DROUGHT IMPACT DETECTION ON CROPS IN THE SAHEL: A CASE STUDY FOR THE 2009 CAMPAIGN

M. Bacci [a, *], A. Di Vecchia [a], L. Genesio [a], V. Tarchiani [a], P. Vignaroli [a]

[a] Institute of Biometerology of National Research Council, via G. Caproni, 8, 50145, Florence, Italy - (m.bacci, a.divecchia, l.genesio, v.tarchiani, p.vignaroli)@ibimet.cnr.it

KEY WORDS: Agriculture, Meteorology, Modelling, Monitoring, Decision Support, Disaster, Developing countries.

ABSTRACT:

Late in the ‘70s, as a consequence of recurrent droughts occurred in West and East Africa, the famine struck millions of people imposing to national authorities and to the international community to coordinate efforts and to develop Early Warning Systems to limit the dramatic impact on the affected population. Between 1980 and 2007 the EWS concepts evolved passing from a stand-alone famine oriented analysis tool to a component either of a comprehensive food security information system or of a disaster prevention system. To early detect areas where drought could affect crop production and food security the “ZAR - Zones at Risk” agrometeorological software, based on Meteosat Second Generation rainfall estimation and Global Forecast System rainfall forecast images, has been developed. ZAR is presently exploited by the National Meteorological Services in various Sahelian countries and by Agrhymet Regional Center for regional assessments. The integration of ZAR impact maps (crop onset, soil water availability, crop conditions and phenological phases in a settled time) with the surveys data has improved National Meteorological Services capability in predicting and identifying areas where drought conditions would jeopardize crop production and consequentially quantify the population involved. The ZAR products are validated with the ground data collected in several agricultural campaigns.
The analysis of the cropping season 2009 and the impact of localized droughts in terms of area and groups at risk for food security are presented. In particular, the dimension of crop production reduction and its geographical areas distribution over the Sahel have been assessed with the identification of the most vulnerable productions systems.

1. INTRODUCTION

In African semi-arid countries, drought is one of the major causes of losses in agriculture. Episodes of strong drought years have brought to the catastrophes of the 1972-73 and to 1983-84 famine episodes. Nevertheless in 1990-1991, 1995-96, 1997-98, 2000-01 and 2005-2006 other localized famines occurred in many countries of the Sahel. In particular Niger, Mali and Burkina Faso suffered critical food situations (CILSS 2004, 2006).
The economy of sahelian countries is essentially based on the primary sector (FAO, 1996) and the population’s food security is strictly linked to rainfed crops production (AP3A, 2001). The latter depends firstly on the onset of the rainy season (Sivakumar, 1988) and later on the dry spells effect during the crops growing cycle (Bacci L. 1992, Maracchi, 1994, Vignaroli, 2001).
The West Africa sahelian countries constitute a belt from Senegal to Chad characterized by a gradient, from south to north, of yearly annual precipitation starting from 1200 mm to values below 150 mm, with unimodal distribution during the summer months (Nicholson , 2001). The rainfall spatial and time distribution are also very variable: dry spells and shifts in the rainy season onset are very frequent (Sultan, 2004).
The climatic factors, particularly rainfall distribution and season length, affecting crops water availability (Maracchi, 1993; 1994), are important drivers of food security.

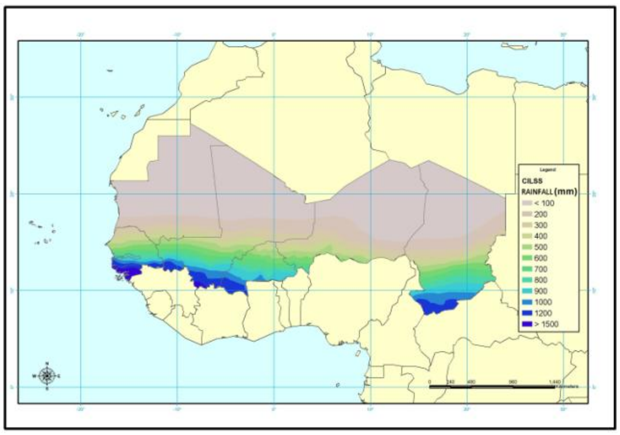

Figure 1. Average yearly rainfall in the Sahel (1971-00)

