USING THE CROPWAT MODEL TO ANALYSE THE EFFECTS OF CLIMATE CHANGE ON RAINFED CROPS IN NIGER

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PREFACE

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

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EXECUTIVE SUMMARY

This study used the CROPWAT model to predict the soil moisture deficit (SMD) with climate change scenarios and assess the crop water requirement (CWR) and the variation in yield of the main rainfed crops in Niger. Two districts, Aguié and Gaya, were selected to conduct the SMD analysis in relation to climate change under different climate and soil characteristics and cropping patterns.

Three types of data were collected and used for the selected districts. Meteorological data were acquired from the national meteorological service. These included temperatures for 1961 to 1990, rainfall for the same period, and evapotranspiration for the period 1978 to 1998 for Gaya and 1978 to 2002 for Aguié. Soil data were supplied by INRAN (Agronomic Research Institute). Crop yields, LGPs (length of growing period), and dates of sowing and harvesting for the selected crops (millet, sorghum and cowpea) were provided by the National Service for Agricultural Statistics.

The MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) coupled to the SCENGEN (SCEnario GENerator) software of the IPCC (Intergovernmental Panel on Climate Change) was used to predict the impact of climate change on the soil water availability and water uptake by crops. The HadCM2 (Hadley center unified model 2 transient, UK) GCM was selected and the actual annual average temperature and rainfall figures for 1961 to 1990 were used as the basic scenario. The choice of 2025 was justified by the availability of demographic projections for Niger at this period.

The study results show a significant difference between the scenario with climate change in 2025 and without climate change for Aguié in terms of soil water availability and soil moisture deficit but this difference is not significant for Gaya where the decrease in rainfall will maintain adequate soil moisture to support production of subsistence crops.

These findings have important implications for Niger's agricultural policy and the country's strategies for adapting to climate variability and change. Cropping systems may need to change as irrigation will be required for crops that are not adapted to Sahelian conditions. Small farmers should be helped to combine into big units (cooperatives) to increase the irrigation efficiency.

1. Introduction

With the predicted decline in agricultural yields as a result of global warming, the pressure on natural habitats and biological resources from agricultural practices is expected to increase. This is of particular concern in the developing world and especially Africa, which has worse starting conditions and limited adaptation options for African farmers and agricultural production systems. Reduced yields will increase the demand for converting land to agricultural use, extracting water for irrigation, introducing more new and exotic plant and animal species and intensifying the use of chemical inputs. This pressure on the land will increase pollution and environmental damage such as erosion, and seriously accelerate biodiversity loss and extinction.

Further warming is expected to reduce crop productivity adversely, and this will have serious consequences because agriculture and agro-ecological systems are especially prominent in the economies of African countries and particularly of Niger and the systems tend to be less capital and technology intensive. It is in this context that the GEF accepted and funded the project *Regional Climate, Water and Agriculture: Impacts on and Adaptation of Agro-ecological Systems in Africa* for which Niger was selected as one of a sample of 11 African countries.

2. Background

Niger is a landlocked country in the Sahel more than 700 km from the sea, with a surface area of 1,267,000 km^2 and a population of about 10 million. The climate is typically Sahelian, with two seasons: a long dry season of eight months and a short rainy season of four months which usually starts in May or June. The rainfall is low, variable and undependable. The cropping area is limited to the area with a length of growing period (LGP) of 75 to 150 days, which is classified as semi-arid.

The semi-arid part of Niger is a region that faces very serious challenges for developing crop production. Cultivating crops and keeping livestock are the most important activities in the rural zone, practiced by 90% of the total population. But harsh environmental conditions – high temperature, low rainfall and low soil fertility – and pests and diseases restrict the range of crops grown. In general, technology based agriculture has not come to Niger on a significant scale (ICRISAT/FAO 1996). Most of the agricultural growth that has occurred is due to the prevalence of extensive farming systems, not yield increases. Low rainfall as a result of climate change, land depletion, the very low level of external input, very little investment in irrigated agriculture, and the lack of adaptive rural credit schemes constitute the major constraints on crop production in the Sudano-Sahelian zone of Niger.

