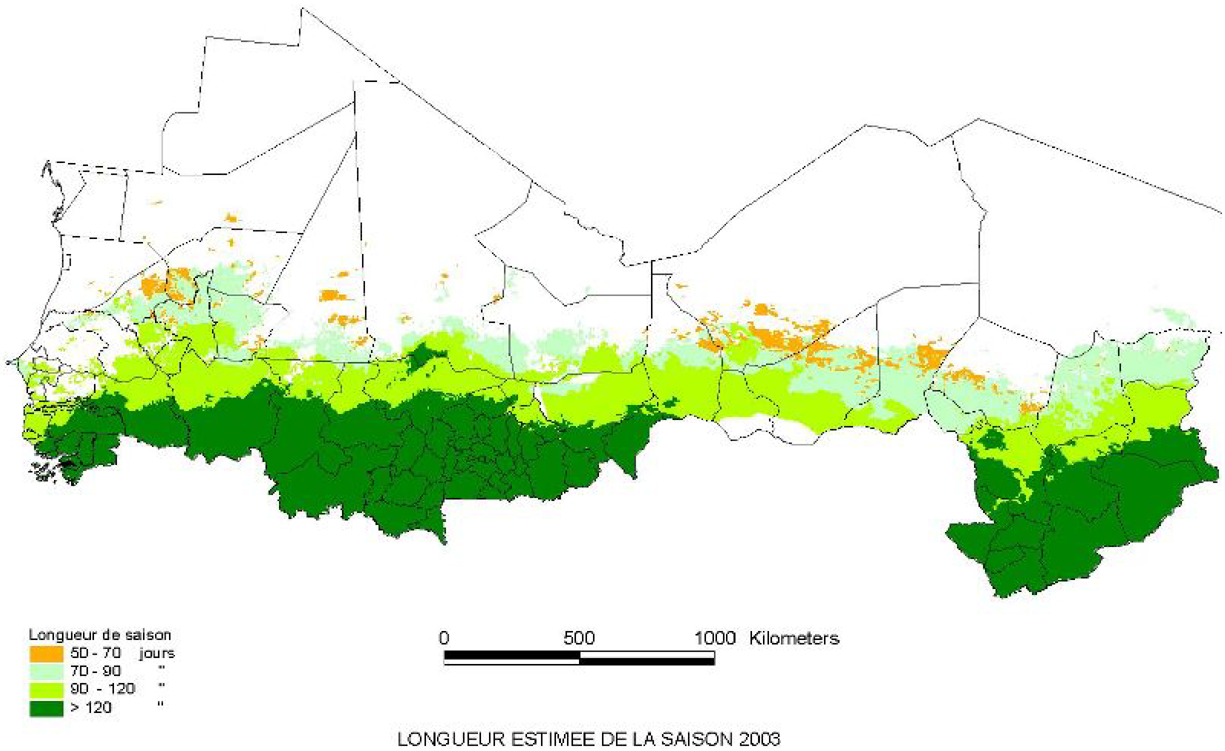

Figure 4. Potential duration of the 2003 cropping season. Source ZAR.

Both these methods use the same principle developed by Stern et al. (1981) and implemented in the INSTAT+ software, which AGRHYMET also makes available to its national components through the SIAC courses organized jointly with the University of Reading, United Kingdom. (www.ssc.rdg.ac.uk/instat).

The results obtained by the two methods can be the same or differ by one to two dekads (10-20 days), depending on the location and the year. They are applied on long time series of data to calculate the "normal" starting date at a given location and to make inter-annual comparisons.

Crop Water Requirements Satisfaction

As with the start of the season, the DHC model is used to monitor the crop water requirements status throughout the season. Once a successful planting date is determined for a given location, the potential crop cycle, the duration of the four main growth stages (initial, development, full vegetation, and maturation) and the crop water requirements for every 10-day period are determined by assuming a fixed ending date: the average date after the 1rst of September on which available soil moisture in the 1-meter layer is irreversibly depleted at less then 90 percent (Bourneuf, et al., 1996). Crop water requirements are determined using a relationship between latitude and the three characteristics values of the crop coefficients (Doorenbos and Pruitt, 1977) derived from measurements on different sites throughout the Sahel (Fréteaud, et al., 1984). The crop water satisfaction index is the ratio of the actual evapotranspiration (AET) to the maximal evapotranspiration (MET) for a given dekad. AET is computed using an algorithm proposed by Eagleman (1971) that relates the water consumption of a crop to its water requirements (MET) and the relative soil moisture content, and MET is the product of the crop coefficient by the potential Penman evapotranspiration

(PET). Other assumptions on bare soil evaporation, root growth and soil drainage are made in the computation of AET (Bourneuf, et al., 1996; Dingkuhn, et al., 2003).