In particular, the seasonal length, compared with crops’ phenological cycle, is a good indicator for drought induced agricultural risks. But the seasonal length by itself cannot explain the intra-seasonal variability, which in case of dry spells can induce water stresses further affecting final production (Bacci L. 1992, Maracchi, 1993, 1994; Vignaroli, 2005).
With less than 90 days of season length, the northern part of the region is most sensitive to climatic fluctuations even if the drought resistance of crops is naturally high. In this zone, the sensitivity to water stress is high at seedling and flowering time. A dry spell during these periods can cause the complete loss of the harvest. Furthermore, critical climatic conditions limit the availability of suitable crops and varieties making farmers more

* Corresponding author. This is useful to know for communication with the appropriate person in cases with more than one author.

vulnerable (Ndiaye, 2004). Contrariwise, in the southern areas the climate is not a limiting factor and the agriculture production systems are more differentiated: cereal crops, with long cycle varieties, are associated with cash crops (groundnut, cotton, sesame, etc.). In this area the probability of drought events is lower but the production systems' vulnerability to drought is higher because the varieties and the species cultivated are not naturally resistant. Thus, the vulnerability changes with the production systems, depending on their capability to cope with drought events (AP3A Project, 2001).

The classification of the region in production systems is indeed an important interpretation key for vulnerability analysis. The prevalence of breeding or agricultural activities is the first element for the identification of the production system, followed by the prevalent crops, the intensity of cultivation, and the eventual co-presence of many systems (AP3A Project, 2001).

The demography of the region is another important factor for understanding the relative impact of drought events in terms of food availability (Bacci M., 2005; FAO, 2008).

In the Sahel, the approach adopted by CILSS (*Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel*) for facing food crises is based on the Food Crises Prevention Calendar (CPC), a methodological framework developed by AGRHYMET Regional Centre (CRA) and IBIMET-CNR in collaboration with WMO. The CPC follows a strict time schedule responding to the need of planning aid mobilization on the suitable spatial and temporal scales (Tarchiani et al, 2009). The approach is based on the characterization of crisis levels demanding the production of appropriate information for decision makers in terms of timing and format. Within the CPC, cartographic, biophysical and socio-economic data, models and analysis are integrated in order to forecast and afterwards to monitor factors affecting food security during the year and to evaluate the impact on population vulnerability caused by natural or human-induced extreme events. In this framework, remote-sensing techniques, and in particular rainfall estimation images, are widely used for drought monitoring. Among CPC tools, the ZAR agro-meteorological model aims to intercept agricultural drought phenomena starting from the crops installation, detecting seeding delays and failures, and analysing the water balance during the season (Di Vecchia et al, 2006). The model can simulate most widespread crops and varieties: Pearl millet 85 days and 110 days, Sorghum, Cowpea and Groundnut 100 days and 130 days.

ZAR uses the 10-days rainfall estimation images and other agroclimatic parameters (evapotraspiration, soil water retention capacity, crops evapotranspiration coefficients – kc - per phenological phase and average crop season onset) to perform an extended analysis of the drought stresses over a wide region with a low cost method. The ZAR products are thematic maps on the crops' installation and satisfaction of crops water needs. The analysis, performed during the season, provide decision makers with up to date characterization of the growing season conditions and the early identification of drought risk areas. The ZAR outputs and their accuracy have been validated with campaign data collected in 2006 and 2007 in Niger and Senegal countries in the context of the SVS (Suivi de la Vulnérabilité au Sahel) and AMMA (African Monsoon Multidisciplinary Analyses) projects with the support of the national meteorological services. The ZAR model is operational at AGRHYMET Regional Centre and the national meteorological services of Burkina Faso and Niger for agro-meteorological monitoring.

This work proposes the analysis of the 2009 crop season monitoring in the Sahel using the ZAR and its verification. The risk areas detected by ZAR are confirmed or not by the information collected on the ground by the National Multidisciplinary Working Groups (*Groupe de Travail Pluridisciplinaire* - GTP) and by the CRA.