At the agro-ecological level, two main production systems can be distinguished as a function of LGP and rainfall:

Rainfed mixed agro-pastoral system

This is the system used in the Sahelian zone. It is characterized by a short rainy season with a rainfall lower than 600mm and an LGP of 60 to 100 days. Grains grown here are predominantly early-maturing varieties. The major constraints on this system are high temperature, uneven rainfall distribution and low soil fertility.

Rainfed mixed cropping system

This is the system used in the northern Sudan savanna zone. It is characterized by an intermediate rainy season with 600 to 800mm of rainfall, and an LGP of 100 to 125 days. Medium to late-maturing varieties of crops are grown for a dual purpose (grains and fodder). The major constraints on this system are low soil fertility and high pest and disease occurrence.

At the regional level, three main typical production systems can be distinguished as a function of LGP, rainfall and soil types: the extensive millet-based system (EMBS), the semi-intensive millet-based system (SIMBS) and the sorghum/millet-based system (SMBS).

At the district level, apart from the irrigated systems that are found along the rivers and streams throughout the country, seven main production systems can be distinguished. Five of them belong to the millet based system, and two to the sorghum/millet-based system.

3. Objectives and methodology of the study

The objective of the study was to use the CROPWAT model (FAO 1979, 1998) to predict the soil moisture deficit (SMD) with climate change scenario and assess the crop water requirement (CWR) and the variation in yield of the main rainfed crops in Niger.

3.1 Soil moisture deficit and climate change scenario

Two districts, Aguié and Gaya, were selected to assess the degree of SMD caused by climate change. Climate and soil characteristics, including other farming and cropping patterns, are summarized in Tables 1 and 2.

Three types of data were collected and used for the selected districts. Meteorological data were acquired from the national meteorological service. These included temperatures for 1961 to 1990, rainfall for the same period and evapotranspiration for the period 1978 to 1998 for Gaya and 1978 to 2002 for Aguié. Soil data were supplied by INRAN (Agronomic Research Institute). Crop yields, LGPs, dates of sowing and harvesting for the selected crops (millet, sorghum and cowpea) were provided by the National Service for Agricultural Statistics.

The MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) coupled to the SCENGEN (SCEnario GENerator) software set up by the IPCC (Intergovernmental Panel on Climate Change) during the second appraisal report (Houghton et al. 2001) was used in this study to predict the impact of climate change on the soil water availability and water uptake by crops. The HadCM2 (Hadley center unified model 2 transient, UK) GCM was selected and the actual annual average temperature and rainfall figures for 1961 to 1990 were used as the basic scenario and IS92A (reference scenario) to generate temperature and rainfall figures for 2025. The choice of 2025 was justified by the availability of demographic projections for Niger at this period. The country’s oldest meteorological stations in the MAGICC/SCENGEN square degrees were identified and selected in order to use the serial climate data available since 1960.

At this step of its development, the MAGICC/SCENGEN can only give temperature and rainfall for 2025 for most of the African regions. The temperature and rainfall generated by the model for Aguié (12°5'N–17°5'N and 2°5'–7°5'E) and Gaya (7°5'–12°5'N and 2°5'–7°5'E) were recorded. The evapotranspiration for 2025 was obtained by using the PENMAN-Monteith method[2] with the

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[2] http://www.fao.org/docrep/X0490E/x0490e06.htm

temperatures for the corresponding period. The other required parameters for 2025 were used as defined in the CROPWAT model. The yields of the main crops, the rainfall and the LGPs were considered.

3.2 Crop water requirement and yield of main rainfed crop

Districts with meteorological stations since 1960 (Birni N'Konni, Gaya, Mainé Soroa, Aguié, Tahoua, Tillabery and Mirriah) were selected to conduct the CWR study. Except for the Gaya district, all the districts have LGPs, T° (temperature), rainfall, ETo (evapotranspiration) and soil characteristics similar to those of Aguié. The same dates of sowing and harvesting were used for each crop for all the districts. The growth cycle for each crop is longer in the Gaya district, as shown in Table 2. The total cropped areas for each crop, and maximum/actual crop yields (millet, sorghum and cowpea) for each district were provided by the National Service for Agricultural Statistics. The Ky (yield reduction) factor from the FAO (Food and Agriculture Organization) was used for each. Among the CROPWAT model outputs, the CWR, ETc (crop evapotranspiration), and Ks (stress factor) were used for crop yield analysis.