The DHC model gives several outputs related to crop water requirements that can be analyzed and mapped to illustrate the crop water status. These are: the water satisfaction index for the last decade; the overall water satisfaction index since the start of the season; the water requirements for the remaining of the crop cycle; and, the currently available soil moisture.

Crop Pests and Diseases

Several sources of information, including regular reports from member countries, the advance of the Intertropical convergence zone (ITCZ), the occurrence of rainfall, the emergence and/or presence of vegetation detected on Normalized Difference Vegetation Index (NDVI) images are used to analyze the crops pest situation and make forecasts on the possible outbreak of the most important crop pests in the Sahelian region. These analyses are based on the knowledge of the relationship between the biology of the insects and the environmental factors such as day length, temperature, soil type and moisture content, vegetation status, wind speed and direction, and the position of ITCZ. For example, the grasshopper *Oedaleus senegalensis* is known to move gradually from south to north at the beginning of the rainy season as the environmental conditions become more and more humid. Towards the end of the season, as the vegetation dries out and the ITCZ moves back southwards, the grasshopper also follows the same direction and may cause massive damage to maturing millet and sorghum crops in the Sahelian and Sudanian zones (Launois, 1978; Lecoq, 1978).

The desert locust *Schistocerca gregaria,* on the other hand, remains mostly in desert areas and may reproduce, multiply, and migrate to agricultural zones if environmental conditions become favorable.

Several studies, including Tucker, et al., (1985); Hielkema, et al., (1981); and FAO (1997) have used remote sensing techniques to evaluate the ecological conditions in the desert locust reproduction zones. Tappan (1991) and Berges, et al., (1991) on one hand and Burt, et al., (1997) on the other hand have also demonstrated the possibility of monitoring and anticipating the outbreak of grasshoppers using NDVI and METEOSAT rainfall estimates, respectively. All these tools are used at AGRHYMET to closely monitor the ecological conditions that may be favorable for the outbreak of these pests, and if necessary, to issue warnings in the regular or special information bulletins.

Status of Natural Vegetation

The analysis of the status of natural vegetation is done mostly with remote sensing data. National Oceanic & Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR) derived NDVI is used to monitor the emergence and the advance of the vegetation front throughout the season. Comparisons of the current dekad values with those of the previous one allow seeing where conditions were favorable or unfavorable to vegetation growth (Figure 5). These results are used by pastoralists and plant protection specialists to evaluate the conditions for livestock or crop pests. Towards the end of the season, the potential productivity of pasture lands throughout the Sahel is evaluated using a model that estimates biomass yield from METEOSAT rainfall estimates and soil data

(AGRHYMET, 2002). The outputs of this model, which makes simple assumptions on water infiltration, runoff, and nitrogen balance are potential dry matter yield in kilogram/hectare (Kg/ha) at the 5 x 5 km scale (Figure 6) and biomass quality based on its nitrogen content. These results are used to evaluate livestock performance in terms of potential meat and milk production (Di Vecchia, et al., 2002).