2. MATERIALS AND METHODS

The 2009 cropping season has been monitored using the ZAR model starting from the 1st of May at regional scale in the Sahel. The 1st dekad of May is normally used as reference date for the start of the cropping season in the sahelian belt (SVS Project, 2006). The study area is the whole of CILSS countries except Cape Vert (about 5,341,000 km²), in order to have a regional view of drought phenomena.

Even if ZAR can use rainfall estimation images coming from many sources, the 2009 campaign has been analysed using the free rainfall images produced and distributed by the African Data Dissemination Service (ADDS) with a 10-days aggregation and a spatial resolution of approximately 8 x 8 km.

Other inputs are the climatic evapotraspiration per dekad and the UNEP/GRID Soil Water Holding Capacity Data Set (Bowman et al, 1993).

The simulated crop is pearl millet (*Pennisetum glaucum*), and in particular a short cycle (85 days) variety. This choice comes from the necessity to use the most represented rainfed crop in the Sahel, with particular attention to its most drought prone area. The used rainfall threshold for the sowing is 20 mm in 10-days, which is the minimum amount of rainfall for considering a sowing date.

The methodology goal is to give an early localization of zones where drought could hinder the millet production. The analysis starts with the detection of the first condition favourable for sowing and goes on analysing the following period, being a critical for crops installation because a water deficit in this phase could cause the sowing failure.

Where the conditions for crops installation are late compared to the average, the remaining time to the average end of the season is compared with the crop phenological cycle. If not enough time for the crop cycle is available, the area is marked as at productive risk. These areas represent the zones where a closer monitoring of crops growth should be carried on to early intercept and evaluate the food security risks for populations.

After the installation phase, the monitoring of the crops water balance allows to indicate the zones where dry spells could hamper vegetation normal development. The final yield will, thus, depend on the length and the timing of the stress linked to specific plant's vulnerability. The zones where severe water stresses occurred during critical phases show a higher risk of production loss.

Afterwards, the importance of risk areas in terms of contribution to agricultural production is assessed using agricultural statistics. Alike, the areas' demography is analysed quantifying the number of persons potentially affected by the drought. The risk level and the area importance in terms of population and agricultural and pastoral productivity confer the crisis degree (Vignaroli et al., 2006).

Moreover, agricultural statistics are used to characterize the agricultural production system of the region. This classification, integrated with other socio-economic data, allows assessing the system vulnerability, which determines the final impact of drought on food availability (Bacci M., 2005).

This information is the basis for an Early Warning of the decision makers appointed to food crises management.
In the present work, phenomena and related areas detected with ZAR have been compared with information on crop season monitoring issued by Meteorological Services, other national institutions and AGRHYMET, on the basis of field surveys. The comparison allows confirming or invalidating the warning.

3. RESULTS

Starting from the 1st of May, ZAR gives each 10-days the successful sowing dates, on the bases of above-mentioned input data and parameters. For each 64 km^2 pixel in the domain, the model evaluates the dekad where good conditions for sowing occurred and were the crop installation has been confirmed analysing the water balance of the following 14 days. This first output is a milestone for all the others model's elaborations. The comparison of 2009 sowing dates with the average reference period gives the localization of sowing anomalies as showed in Fig.2.

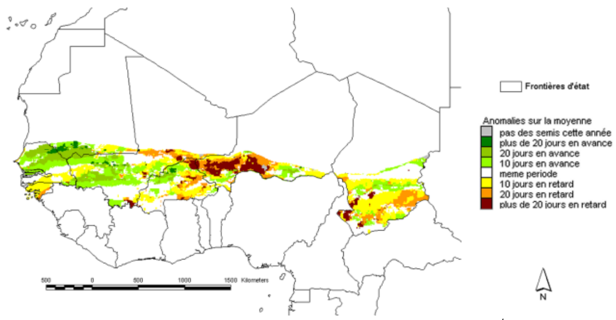

Figure 2. Anomaly of sowing date ZAR output (1st dekad of August)

In 2009 there is a quite clear distribution of sowing anomalies in the Sahel. In the western part of the region, including Senegal, Mauritania and western Mali and Burkina there is a generalized anticipation of the crop installation conditions. In the agropastoral zone of Mali, the eastern part of Burkina Faso, in the most part of Niger and in Chad the crop installation shows a delay of 20 days or more.
Sowing failures, where a dry spell hamper the crop installation after favourable conditions for sowing, are showed in the figure 3.

