جامعة أبو بكر بلقايد
UNIVERSITÉ DE TLEMCEN

Pan African University
Institute of Water
and Energy Sciences

PAN AFRICAN UNIVERSITY
Institute of Water and Energy Science (Including Climate Change)

Master Dissertation

Submitted in partial fulfillment of the requirements for the
Master degree in Water Engineering
Presented by
Julius Okoth OMONDI

TITLE:
Drought analysis for water planning in Agriculture
(A case-study of Gourma Province, Eastern Burkina Faso)

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Declaration

I **Julius Okoth Omondi**, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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Abstract

Drought is a naturally occurring event that human beings grapple with the question of how to mitigate its impacts. Certainly, Agriculture is one of the biggest casualties of drought events but the extent to which the sector is affected is imperceptible. This thesis report presents a method of quantifying the impact of drought on Agriculture and proposes a method of selecting mitigation strategies suited to Gourma province. Stakeholders in the agricultural sector have to make policy and technical decisions affecting their citizens based on inaccurate information and thus end up reacting to droughts while the damage is already done. Farmers get reduced yields at the end of the season and have nothing to eat or generate income due to inadequate planning at start of season. Based on the Effective Reconnaissance Drought index (eRDIst), this study characterises all the agro-meteorological drought events in Gourma province between 1979 and 2013. Potential yield (Yp) and water limited yield (Yw) simulations help determine the yield gap (Yg) and by regression modelling, the relationship between drought and yields is established through a mathematical model and is further used to estimate farmer’s losses. Multi Criteria Decision Making (MCDM) provides a way of selecting suitable Drought Mitigation Options (DMOs) from the available options. Analysis of eRDIst shows occurrence of three drought events spread out in nine years with different levels of severity, frequency and duration. The years 1983 and 2008 show low drought intensity while the event between 1999 and 2005 has the highest intensity. From the resulting mathematical models, both drought and extremely wet conditions affect the yields. Analysis using the mathematical models show that a unity change in the drought conditions only results in a reduction of yields by 775Kg/Ha translating to losses of 676$/Ha while in the case of both drought and extremely wet conditions, the mathematical model shows that yield reduction stands at 995 Kg/Ha which is equal to 760$/Ha. Under short term DMOs, the over exploitation of aquifers, restricted irrigation during droughts and reallocation of water were found to be suitable while for long term solutions, insurance was found to be the best performing. This study finally recommends *Le Guardien de l’espoir* insurance scheme as a safety net for the farmers. From this study, a more accurate method of demonstrating the impact of drought on Agriculture has been established. It is also key to note that more research needs to be carried out on why the relationship between drought and yields in medium textured soils is stronger than in fine textured soils. The suitability of insurance schemes for farmers managed by the farmers themselves as a tool for mitigating the drought impacts needs to be further researched on too.

Résumé

La sécheresse est un phénomène naturel sur lequel les êtres humains s’interrogent de savoir comment atténuer ses impacts. Certes, l'agriculture est l'une des plus grandes victimes des sécheresses, mais la mesure dans laquelle le secteur est touché est imperceptible. Ce rapport de thèse présente une méthode de quantification de l'impact de la sécheresse sur l'agriculture et propose une méthode de sélection des stratégies d'atténuation adaptées à Gourma. Les acteurs du secteur agricole doivent prendre des décisions politiques et techniques affectant les citoyens sur la base d'information inexacte et finissent par réagir aux sécheresses alors que le mal est déjà connu. Les agriculteurs obtiennent des rendements réduits à la fin de la saison et n'ont rien à manger ou à générer des revenus en raison d'une planification inadéquate en début de saison. Basée sur l'indice eRDIst, cette étude caractérise tous les événements de sécheresse agro-météorologique dans la province de Gourma entre 1979 et 2013. Les simulations de rendement potentiel (Yp) et de rendement limité en eau (Yw) permettent de déterminer l'écart de rendement (Yg) et par modélisation de régression, la relation entre la sécheresse et les rendements est établie au moyen d'un modèle mathématique et est ensuite utilisée pour estimer les pertes des agriculteurs. La prise de décision multicritères (MCDM) permet de sélectionner des options d'atténuation de la sécheresse (DMO) appropriées parmi les options disponibles. L'analyse de l'eRDIst montre l'occurrence de trois événements de sécheresse répartis sur neuf ans avec différents niveaux de gravité, de fréquence et de durée. Les années 1983 et 2008 montrent une faible intensité de sécheresse tandis que l'événement entre 1999 et 2005 est le plus intense. À partir des modèles mathématiques obtenus, la sécheresse et les conditions extrêmement humides affectent les rendements. L'analyse utilisant les modèles mathématiques montre qu'un changement d'unité dans les conditions de sécheresse n'aboutit qu'à une réduction des rendements de 775 Kg / Ha, se traduisant par des pertes de 676 $ / Ha, tandis que le modèle mathématique montre que la réduction du rendement est de 995 Kg / Ha, ce qui équivaut à 760 $ / Ha. A court terme, l'irrigation restreinte en période de sécheresse est appropriée tandis qu’à long terme, l'assurance a été jugée la plus performante. À partir de cette étude, une méthode plus précise de démonstration de l'impact de la sécheresse sur l'agriculture a été établie. Il est également essentiel de noter que davantage de recherches doivent être menées sur la raison pour laquelle la relation entre la sécheresse et les rendements dans les sols à texture moyenne est plus forte que dans les sols à texture fine. La pertinence des systèmes d'assurance pour les agriculteurs gérés par les agriculteurs eux-mêmes en tant qu'instrument d'atténuation des impacts de la sécheresse doit également faire l'objet de recherches.