4. Results and discussion

4.1 Effect of climate change on the soil moisture deficit in two different districts

The MAGICC/SCENGEN outputs predict that in 2025 the amount of rainfall will decrease and temperature will increase in both Aguié and Gaya. The CROPWAT outputs such as TAM Lost(mm), RAM User(mm), Total Rain(mm), Efct.Rain(mm), Etc(mm), Etc/Etm (%) and considered as crop yield parameters are shown in Tables A1 to A5 for the three selected crops and locations. The SMD variation for each crop and location, with and without climate change, are shown in Figure 1.

The trends of SMD are the same for both the reference period and 2025 but different in Aguié and Gaya. Figure 1 shows that the trend of the SMD is more critical at Aguié than at Gaya for both the reference period and for 2025. For all the selected crops, the SMD will be increased in 2025. The SMD is almost the same for the two scenarios during the first crop growth stage and does not exceed the evapotranspiration. The SMD decreases drastically during the vegetative phase and maturity. The CROPWAT analysis also shows that there is a significant decrease in crop yield for all crops and locations. This decrease is more significant at Aguié which will have less rainfall in 2025. In Gaya the decrease in the millet yield is not significant as there will be enough rainfall to maintain soil moisture during the crops' maturity.

These results seem to match the climate change scenario as predicted in the literature, but further discussion is needed to bring them in line with the project's objectives and needs.

4.2. Effect of crop water requirements on the yield of the main rainfed crops

4.2.1 Crop water use for millet (Table 3)

Millet is the most common rainfed crop in Niger and the subsistence nature of the crop is well documented. Millet farming suits almost all the studied districts. The highest value of ETo was observed in the Tahoua district with 741mm. This district is in fact located in the central northern part of the country at the limit of the Sahara Desert and characterized by a high diurnal temperature during the rainy season. Mainé Soroa, located in the eastern part of the country, shows the highest Etc owing to the high evaporation demand linked to a high temperature and a low hygrometry. There is some variation in CWR between districts, given that millet is a crop which does not need a lot of water and the most commonly cultivated variety has a short cycle in all the districts except Gaya, where varieties with a long cycle are used. The maximum yields were obtained in Gaya (815kg/ha), where the annual average rainfall is 800mm, and Aguié (757 kg/ha), where cropping systems are more intensive, with higher inputs.

4.2.2 Crop water use for cowpea (Table 4)

The ETo of the cowpea growing period was above 400mm in all the districts. Tahoua and Mainé Soroa have the highest rates, with 816 and 747 mm/period respectively. The CWR is almost the same for all the districts, around 200mm and 300mm, except for Tahoua (325mm). The response coefficients due to water stress are low everywhere except in Tahoua (0.96) and Mirriah (0.89). This is explained by a poor rainfall distribution in time (during the various growth phases of the crop) that caused a critical drying up of the soil's usable moisture. Thus the yield reduction can be considered significant or not at harvest according to the phase when the SMD has been critical.

4.2.3 Crop water use for sorghum (Table 5)

Sorghum being a water demanding crop, only the area of Gaya that has favorable meteorological and edaphic conditions presents a optimal yield. Here, the need for crop water is almost entirely satisfied (CWR is 46mm for the whole cycle). In fact, the rainy season covers the sorghum cycle and the clayey-sandy and clayey-loamy soil has a fairly good retention capacity. The areas of Tillabery, Konni and to some extent Aguié have favorable valleys and alluvial plains where sorghum is farmed, but the high evaporation demand (ETo above 500 mm) increases the evapotranspiration of the crop and therefore the demand for water. The additional water CWRs of the sorghum for the areas mentioned above are 114mm, 154mm, 121mm respectively. This water deficit thus can be seen to affect the yield: only 363kg/ha in Tillabery, 351kg/ha in B. Konni and 190kg/ha in Aigué. The very low yield in Aguié is explained by the type of soil, which is subject to overcropping.

5. Conclusion and policy recommendations

The major crops covered in this report are cultivated in mixed cropping systems in all the districts studied. This mixture of crops allows us to forecast the risks related to the amount and timing of the rainfall during the cropping season as all these selected crops are exclusively cultivated during the rainy season. There is no chance for irrigation, even if the rainfall deficit is critical, as farmers cannot afford the required input. In all the districts the fertile areas in the field are allocated to cash crops such as okra, tobacco, sesame, galingale (an aromatic ginger-like root used for medicine) and maize. These cropping systems are common and known at national level as a confirmed strategy for adapting to climate variability and change.