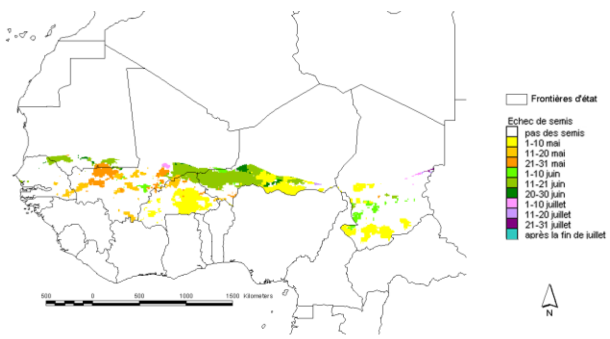

Figure 3. Sowing failure date ZAR output (1st dekad of August)

The extension of sowing failures in 2009 is quite large. Sowings of the first dekad of May failed in the southern part of Burkina Faso, Niger and Chad. In the second and third dekad of May sowing failures are concentred in Mali. In June, especially in the second dekad, failures affected the north-western part of Niger agricultural zone and some spot areas in Mauritania and Chad.
The combination of these two outputs synthesizes the drought impact on sowings. In the western Sahel, failures occurred mainly in areas characterised by an early onset of the cropping season.
In case of early failure, the farmers have the possibility to recover the situation with a second sowing if seeds are available. The 2008 agricultural campaign has been one of the most favourable in the last years so the availability of seeds has been good in each country. Especially for the millet and sorghum crops the re-sowing technique doesn't represent a problem for farmers that use local seeds. More problems are encountered in the sowing failure for the cash crops where the seeds represent an outlay cost.
Contrariwise, the risk is higher where the sowing failure is associated with a delay of the sowing date. This applies, in 2009, to Niger and the southern part of Chad. In Niger, particularly, sowings are perturbed in a very large area, which is, moreover, particularly vulnerable to food insecurity in its northern part. The southern band, inversely, is less vulnerable but is a key production area for cereals.
The phenomena highlighted in the sowing phase over the Sahel with ZAR are compared with available surveys data contained in agro meteorological or food security bulletins. Table 4 shows the results of the qualitative verification.

ZAR		Confirming surveys	
Phenomena	Areas	Source	Date
Delay of sowing	Chad	Fewsnet-Chad	31/07/09
	North Western Niger	GTP-Niger	10/08/09
	Eastern Burkina	DMN-Burkina	30/06/09
	All above areas	Agrhymet CILSS	10/08/09 06/11/09
Advance of sowing	Central-northern Senegal	GTP-Senegal	10/07/09
	Central-western Mali	GTP-Mali	10/07/09
	Mauritania	Fewsnet-Maurit.	31/07/09
	North-western Burkina	DMN-Burkina	30/06/09
	All above areas	Agrhymet CILSS	10/08/09 06/11/09
Sowing failure	Niger	GTP-Niger	30/06/09
	North-eastern Burkina	DMN-Burkina	30/06/09
	Mali (spot)	Fewsnet-Mali	31/07/09
	Chad (spot)	Fewsnet-Chad	31/07/09
	All above areas	Agrhymet	10/08/09 and 11/09

Table 4. 2009 Start of season verification

Generally the phenomena are correctly detected by ZAR at national level as confirmed by the different sources of information. More close monitoring with ZAR should be conduced in order to better investigate the impacts of drought at sub-national level.
As considered in the CPC methodology previously described, the importance in this phase of the analysis is understanding if the conditions could drive to a regional scale food crisis and

eventually launching a pre-alert status. For the 2009 case, the general condition in the CILSS countries is not particularly compromised. A close monitoring, along the season, of those zones showing installation problem, is recommended to see if crops are able to recover the late start of the season.

The next step of the analysis, rainy season advancing, is the crops water balance monitoring. The water needs satisfaction is calculated by ZAR on the basis of the detected installation date. Water stress areas are marked where the water balance is in deficit. During the 2009 cropping season, some drought stresses have been detected in the region. In many cases the stress hit the crops in a non vulnerable growing phase. As example of drought detection in a sensible phase we examined the outputs of the 1st dekad of August, where a zone of acute stress conditions for plant growth is highlighted between Senegal (Matam Department) and Mauritania (Assaba Region) (Fig. 5).