Acknowledgment

Firstly, I would like to thank God for life and my parents for having educated me up to this level. I would also like to acknowledge the inputs of friends and colleagues at Pan African University Institute of Water and Energy Sciences (PAUWES) in Tlemcen, Algeria and International Institute for Water and Environmental Engineering (2iE) in Ouagadougou, Burkina Faso. I thank my supervisor, Dr Amadou Keita for the advice and guidance throughout this process.

A special mention goes to Dr Korodjouma Ouattara of Institute of Environment and Agricultural Research - Ouagadougou (INERA) for all the guidance in soil science and crop modelling and also Dr Georges Zomboudre of INERA-Fada N'Gourma for the guidance and support in the field. I would also like to recognize the contribution of Mr. Paul Yameogo and Ms. Adda Tchoroma for their efforts during the interviews with farmers.

Lastly, I thank the African Union Commission (AUC) which through the Pan African University (PAU) and PAUWES gave me the chance to study and apply myself by contributing solutions to problems that face human beings.

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List of Abbreviations

CFSR-Climate Forecast System Reanalysis
COP-Cost of Production
CSM-Cropping system model
CWSI-Crop water stress index
DEM-Digital Elevation Model
DEWS-Drought early warning system
DGAE-Direction Générale de l’Agence de l’Eau du Gourma
DGESS-Direction générale des statistiques sectorielles
DMO-Drought Mitigation Option
DrinC-Drought indices calculator
DSSAT-Decision Support System for Agrotechnology Transfer
DUR-Duration of simulation period (d)
ENSO-El Niño/Southern Oscillation (ENSO) cycles
eRDI-effective Reconnaissance Drought Index
EVI-Enhanced Vegetation Index
FAO-Food and agriculture organisation
FCFA-Franc CFA (Communauté Financière Africaine)
FYgD-Fine texture, Yg, drought conditions only
FYgDW-Fine texture, Yg, drought and wet conditions
FYpD-Fine textured soils, Yp, Drought conditions only
FYpDW-Fine textured soils, Yp, Drought and wet conditions
FYwD-Fine textured soils, Yw, Drought conditions only
FYwDW-Fine textured soils, Yw, Drought and wet conditions
GYGA-Global Yield Gap Atlas
HINDEX-Harvest index: weight of storage organs / weight of total above ground crop
IB-WTS-Inter-basin water transfer system
INERA-Institut de l’Environnement et de Recherches Agricoles
ISRIC-International Soil Reference and Information Center
LAIM-Maximum leaf area index (ha/ha)
LST-Land Surface Temperature
MAAH-Ministère de l’Agriculture et des Aménagements Hydraulique
MCDA-Multi Criteria Decision Analysis
MCDM-Multi Criteria Decision Making
MYgD-Medium texture, Yg, drought conditions only
MYgDW-Medium texture, Yg, drought and wet conditions
MYpD-Medium textured soils, Yp, Drought conditions only
MYpDW-Medium textured soils, Yp, Drought and wet conditions
MYwD-Medium textured soils, Yw, Drought conditions only
MYwDW-Medium textured soils, Yw, Drought and wet conditions
NCEP-National Centres for Environmental Prediction
NDMC-National Drought Mitigation Center
NDVI-Normalized difference vegetation index
NESDIS- National Environmental Satellite, Data, and Information Service
NOAA- National Oceanic and Atmospheric Administration
PET-Potential evapotranspiration
RDI-Reconnaissance Drought index