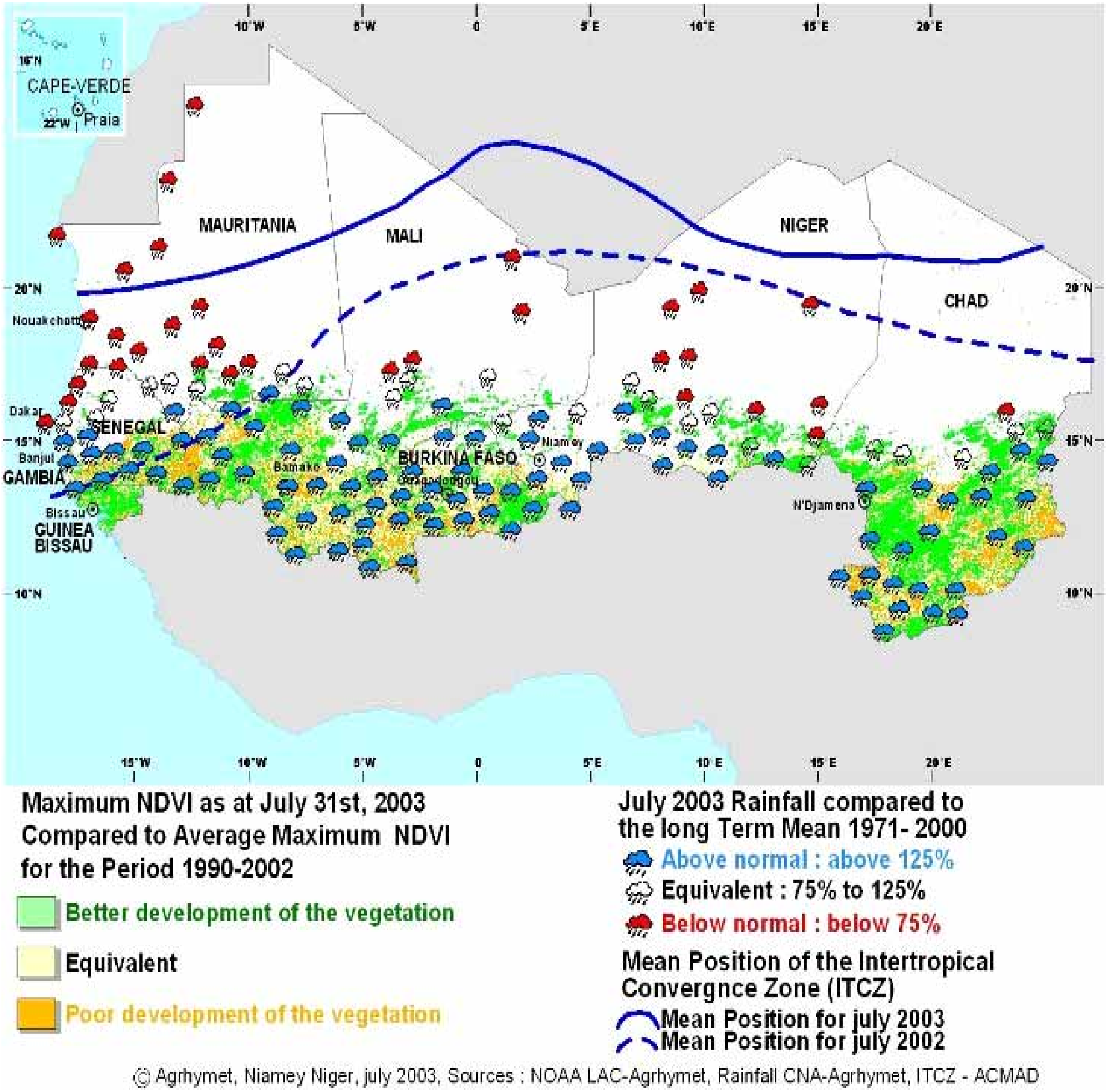

Figure 5. Average positions of ITCA, with rainfall and NDVI values of July 2003 compared with respective averages.