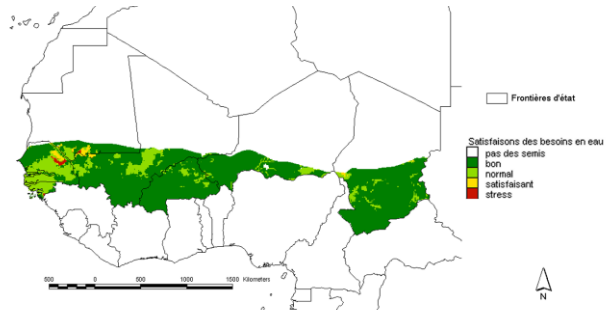

Figure 5. Water crops satisfaction rate (1st dekad of August)

This information has to be evaluated in comparison with the actual phenological phase of the studied crops (Fig. 6) to understand the importance of the drought impacts.

The phenological phases are calculated starting from the sowing date and considering the normal crop evolution. Each growing phase is characterized by a specific vulnerability to water stress, varying with crops and varieties. The pearl millet is particularly resistant in the most part of the growing cycle, only the flowering period is considered very vulnerable to water stresses, which can cause losses up to more than 80% of production (Bacci, 1992).

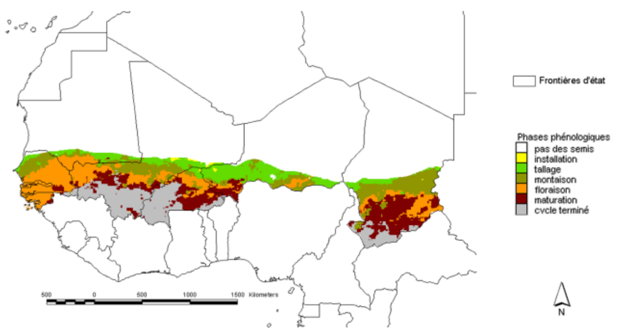

Figure 6. Phenological phases (1st dekad of August)

The zones of Matam and Assaba suffered a water stress exactly during the flowering period of the short cycle millet. This means that this event could have tough impacts on final production. Nevertheless, this information must be considered as probabilistic and has to be confirmed by field surveys. The importance of ZAR in this case is the early detection of areas to be closely monitored.

The case study 2009 has highlighted a dry period in the flowering time in the area between Senegal and Mauritania that doesn't have a great impact for the economy of the two countries. Matam is one of the less populated regions of Senegal (4.3% of total Senegal population), agriculture is essentially dominated by the rainfed crops that represent about the 4% of the national production (ANSD, 2009).

The dry spell detected in Mauritania hits in particular the Assaba Region, that is populated by 284,000 inhabitants representing the 9% of Mauritania population; the economy of the region is principally dependent of agriculture and livestock. The rainfed crops like pearl millet and sorghum are the only crops cultivated and the importance of the local production is about 6-7% of the national cereals production (ONS, 2008). Thus, in both cases the warning do not represent a food security problem at national level but at local one.

In this case, the early confirmation by ground data could allow the mobilisation of stocks from other departments to reduce the local impacts on food availability.

Using the bulletins of Senegal and Mauritania institutions and the information of the Agrhymet regional centre it is not possible to verify in detail the stress areas detected by ZAR (Table 7).

Drought event	Analysis
Matam department 1st dekad of august	The CSE bulletin shows that the vegetation problems at the beginning of august are proxy to Matam department in Linguere and Podor dept. Also for the CRA bulletin the problems in water satisfaction index are encountered in the northern part of Senegal.
Assaba region 1st dekad of august	The August FEWSNET Mauritanian bulletin shows a deficit in the status of vegetation in this region. The CRA bulletin instead doesn't signal stresses for this region. But the CILSS report expect for the Mauritania a deficit of 24% of cereal production respect the last year. Considering the advance of the sowing date registered in the country a stress should have hit the crops during the season.