According to the above, the CROPWAT model is applicable in Niger country conditions even if irrigation is not common, with less than 60,000ha being used for irrigated agriculture.

The study results show a significant difference between the scenario with climate change (2025) and without climate change for Aguié in terms of soil water availability and soil moisture deficit but this difference is not significant for Gaya where the decrease in rainfall with this scenario (2025) will maintain adequate soil water availability for producing subsistence crops. For all these districts, except Gaya, there is little chance of irrigation for subsistence crops in the future.

These findings may have important implications for Niger's agricultural policy. Based on these intermediate conclusions, the following recommendations can be made:

1. Strategies for adapting to climate variability and change should be formulated and adopted at community, district and national level

2. Cropping systems should be improved by changing to irrigation for crops that are not adapted to Sahelian conditions.

3. Small farmers should be helped to combine into big units (cooperatives) to increase the irrigation efficiency.

4. Water resource management should be recognized as the main constraint on crop productivity in the country and steps taken to improve it.

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Table 1: Characteristics of selected districts, Aguié and Gaya

	Aguié	**Gaya**
Geographical area	Sahelian zone	Sudan savanna zone
Type of system	Short season SAT, rainfed mixed agro-pastoral	Intermediate season SAT, rainfed mixed cropping
Length of growing period (days)	60–100	100–125
Soil (Hcr %)	Sandy (9)	Loamy (22)
Rainfall (mm)	< 600	600–800
Based system	Semi-intensive millet-based system (SIMBS)	Sorghum/Millet-based system (SMBS)
Main crops	Millet, sorghum, cowpea, groundnut	Sorghum, millet, cowpea, groundnut
Intensity of crop PS	Low–medium	Low
Cash crops	Reasonable	Limited/Reasonable
Role of trees	Fertility management	Fruit, firewood
Role of livestock	Manure, transport, animal traction	Corralling, transport
Major constraints	Rainfall, high temperature, soil fertility	Soil fertility
	Livestock shortage in farming systems, priority for crop production without any specific pasture area	Reduction of fallow, pest and disease management
Sub Systems	Millet-cowpea-sorghum-groundnut low external input	Sorghum-millet-cowpea-groundnut

Table 2: Length of growing period, mean yield, date of sowing and date of harvesting and for main crops in the two selected districts, 2003

	Gaya		**Aguié**	
	Cycle (days)	**Yield (kg/ha)**	**Cycle (days)**	**Yield (kg/ha)**
Millet	120	604	90	401
Sorghum	140	596	105	185
Cowpeas	120	124	100	108
	Date of sowing		**Date of harvesting**	
	Gaya	**Aguié**	**Gaya**	**Aguié**
Millet	10 May	15 June	10 Sept	15 Sept
Sorghum	30 May	30 June	20 Oct	15 Oct
Cowpeas	30 May	30 June	20 Oct	10 Oct

Table 3: CROPWAT outputs for millet

District	ETo mm	Kc	ETc mm	Ky	Ya kg/ha	Ym kg/ha	Area cropping intensity, %	Ks	Eta mm	CWR mm
B. Konni	581	1.00	380	1.20	502	543	45	0.94	356	196
Gaya	451	1.00	305	1.20	746	851	50	0.90	275	153
Mainé S.	682	1.00	440	1.20	372	524	71	0.76	334	232
Aguié	536	1.00	363	1.20	483	757	51	0.70	254	181
Tahoua	741	1.00	416	1.20	298	312	53	0.96	399	251
Tillabery	636	1.00	432	1.20	412	428	60	0.97	419	216
Mirriah	597	1.00	405	1.20	408	461	55	0.90	365	203

Notes: ETo (reference crop evapotranspiration), ETc (evapotranspiration of the crop), Ky (yield reduction factor), Ya (actual yield of the crop), Ym (maximum yield of the crop), Ks (stress factor), CWR (crop water requirement), ETa (actual evapotranspiration).