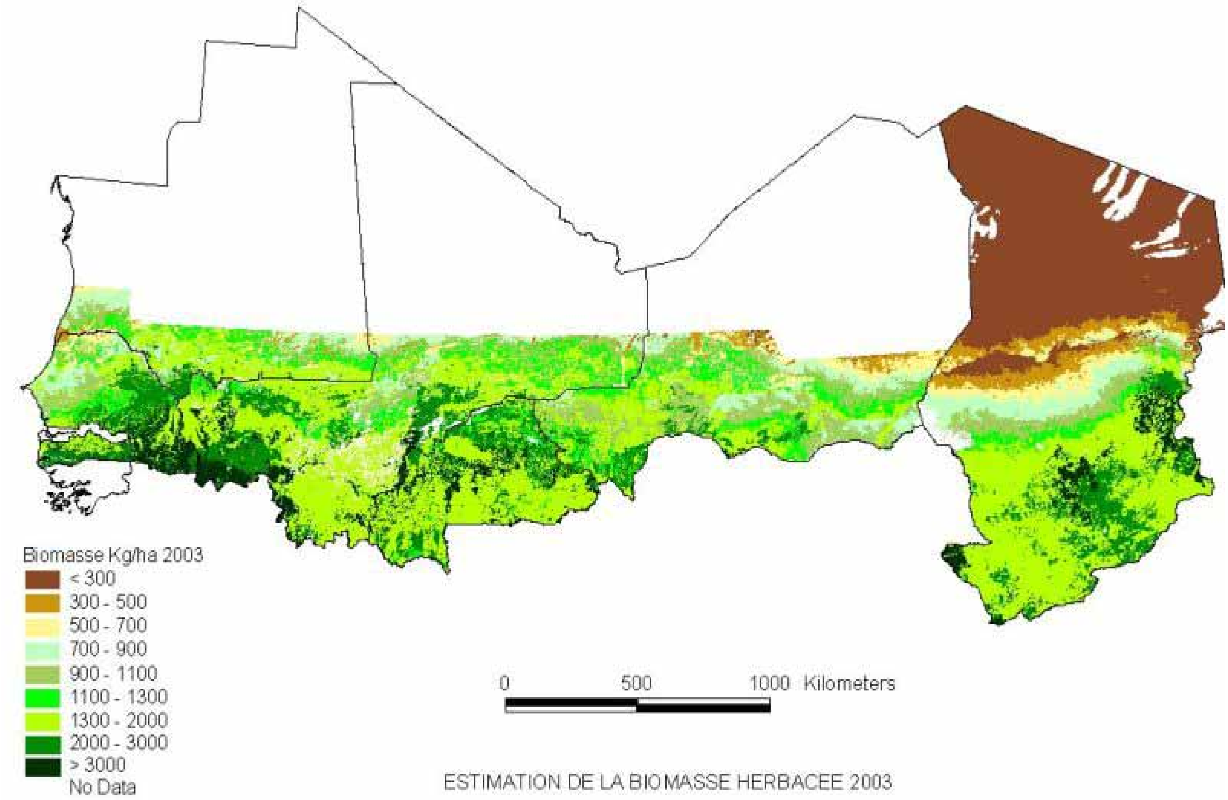

Figure 6. Potential biomass yield as of September 30, 2003.

Crop Yield Forecasting

The main crop yield forecasting tool used at AGRHYMET and in the member countries is the DHC model (Samba, 1998). As already described, this model calculates the actual crop evapotranspiration (water use) every dekad and evaluates to what extent its water requirements have been satisfied. Following a 3-year survey in six West African countries (including Burkina Faso, Mali, Niger, and Senegal), an empirical relationship was established between millet yields observed on farmers' fields and an index derived from the outputs of the DHC model (Girard, et al., 1994; Bourneuf, et al., 1996; Samba, 1998; Dingkuhn, et al., 2003). This relationship is used in the model to predict expected millet yields throughout the Sahel. A first yield estimate is made at the end of August and updated at the end of September. The comparison with the average expected yield gives an indication of a zone being at risk or not at risk (Figure 7).