ROI-Return on Investment
SPAM-Spatial Production Allocation Model
SPAW-Soil physical characteristics
SPI-Standardized Precipitation Index
TAGP-Total above ground production (dead and living plant organs) (kg. ha^{-1})
TCI-Temperature Condition Index
TSUM1- temperature sum from emergence to anthesis
TSUM2- temperature sum from anthesis to maturity
USGS- United States Geological Survey
VCI-Vegetation condition index
VHI-Vegetation health index
VTCI-Vegetation temperature condition index
WCC-WOFOST Control Centre
WISE-World Inventory of Soil Emission Potentials
WOFOST-World food studies
WSN-Water supply network
WWCS-Waste water collection system
WWTP-Waste water treatment plant
Yg-Yield gap
Yp-potential yield
Yw -Water-limited yield
4MJL-eRDIst calculated for 4months starting July
5MJL-eRDIst calculated for 5months starting July
5MJU-eRDIst calculated for 5months starting June
6MJU-eRDIst calculated for 6months starting June

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	Mr Ouedraogo (carrying a hand hoe and a hat) and his family, pearl millet farmer in Kouare village.
	Ms Adda (in yellow) interviewing female correspondents in Kouare village.
	Mr Omondi (in black coat on his knees) interviewing the male correspondent.
	Group photo with pearl millet farmers on Mr Kompaoré's farm.

CHAPTER 1. INTRODUCTION

1.1 Background Information

Historically, there are 12 drought events recorded in Burkina Faso between 1900 and 2013 (Masih, Maskey, Mussá, & Trambauer, 2014). These events impacted negatively on agricultural production but the severity is not clearly known. In order to make sound decisions on policies, focus of research agenda, development and investment plans, we can inform ourselves using the past in order to adequately plan for the future.

The great drought of 1983-1984 in the Volta Basin was the most severe and during which about 90% of the basin was affected (Kasei, Diekkrüger, & Leemhuis, 2010). In Burkina Faso, the dry seasons have become more frequent and occur in short intervals. Rainfall deficits and more droughts result in a drastic reduction of rain-fed agricultural production.

With the world's population projected to hit the 9.8 billion mark in 2050 and 11.2 billion by 2100 (United Nations, 2017) there is no doubt that agricultural production must increase in order to satisfy the exponentially increasing demand.

According to a statement issued by the Regional System for the Prevention and Management of Food Crises (PREGEC) in Ouagadougou, on 28th March 2018, cereal production in Burkina Faso shall decrease by 11.03 % for the 2017-2018 cropping season (CLISS, 2018).

Climate change increases the odds of worsening the drought situation but its impact on agriculture can be mitigated through sound planning and management. For the efficient management and planning for drought conditions, there is need to adequately characterize the drought and thus be able to describe the severity, identify the changes in frequency, magnitude, duration, and intensity of a drought event.

Using the case study of Gourma Province in Burkina Faso, this study seeks to determine the implication of the occurrence of drought on agriculture by scrutinizing the relationship between agricultural production and drought events from history and then use this information to suggest plans for adapting to these drought situations.

1.2 Problem Statement

Drought is a naturally occurring phenomenon during which there are long periods of consistently "below normal" supplies of natural water. The notion of "below normal" varies from one place to another and from one user to another. Drought is recurrent and each time it occurs, it affects human beings, livestock and crops.

Gourma province, lies within the Sudano-Sahelian region of west Africa which is known to have started experiencing meteorological droughts in the 1970s up to present (Agnew & Chappell, 1999).

Sahel region is said to be “one of the harshest climatic regions of the world, with low and highly variable rainfall, high soil and air temperatures, high evaporative demand, and poor soils” by Sivakumar, Wallace, Renard, & Giroux, (1991).

Both Lamb, (1995) and Winstanley, (1973), climatologists, observed a downward trend in rainfall in Sahel region while Agnew & Chappell, (1999) quoted FAO (11/5/1973) as having noted that “In some areas there now appears serious risk of imminent human famine and virtual extinction of herds vital to nomad populations” in the Sahel region.