Table 4: CROPWAT outputs for cowpea

District	ETo mm	Kc	ETc mm	Ky	Ya kg/ha	Ym kg/ha	Area cropping intensity, %	Ks	Eta mm	CWR mm
B. Konni	633	1.15	502	1.15	142	314	36	0.52	261	251
Gaya	497	1.15	396	1.15	171	317	30	0.60	240	198
Mainé S.	747	1.15	452	1.15	51	87	13	0.64	289	298
Aguié	581	1.15	461	1.15	134	304	23	0.51	237	231
Tahoua	816	1.15	427	1.15	122	189	32	0.69	294	325
Tillabery	697	1.15	496	1.15	207	216	28	0.96	476	278
Mirriah	650	1.15	494	1.15	189	216	29	0.89	440	258

Table 5: CROPWAT outputs for sorghum

District	ETo mm	Kc	ETc mm	Ky	Ya kg/ha	Ym kg/ha	Area cropping intensity, %	Ks	Eta mm	CWR mm
B. Konni	650	1.00	450	1,25	351	385	18	0.93	418	154
Gaya	519	1.00	362	1,25	676	800	15	0.88	317	46
Mainé S.	771	1.00	473	1,25	111	160	10	0.76	357	280
Aguié	592	1.00	408	1,25	190	309	10	0.69	282	121
Tahoua	832	1.00	486	1,25	275	276	11	1.00	486	321
Tillabery	697	1.00	492	1,25	363	409	10	0.91	448	114
Mirriah	666	1.00	456	1,25	198	248	12	0.84	383	195

APPENDICES

Table A1: Cowpea Aguié

Date	TAM lost (mm)		RAM user (mm)		Total rain (mm)/dcd		Efct. rain (mm)/dcd		Etc (mm)/dcd		Etc/Etm (%)		SMD (mm)	
	Réf.	2025	Réf.	2025	Réf.	2025	Réf.	2025	Réf.	2025	Réf.	2025	Réf.	
30/6	30	30	13.5	13.5	00	00	00	00	2.5	2.7	100	100	2.5	
4/7	35.6	35.6	16	16	55.4	42.7	7.5	8.1	2.5	2.7	100	100	2.5	
14/7	49.6	49.6	22.3	22.3	62.1	51.2	24.4	26.1	2.4	2.6	99.9	99.2	2.4	
24/7	63.6	63.6	28.6	28.6	68.1	57.3	25.4	27	3.1	3.3	100	100	3.1	
3/8	77.6	77.6	34.9	34.9	72.3	59.5	37.3	39	4.5	4.7	100	99.9	4.5	
13/8	91.6	91.6	41.2	41.2	73.9	57.2	40	40	5.8	6	99	98.4	16.1	
23/8	100	100	45	45	71.7	49.9	40	40	6.4	6.5	92.2	90.4	34.1	
2/9	100	100	45	45	64.9	38.3	40	38.3	6.3	6.4	78.4	75.9	43.6	
12/9	100	100	45	45	53.5	24.2	40	24.2	6.2	4.8	69.7	63.7	47	
22/9	100	100	45	45	38.1	10.6	38.1	10.6	6.1	2.6	66.5	43.6	49.8	
2/10	10	100	48.8	48.8	20.5	1.4	20.5	1.4	3.8	0.9	62.4	24	65.3	
12/10	100		56.3		4.6		4.6		1.4		52.4		80.8	
Total					585	392.3	318	254.8	406	355	79.4	67.6		

Table A2: Millet Aguié

Date	TAM lost (mm)		RAM user (mm)		Total rain (mm)/dcd		Efct. rain (mm)/dcd		Etc (mm)/dcd		Etc/Etm (%)		SMD	
	Réf	2025	Réf	2025	réf	2025	réf	2025	réf	2025	réf	2025	réf	
15/6	30	30	15	15	00	00	00	00	1.9	2.1	100	100	1.9	
24/6	46.2	46.2	23.9	23.9	48.6	33.1	15.3	16.9	1.9	2.1	100	100	1.9	
4/7	64.2	64.2	34.5	34.5	55.4	42.7	18.8	20.5	1.9	2	100	100	1.9	
14/7	82.2	82.2	45.9	45.9	62.1	51.2	24.8	26.6	3.2	3.4	100	100	3.2	
24/7	100	100	57.8	57.8	68.1	57.3	38.2	40	4.5	4.8	100	100	4.5	
3/8	100	100	59.8	59.8	72.3	59.5	40	40	5.8	6	100	100	16.7	
13/8	100	100	60	60	73.9	57.2	40	40	5.7	5.8	99.4	97.8	33.5	
23/8	100	100	60	60	71.7	49.9	40	40	5.5	5.7	91.1	86.7	44.5	
2/9	100	100	60	60	64.9	38.3	40	38.3	5.5	5.5	81.7	77.7	49.4	
12/9	100	100	60	60	53.5	24.2	40	24.2	5.4	5	76.9	71.6	51	
22/9	100	100	60	60	38.1	10.6	38.1	10.6	5.3	2.6	75.4	47.9	53.2	
2/10	100	100	63.3	63.3	20.5	1.4	20.5	1.4	3.9	0.7	77.5	26.3	68.4	
12/10	100	100	66.7		4.6		4.6		1.4		61		84.3	
Total					633.7		360.2		454.4		85.3			