Table 7. 1st dekad of August 2009 drought stress monitoring and verification

The results coming from ZAR analysis of the 1st dekad of August don't find any direct confirmation. Thus, it remain unclear if it was a false alarm advice for Mauritania and an inexact localisation for Senegal or if such localised events have not been registered in the national bulletins.

4. CONCLUSIONS

The sparse rain gauge network and the difficulties in information circulation in the Sahel region attribute to remote sensing an important role in rainfall estimation; indeed, rainfall data are essential to early detect drought events, which could hamper rainfed crops production and thus endanger food security.

The Food Crises Prevention Calendar, where the ZAR model operates, aims to integrate tools and methodologies for the forecast of food crises and an early identification of agrometeorological risk zones. Information on risk zones, their vulnerability to drought and the potentially involved population are key elements in the decision making process for crises mitigation and management.

Our study analysed the 2009 agricultural campaign using the ZAR model. Most important phenomena during the cropping season onset are the delay and failures of sowing detected in the Sahel region, particularly dangerous in its eastern part. The model outputs are verified with the bulletins issued by the national Early Warning systems and the CRA. At regional scale, ZAR demonstrate to be able to detect sowing anomalies and failures. The cropping season onset, as described by ZAR, summarizes the main factors affecting the 2009 campaign, whose results can be synthesised in: surplus in western countries' productions and deficit in eastern countries (CILSS/AGRHYMET, 2009).

When local situations are analysed, as the example of stresses during the millet flowering period in Senegal and Mauritania, ZAR results cannot be verified using national early warning systems or CRA bulletins. Indeed, localised events, moreover if they occur in non-strategic areas relating to national crop production or involved population, are not analysed in detail by national/regional bulletins.

More investigation is needed in order to appreciate the real accuracy of ZAR products, especially considering the accuracy of used rainfall estimation images, the availability of agronomic field data and the season final production data that normally are available in January-February of the next year.

Two aspects on which further developments and research should be carried out are the use of higher temporal resolution in rainfall estimations (5-days periods) and the use of real evapotranspiration data.

However, on the basis of such conclusions, this study confirms that ZAR can be profitably used for producing early information, from national to regional scale, on cropping season development, traducing meteorological drought data into crops risk levels, efficiently integrating the national early warning process.

Acknowledgements: This work was developed within WP5.2 "Early Warning Systems for food Security" of AMMA EU Integrated Project: African Monsoon Multidisciplinary Analysis. Based on a French initiative, AMMA was built by an international scientific group and is currently funded by a large number of agencies, especially from France, UK, US and Africa. Detailed information on scientific coordination and funding is available on the AMMA International web site http://www.ammainternational.org

5. REFERENCES

Africa Data Dissemination Service, 2009. http://earlywarning.usgs.gov/adds/ (accessed 16 Nov. 2009)

Agence Nationale de la Statistique et de la Démographie of Senegal, 2009 - http://www.ansd.sn (accessed 10 Nov. 2009)

Agence Nationale de la Statistique et de la Démographie (ANSD) du Sénégal, 2007. Situation économique et sociale de la région de Matam. http://www.ansd.sn/publications/annuelles/SES_Region/SES_Matam_2007.pdf (accessed 19 Nov. 2009)

AGRHYMET Regional Centre, 2009. Bulletin Spécial Campagne Agropastorale N° M04/09 - Situation au 10 août. Niamey, Niger. http://www.agrhymet.ne/PDF/Bulletin%20mensuel/Situation%20au%2010%20ao%FBt%202009%20(1).pdf (accessed 19 Nov. 2009)

AP3A, 2001. *Le contexte de la Vulnérabilité Structurelle par Système de Production dans les pays du CILSS*. CILSS-OMM-Cooperation Italienne, Florence, pp. 204.

Bacci, L., Maracchi, G., Senni, B., 1992. Les stratégies agrometeorologiques pour les pays sahéliens, Actes de séminaire, Florence 7 au 10 juillet. CILSS-OMM-Cooperation Italienne, Florence.

Bacci, M., De Filippis, T., Di Vecchia, A., Djaby, B., Incerti, F., Labo, M., Rocchi, L., Straccali, F., Vignaioli, P., 2005. Vulnerability Assessment for Food Crisis Management in the Sahel Region. The First International Symposium on Geo-information for Disaster Management, Delft.