Every drought event has an impact on Agriculture and characterizing them helps to scrutinise their impact on Agriculture. If another drought event occurred, it is vital to be aware of its start and end date and by how much will the agricultural yields reduce.

1.3 Justification

Droughts result in crop failure and death of human beings, animals and livestock. The economic impacts of prolonged droughts are dire and thus humans can choose to increase the impact of drought or to take measures to reduce them but what remains a fact is that Droughts are unpreventable. Historical drought conditions of a particular area are the major points of focus for purposes of drought analysis. Actually, drought analysis provides information needed for understanding the droughts in a given area and thus drought risk planning.

The benefits of Drought analysis and characterisation include: ability to evaluate risk of future droughts, determination of impacts of droughts on various sectors (economy, society and environment,) and the design of preparedness plans used for management of the anticipated impacts of drought events (Rossi, Benedini, Tsakiris, & Giakoumakis, 1992)

The scrutiny of rainfall departures from the norm as a method of analysing drought does not give the direct impact of drought and especially on Agriculture. By 1999, Agnew & Chappell, (1999) stated that the rainfall standardization period had moved from 1931-1960 to 1960-1990 and yet the drought impacts in the Sahel region were yet to be determined.

Today, the rainfall standardization period has shifted to 1981-2010 and to this day also, the impact of drought on Agriculture in Gourma province has not been established.

This study seeks to analyze agro-meteorological drought, establish its impact on Agriculture and propose sustainable policies for mitigating impacts of drought in the Sahel region. This will protect the farmers’ income and ensure food security in the region. In order to establish a pro-active approach to drought events, there is need to look at the past events and thus plan for the future.

1.4 Objectives

1.4.1 Main Objective

Analysis of Drought for water planning in Agriculture in Gourma province of Burkina Faso.

1.4.2 Specific Objectives

a) Characterisation of the drought in Gourma Province of Burkina Faso.

b) Demonstrate the implication of the occurrence of drought on agriculture

c) Critically analyse and identify options to mitigate a drought event

d) Make scientific and policy recommendations for the case of Gourma province.

1.5 Research Questions

What is the relationship between drought levels and agricultural crop-production?

How much does a farmer lose as a result of a drought event?

1.6 Scope and Limitations of the study

This study focuses on Gourma province in Burkina Faso which is just part of the Sahel region and Burkina Faso as a country. The impacts of drought on Agriculture as depicted by this study might not be the same throughout the Sahel region or in Burkina Faso.

Agriculture in Gourma province is predominantly rain-fed and subsistent. It is characterized by compound fields (from 1.5 to 12 ha per household). Crops grown under irrigation include fruit crops, sugar cane and vegetables. These practises vary from one place to another and therefore some assumptions have to be made in order to achieve objectives of this study. One assumption is that the crop management practices are same for majority of the farmers and also that the Yield Gap (Yg) is as a result of drought. There could be other factors such as soil fertility or management practices that influence the Yield Gap (Yg) but they are not the focus of this study and thus are not analysed.

1.7 Key definitions

The following are definitions of key terms used in this study as earlier defined by Evans, (1997) and M.K. van Ittersum & Rabbinge, (1997):

Yield potential (Yp):

Refers to the yield of a crop cultivar grown with water and biotic stresses effectively controlled and nutrients not limited. Under these conditions, the crop growth rate is thus influenced by: temperature, solar radiation, atmospheric CO_2 concentration, and genetic characteristics that determine length of growing period i.e. cultivar or hybrid maturity and light interception by the crop canopy i.e. canopy architecture.

Water-limited yield (Yw)

Refers to crop cultivar grown under conditions of limited water supply i.e rainfed crops and hence crop growth is influenced by soil type and field topography. Yw is used as benchmark for estimating yield gaps only for rainfed crops.

Yield gap (Yg)

Yield Gap (Yg) is the difference between Yield Potential (Yp) and water limited yield potentia (Yw).

Average actual yield (Ya)

Average yield (Ya) is defined as the average (of for instance the past 5 years for irrigated and 10 years for rainfed cropping systems) yield achieved by farmers in a given region under dominant management practices (sowing date, cultivar maturity, and plant density) and soil properties.