Table A3: Sorghum Aguié

Date	TAM lost(mm)		RAM user(mm)		Total rain (mm)/dcd		Efct. rain (mm)/dcd		Etc (mm)/dcd		Etc/Etm (%)		SMD (mm)	
	Réf	2025	Réf	2025	Réf	2025	réf	2025	réf	2025	réf	2025	réf	2
30/6	30	30	18	18	00	00	00	00	1.9	2	100	100	1.9	2
4/7	38	38	22.5	22.5	55.4	42.7	5.6	6.1	1.9	2	100	100	1.9	2
14/7	58	58	33.3	33.3	62.1	51.2	18.4	19.8	1.8	1.9	100	100	1.8	1
24/7	78	78	43.4	43.4	68.1	57.3	19.1	20.3	2.4	2.5	100	100	2.4	2
3/8	98	98	52.7	52.7	72.3	59.5	28.6	30	3.5	3.6	100	100	3.5	3
13/8	100	100	52	52	73.9	57.2	39.5	40	4.5	4.7	100	100	4.5	5
23/8	100	100	50	50	71.7	49.9	40	40	5.5	5.7	100	100	15.4	1
2/9	100	100	50	50	64.9	38.3	40	38.3	5.5	5.5	97.4	95.9	29	3
12/9	100	100	50	50	53.5	24.2	40	24.2	5.4	5.4	89.7	85.7	37.5	5
22/9	100	100	50	50	38.1	10.6	38.1	10.6	5.3	2.8	82.8	57.3	43.7	7
2/10	100	100	50	50	20.5	1.4	20.5	1.4	4.4	1.1	75.2	29.9	62.9	9
12/10	100		60		4.6		4.6		2		53.5		84.2	
Total					585	392	294	231	395	333	78.2	64.1		

Table A4: Millet Gaya

Date	TAM lost (mm)		RAM user (mm)		Total rain (mm)dcd		Efct. rain (mm)dcd		Etc (mm)/dcd		Etc/Etm (%)		SMD (mm)	
	Réf	2025	Réf	2025	réf	2025	réf	2025	réf	2025	réf	2025	Réf	20
10/5	42	42	21	21	00	00	00	00	2	2	100	100	6.2	6.
15/5	54.6	54.6	27.8	27.8	26.1	25.4	7.7	7.7	1.9	1.9	100	100	1.9	1.
25/5	79.8	79.8	42.3	42.3	31.5	30.9	18.9	18.7	1.8	1.8	100	100	1.8	1.
4/6	105	105	57.8	57.8	36.8	36.4	20.2	19.8	2.6	2.5	100	100	2.6	2.
14/6	130	130	74.2	74.2	42.3	42.2	31.6	30.5	3.8	3.7	100	100	3.8	3.
24/6	140	140	82.6	82.6	48.3	48.6	40	40	4.9	4.7	100	100	8.3	6.
4/7	140	140	84	84	54.6	55.4	40	40	5.2	5	100	100	20.8	15
14/7	140	140	84	84	60.8	62.1	40	40	5	4.8	100	100	32	24
24/7	140	140	84	84	66.4	68.1	40	40	4.9	4.6	100	100	41.2	31
3/8	140	140	84	84	70.4	72.3	40	40	4.7	4.5	100	100	48.9	37
13/8	140	140	84	84	71.8	73.9	40	40	4.6	4.5	99.6	100	55.1	42
23/8	140	140	86.8	86.8	69.5	71.7	40	40	3.9	3.9	99.2	100	58	44
2/9	140	140	91.5	91.5	62.8	64.9	40	40	2.8	2.8	100	100	50.8	37
12/9	140	140	96.1	96.1	51.6	53.5	40	40	1.8	1.8	100	100	33	20
Total					693	705	438	437	479	465	99.9	100		