Centre de Suivi Écologique (CSE), 2009. Suivi de la croissance de la végétation N°18 Août - Bilan à mi-parcours. CSE, Dakar, Senegal. http://www.cse.sn/documents/bulletin_18_aout2009.pdf (accessed 19 Nov. 2009)

CILSS, 2004. *Twenty Years of Food Crisis Prevention in the Sahel: Assessment & Perspectives*. CILSS, Ouagadougou, Burkina Faso.

CILSS, 2006. *Cadre Harmonisé d'Analyse Permanente de la Vulnérabilité Courante au Sahel*. CILSS, Ouagadougou, Burkina Faso.

CILSS, FEWSNET, FAO, 2009. Avis régional sur les perspectives agricoles et alimentaires 2009/2010 au sahel et en Afrique de l'ouest. Accra, Ghana. http://www.agrhymet.ne/PDF/Avis%20r%E9gional%20sur%20les%20perspectives%20agricoles%20et%20alimentaires%202009%202010.pdf (accessed 19 Nov. 2009)

CILSS/AGRHYMET, 2009. *Réunion de concertation technique sur les bilans céréaliers et alimentaires prévisionnels 2009-2010 et ex-post 2008-2009 des pays du CILSS et de la CEDEAO.* AGRHYMET, Niamey, Niger.

Di Vecchia, A., Djaby, B., Vignaroli, P., 2002. Les crises alimentaires et les systèmes de prévision au Sahel. Réunion annuelle du Réseau de Prévention des Crises Alimentaires au Sahel. Bruxelles, Belgium. http://www.case.ibimet.cnr.it/SVS/data/publications/CA_SPS.pdf (accessed 19 Nov. 2009)

Di Vecchia, A., Bacci, M., Pini, G., Tarchiani, V., Vignaioli, P., 2006. Meteorological forecasts and agrometeorological models integration: a new approach concerning early warning for food security in the Sahel. In: AARSE 2006 : *Proceeding of the 6th AARSE international conference on earth observation and geoinformation sciences in support of Africa's development, 30 October - 2 November 2006, Cairo, Egypt.* Cairo : The National

Authority for Remote Sensing and Space Science (NARSS), 2006. ISBN 1-920-01710-0.

Direction de la Météorologie Nationale (DMN) du Burkina Faso, 2009. *Bulletin Agrométéorologique Décadaire n° 07 / 2009.* DMN, Ouagadougou, Burkina Faso.

FAO, 1996. Rome Declaration on World Food Security and World Food Summit Plan of Action. World Food Summit 13-17 November 1996, FAO, Rome. http://www.fao.org/docrep/003/w3613e/w3613e00.HTM (accessed 19 Nov. 2009)

FAO, 1996, *The state of food and agriculture*. FAO, Rome ISBN 92-5-103858-9.

FAO 2008, *The State of Food Insecurity in the World*. FAO, Rome. ISBN 978-92-5-106049-0

FEWSNET, 2009. Chad Food Security Update July 2009 http://www.fews.net/docs/Publications/Chad_FSU_2009_07_en.pdf (accessed 19 Nov. 2009)

FEWSNET, 2009. Mauriania Food Security Update July 2009 http://www.fews.net/docs/Publications/Mauritania_fsu_2009_08_en.pdf (accessed 19 Nov. 2009)

FEWSNET, 2009. Mali Food Security Update July 2009 http://www.fews.net/docs/Publications/Mali_FSU_July_2009_final_ENG.pdf (accessed 19 Nov. 2009)

Garavini, M., 1997. *La définition du concept de risque dans le cadre d'un système d'alerte précoce agrométéorologique*. AP3A Projet - CILSS-OMM-Italian cooperation, Florence.

Groupe de travail pluridisciplinaire d'assistance météorologique, 2009. *Bulletin d'information Agro-Hydro-Météorologique décadaire. Décade du 1er au 10 juillet*. GTP, Bamako, Mali.

Groupe de travail pluridisciplinaire (GTP) Niger, 2009. *Bulletin Agro-Hydro-Météorologique décadaire. Décade du 21er au 30 juin*. GTP, Niamey, Niger.