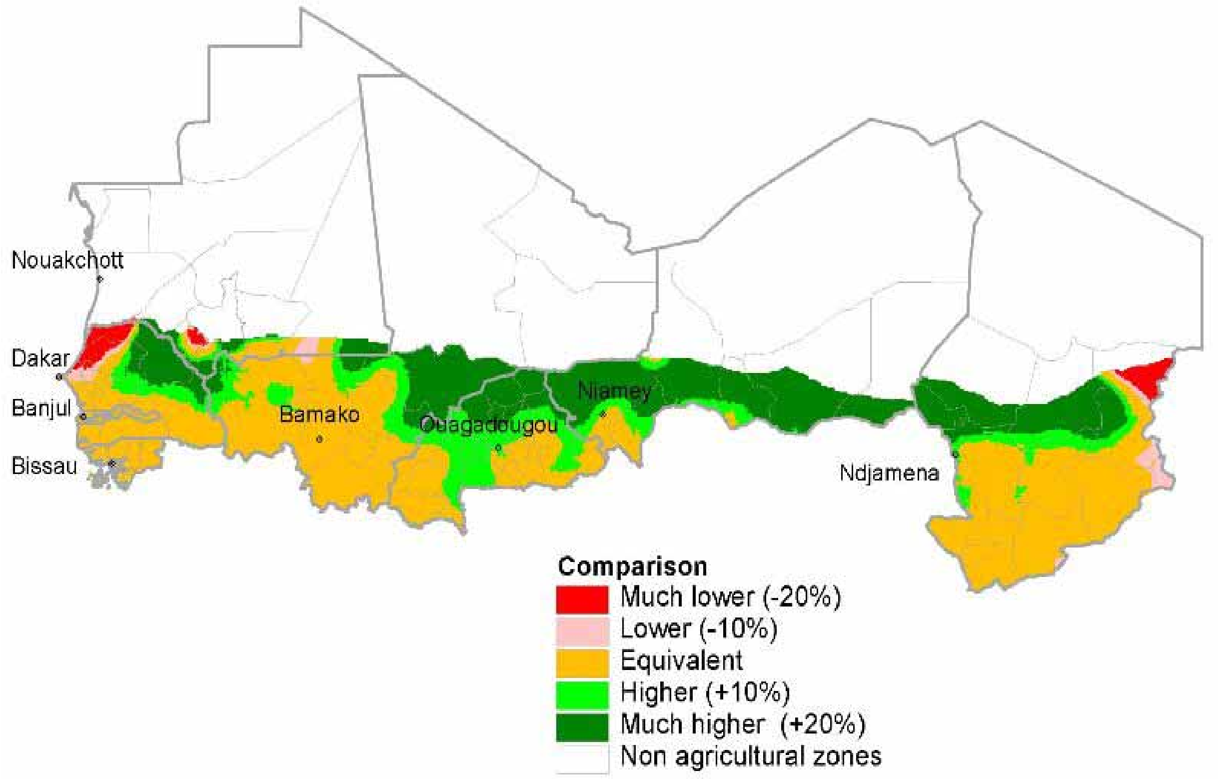

Figure 7. Year 2003 expected pearl millet yields compared with the 1971-2000 average. Source DHC.

Risk Zones

All the above mentioned indicators may be used to declare a zone "at risk." The first signal is given by a delay of more than two dekads in the current year's starting date relative to the average (Figure 8). If that happens in a given location, this usually means that there will be less time for crops to develop and give adequate yield, because of a shortened season. This is based on the observation that the starting date of the rainy season in the Sahel is much more variable than its ending date (Sivakumar, 1988), and that a season starting late does not necessarily mean that it will also end late (Traore et al., 2000). At the AGRHYMET center, a final assessment of the starting conditions is done at the end of July and all zones with a late start are declared to be at risk (Figures 3 and 8). Once the season is installed, other indicators are used to determine risk zones, namely, if the crop water satisfaction index falls below 50 percent for two consecutive dekades, or if NDVI values regress from one dekad to the next. Important outbreaks of pests, floods, and below-average potential millet yields may also indicate that a particular zone should be considered as at risk. This gives basis for decision makers to focus their attention to those areas by closely monitoring not only rainfall conditions, but also socioeconomic activities and taking adequate measures to prevent famine.