Table A5: Sorghum Gaya

Date	TAM lost (mm)		RAM user (mm)		Total rain (mm)/dcd		Efct. rain (mm)/dcd		Etc (mm)/dcd		Etc/Etm (%)		SMD (mm)	
	Réf	2025	Réf	2025	réf	2025	réf	2025	réf	2025	réf	2025	réf	20
30/5	54	54	32.4	32.4	00	00	00	00	1.8	1.8	100	100	7.2	7.
4/6	72	72	42.5	42.5	36.8	36.4	7.2	7	1.8	1.7	100	100	1.8	1.
14/6	108	108	61.9	61.9	42.3	42.2	17.4	16.8	1.7	1.6	100	100	1.7	1.
24/6	144	144	79.9	79.9	48.3	48.6	18.4	17.5	2.3	2.2	100	100	2.3	2.
4/7	180	180	96.5	96.5	54.6	55.4	27.2	25.9	3.2	3.1	100	100	3.2	3.
14/7	180	180	93.3	93.3	60.8	62.1	36.4	34.5	4.1	3.9	100	100	4.1	3.
24/7	180	180	90	90	66.4	68.1	40	40	4.9	4.6	100	100	9.8	7.
3/8	180	180	90	90	70.4	72.3	40	40	4.7	4.5	100	100	17.5	13
13/8	180	180	90	90	71.8	73.9	40	40	4.6	4.5	100	100	23.9	18
23/8	180	180	90	90	69.5	71.7	40	40	4.5	4.5	100	100	29.3	23
2/9	180	180	91.8	91.8	62.8	64.9	40	40	4.4	4.5	100	100	34.1	28
12/9	180	180	110	110	51.6	53.3	40	40	3.7	3.9	100	100	34.3	29
22/9	180	180	128	128	36.5	38.1	36.5	38.1	3.1	3.3	100	100	31.4	26
Total					672	687	383	380	441	435	100	100		

Table A6: Cowpea Gaya

Date	TAM lost (mm)		RAM user (mm)		Total rain (mm)/dcd		Efct. rain (mm)/dcd		Etc (mm)/dcd		Etc/Etm (%)		SMD	
	Réf	2025	Réf	2025	réf	2025	réf	2025	réf	2025	réf	2025	réf	20
30/5	42	42	18.9	18.9	00	00	00	00	2.4	2.4	100	100	6.6	6.
4/6	51.8	51.8	23.3	23.3	36.8	36.4	9.6	9.3	2.4	2.3	100	100	2.4	2.
14/6	71.4	71.4	32.1	32.1	42.3	42.2	23.2	22.4	2.3	2.2	100	100	2.3	2.
24/6	91	91	41	41	48.3	48.6	24.4	23.3	3	2.9	100	100	3	2.
4/7	111	111	49.8	49.8	54.6	55.4	35.4	33.6	4.2	4	100	100	4.2	4
14/7	130	130	58.6	58.6	60.8	62.1	40	40	5.3	5	100	100	12.1	9.
24/7	140	140	63	63	66.4	68.1	40	40	5.6	5.3	100	100	28.1	22
3/8	140	140	63	63	70.4	72.3	40	40	5.4	5.2	98.4	99.8	42	35
13/8	140	140	63	63	71.8	73.9	40	40	5.3	5.2	93.3	96.9	51.8	45
23/8	140	140	63	63	69.5	71.7	40	40	5.2	5.2	87.7	92.1	57.6	52
2/9	140	140	69.3	69.3	62.8	64.9	40	40	4.1	4.1	85.8	89.5	58.6	55
12/9	140	140	79.8	79.8	51.6	53.5	40	40	2.3	2.4	98.3	99.2	48.8	47
Total					635	649	373	369	431	426	96	97.5		

Figure 1: Variation of soil moisture deficit (SMD) according to crop and location for reference period (1960–1990) and 2025