Groupe de travail pluridisciplinaire (GTP) Niger, 2009. *Bulletin Agro-Hydro-Météorologique décadaire. Décade du 1er au 10 août*. Niamey, Niger.

Groupe de Travail Pluridisciplinaire Sénégal, 2009. *Bulletin agrométéorologique décadaire. Décade du 1 au 10 Juillet*. GTP, Dakar, Senegal.

Guarnirei, F., Pasqui, M., Genesio, L., Melani, S., Vignaroli P., 2006. Statistical downscaling for GFS precipitation forecast over Sahel region based on Meteosat Second Generation rainfall estimates. 14th Conference on Satellite Meteorology and Oceanography, Atlanta, USA.

Maracchi, G., Martini, M., Bacci, L., Boulama, M., Dauda, M., Popov, G., 1994. *Effects of water stress on pearl millet. Bilan hydrique agricole et sécheresse en Afrique tropicale*. Ed. John Libbey Eurotext. Paris. pp. 167-177.

Maracchi, G., Bacci, L., Cantini, C., Haimanot, M.T., 1993. Effects of water deficit in vegetative and post-flowering phases on pearl millet grown in controller environment. *Agr. Med.*, 123, pp. 65-71.

Martini, M., 1994. Méthodologie pour déterminer les zone à risque pour les cultures céréalières pluviales au Sahel. In Bernard Guillot Ed. *Actes de l'Atelier 'Problèmes de validation des méthodes d'estimation des précipitations par satellite en Afrique intertropicale*. ORSTOM, Niamey. pp 151-161.

Ndiaye, M., 2004. Impacts of agrometeorological applications for sustainable management of farming systems, forestry and livestock in sub-saharan Africa. In: Kleschenko, A., Grom, L., Ndiaye, M., Stefanski, R. Eds. *The impacts of agrometeorological applications for sustainable management of farming, forestry and livestock systems.* Report CagM WMO/TD No. 1175, World Meteorological Organisation, Geneva, Switzerland.

Nicholson, S.E., 2001. Climatic and environmental change in Africa during the last two centuries. *Clim Res*, 17, pp. 123–144.

Office National de la Statistique (ONS) de la Mauritanie, Direction des statistiques régionales, 2008. Assaba en chiffres 1995-2007. http://www.ons.mr/images/stories/doc/Nouveautes/w3enchiffres.pdf (accessed 19 Nov. 2009)

Pini, G., 2005. Modèle zone à risque et information au paysan. Rapport d'activités. SVS project, CILSS-OMM-Cooperation Italienne. http://www.case.ibimet.cnr.it/SVS/data/publications/rapport_ZAR.pdf (accessed 19 Nov. 2009)

Sivakumar, M.V.K., 1988. Predicting rainy season potential from the onset of rains in Southern Sahelian and Sudanian climatic zones of West Africa. *Agr. Forest Meteorol.*, 42, pp. 295-305.

Sultan, B., Janicot, S., 2004. La variabilité climatique en Afrique de l'Ouest aux échelles saisonnière et intra-saisonnière. I : mise en place de la mousson et variabilité intra-saisonnière de la convection. *Sécheresse*, 15(4), pp. 321-30.

SVS Project, 2006. Manuel du calendrier de prévision des crises alimentaires. CILSS-OMM-Cooperation Italienne. http://www.case.ibimet.cnr.it/SVS/data/publications/Manuel_CPCA_v4_cra.pdf (accessed 19 Nov. 2009)

SVS Project, 2006. *ZAR Modèle Zones à Risque Manuel de l'utilisateur*. Florence, CILSS-OMM-Cooperation Italienne.

Tarchiani, V., Vignaroli, P., Bacci, M., Di Vecchia, A., 2009. *La prévention des Crises Alimetaires au Sahel.* Aracne Editrice, Roma, pp. 67.

Vignaroli, P., Tarchiani, V., Sorbi V., 2006. Le Calendrier de Prévision des Crises Alimentaires: Une approche opérationnelle à support des actions de prévention et gestion des crises alimentaires au Sahel. CILSS-OMM-Cooperation Italienne, Florence, Italy. http://www.ibimet.cnr.it/Case/SVS/content.php?page=publi&menu=publi&id=TC (accessed 19 Nov. 2009)