CHAPTER 2. LITERATURE REVIEW

2.1 Drought

Drought refers to an event during which supplies of water are ‘substantially below’ the usual levels of supply in a particular spatial and temporal resolution (Loucks & van Beek, 2005) In the Libyan coast, a drought occurs when total annual precipitation is less than 180 mm while in Bali, absence of precipitation in one week is considered a drought. Thus, it’s difficult to consistently define drought.

Other researchers such as (Vogt & Somma, 2000) also defined drought as a casual (random) condition of "severe reduction" of water availability compared to the normal values extending along a "significant period" of time over a "large region" unlike aridity, which refers to a permanent climatic condition with very low annual or seasonal rainfall. They further define desertification as an indication of an irreversible process of decrease or destruction of biological soil potential fostered by several factors (soil properties, climate and human activities) and drought might accelerate the process.

2.1.1 Drought causes

According to Loucks & van Beek, (2005), global patterns such as El Niño/Southern Oscillation (ENSO) cycles influence the occurrence of droughts and floods. These global patters are as a result of Ocean currents and winds that shift off the western coast of South America every two to seven years. Warm water is carried westward by these currents and end up displacing nutrient-rich cold water that normally wells up from deep in the ocean. This phenomenon peaks in Christmas period and was named *El Niño* (‘the Christ Child’ or the little boy) by fishermen. Impacts of these cycles are the El Niño and La Nina. ENSO cycles cause the subsidence of air masses resulting in high pressure that inhibits cloud formation and thus less precipitation and low relative humidity.

2.1.2 Drought indicators and indices

According to Svoboda & Fuchs, (2017), **Indicators** – refer to parameters or variables used to describe drought conditions such as; groundwater and reservoir levels, temperature, soil moisture and snowpack, precipitation and streamflow while **Indices** – refers to numerically computed representations of drought characteristics using climatic or hydro-meteorological inputs such as the indicators.

2.1.3 Basic drought types and measurement methods

Figure 1 below depicts the common drought types and their sequence of occurrence. Clearly, insufficient precipitation is the cause of all the other drought types (NDMC)