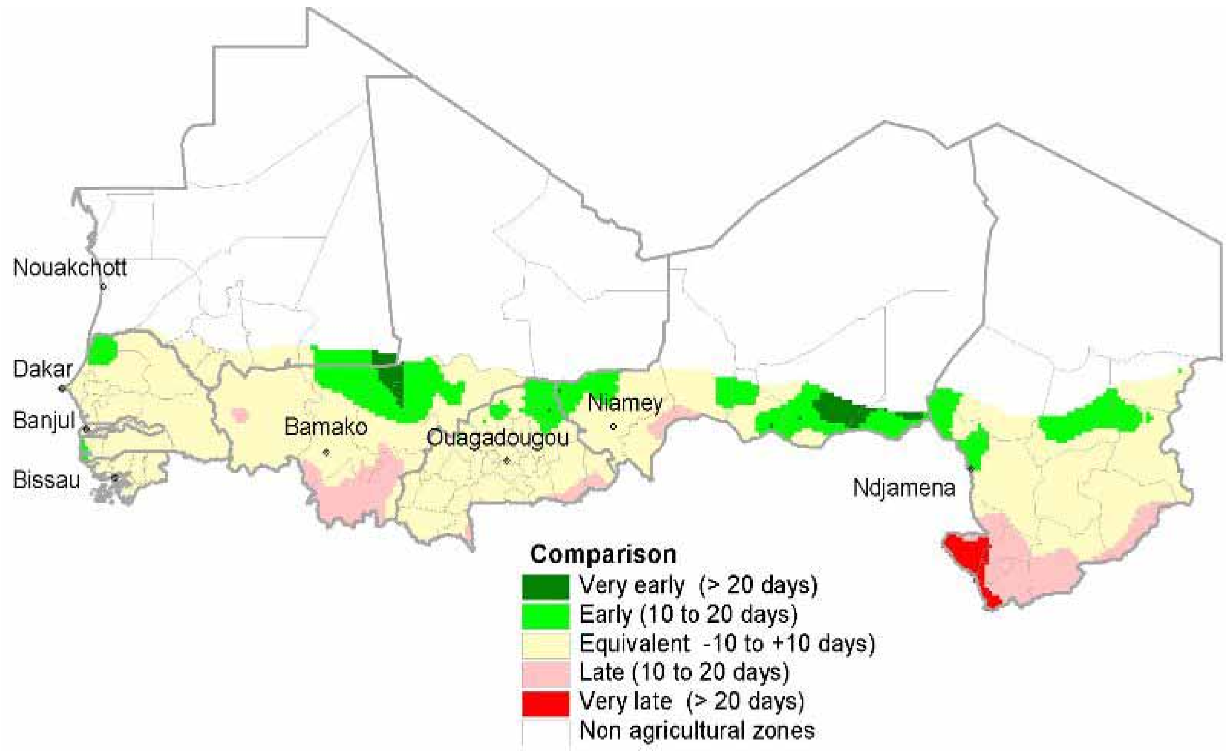

Figure 8. Year 2003 "successful" sowing dates compared with the average of the 1971-2000 period. Source DHC.

Assistance to Producers

In addition to giving information to policy makers, AGRHYMET and it member countries also assist the producers so that they can enhance their production by using agrometeorological information. Indeed, in some countries and at the regional level, advisories are also given to producers allowing them to take particular actions given certain conditions. The tendency is now to develop methodologies allowing producers (farmers, livestock breeders, fishermen, etc.) to enhance their production and income based on the exploitation of appropriate agrometeorological information. These types of activities are conducted mostly within the framework of pilot projects, some of which have been conclusive and are now being extended. This is the case of the Mali agrometeorological assistance project, where farmers receive, through broadcasts on national radio and television, directives from the MWG on adequate times for sowing, fertilizer application, weeding, phytosanitary treatments, etc. In many member countries, agrometeorological bulletins give advice to herders on where to find abundant pastures and when to vaccinate their livestock if a risk of disease outbreak is sought. In this regard, AGRHYMET has recently conducted with success a pilot project in the Tahoua region of Niger, where herders were given information on where to locate good pastures every 10 days through the Radio and Internet for Communication of Hydro-Meteorological and Climate Related Information (RANET) system.

Problems and Perspectives

In implementing all these activities, the Center and its partners face several problems, most of which relate to data acquisition in member countries, their timely transmission, and the small number of observation points. Since the late 1980s, the Center has considered the use of satellite imagery to compensate for the lack of sufficient and timely acquisition of ground data. This has prompted the development of a spatial version of the water balance simulation and yield forecasting model, DHC-CP that uses rainfall estimates from METEOSAT images (Samba, 1998). The ZAR and the BIOMASS models also use METEOSAT rainfall estimates to calculate the starting date and the potential length of the growing season on one hand, and the potential biomass productivity of pastures, on the other hand.

Activities are currently underway to upgrade the crop monitoring and yield forecasting model, so that it simulates not only crop water balance, but also crop growth and development using solar radiation and air temperature data. The new model, called SARRA_H (Dingkuhn, et al., 2003), was developed in collaboration with CIRAD and CERAAS, and is now being tested for Sahelian farming conditions. The new functionalities of the model should allow the yield forecasting to be extended to other crops and agroclimatic situations for which water is not the main limiting factor. This is in accordance with the new mandate of the Center to cover all ECOWAS member countries. In the process of upgrading the new crop model, the new procedures proposed by the FAO (Allen, et al., 1998) will be implemented, namely, calculating crop and reference evapotranspiration using the Penman-Monteith method. AGRHYMET operational units are also preparing for the arrival of the new METEOSAT Second Generation receiving station, which should allow the derivation of climatic variables to feed the different models in use at the Center at better time and spatial resolutions.

With regards to agrometeorological assistance to producers, discussions are currently underway with Niamey area vegetable growers in Niger, and with farmer associations in the Senegal River valley on how to assist them to better manage their irrigation water and obtain good quality products.

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