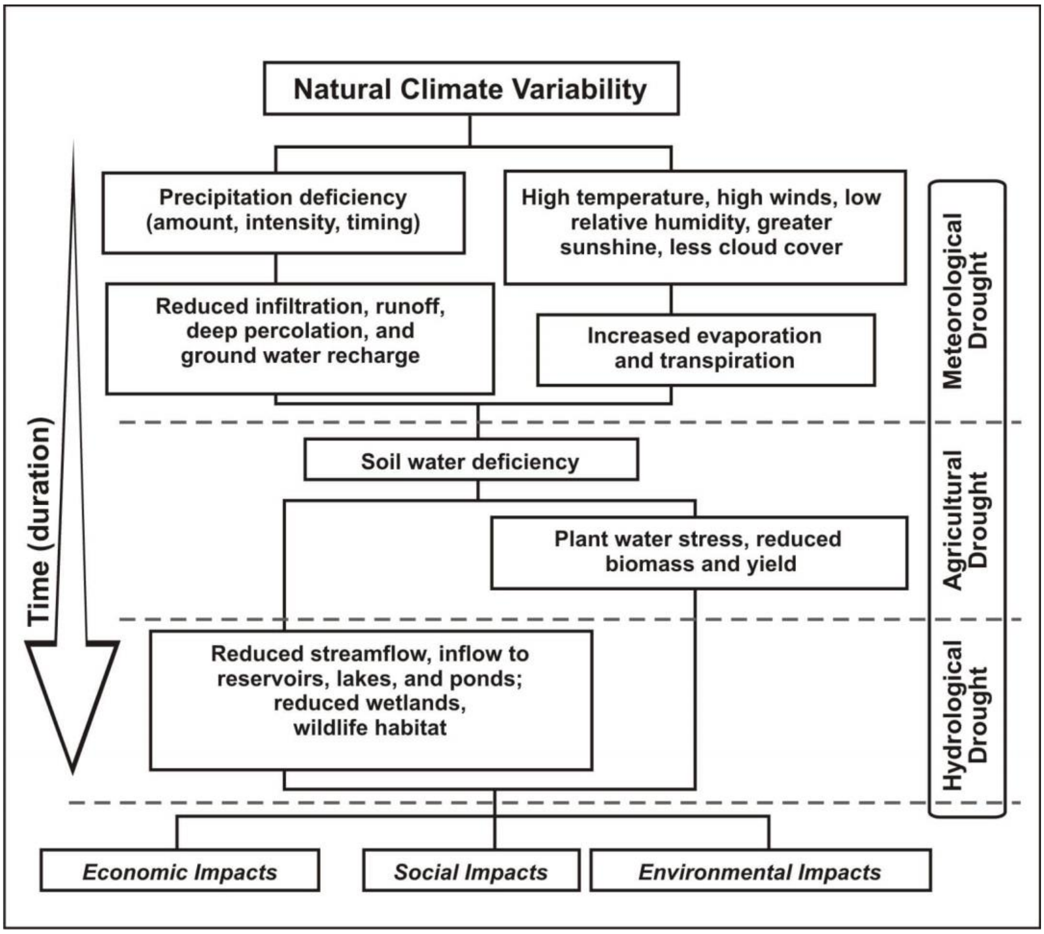


Figure 1: Drought types
Source: (NDMC, 2013)

Drought reduces agricultural yield directly in rain fed agriculture while in irrigated agriculture, the severity of the impacts may vary depending on several factors, such as the available infrastructure and the initial hydrological conditions. Drought affects plants due to high temperatures which increase crop water needs due to the higher evapotranspiration and to potential temperature stress during critical plant development stages.

2.1.3.1 Meteorological drought

Meteorological drought is defined on the basis of the degree of dryness (in comparison to some “normal” or average amount) and the duration of the dry period. In this definition, drought is considered to be region specific because the below “normal” precipitation results from atmospheric conditions that vary from one region to another (Wilhite & Glantz, 2009).

Meteorological drought can be mesured using indices such as Deciles, Percent of Normal Precipitation and Standardized Precipitation Index (SPI).

Meteorological drought can also be analysed by using the Reconnaissance Drought index (RDI) (Tigkas, Vangelis, & Tsakiris, 2016) as well as the effective Reconnaissance Drought Index (eRDI) which is a modification of RDI aimed at improving its ability to assess agricultural drought (Dimitris Tigkas, Vangelis, & Tsakiris, 2017).

2.1.3.2 Agricultural Drought

Conventionally, the gravity of drought impacts on crops, considering the susceptibility of the plants to the meteorological and hydrological conditions, is referred to as agricultural drought (Dimitris Tigkas et al., 2017).

Agricultural drought takes the differences between actual and potential evapotranspiration, precipitation shortages, reduced groundwater or reservoir levels and soil water deficits into consideration while developing a relationship with meteorological and hydrological droughts. When defining agricultural drought, the fact that susceptibility of crops varies with growth stages is considered. If at planting the topsoil has insufficient moisture, germination is impeded but if topsoil moisture is sufficient and subsoil moisture is insufficient at plating, then germination will still proceed. This changes as plant grows to maturity. Agricultural drought can be mesured using indices such as Crop-specific Drought Index (CSDI) and Soil Moisture Deficit Index (SMDI).

2.1.3.3 Hydrological Drought

Hydrological drought is related to impact of frequency and severity of precipitation (including snowfall) shortfalls on surface or subsurface water supply (i.e., streamflow, reservoir and lake levels, groundwater) mostly at a watershed or river basin level.

Hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts. Precipitation deficiencies take longer to affect the components of the hydrological system such as soil moisture, streamflow, groundwater and reservoir levels. The lagging effect is transferred to the economic sector as well i.e. inadequate precipitation may result in insufficient soil moisture but this doesn’t immediately translate to low reservoir water levels and may not affect hydroelectric power production for some time. Hydrological drought can be mesured using indices such as Palmer Hydrological Drought Severity Index (PHDI) and Standardized Streamflow Index (SSFI).

2.1.4 Drought Indices Calculator (DrinC)

DrinC (Drought Indices Calculator) is a computer software package designed to facilitate the calculation of drought indices which are used for Drought analysis.

The intricacy of comprehending Drought as a phenomenon leaves us with its severity, duration and areal extent as the main ways of characterizing it. For drought analysis, drought severity is the key characteristic used (Dimitris Tigkas & Tsakiris, 2015).

DrinC can be used for the calculation of:

1. Reconnaissance Drought Index (RDI)
2. Streamflow Drought Index (SDI)
3. Standardized Precipitation Index (SPI)
4. Precipitation Deciles (PD)

DrinC can also estimate potential evapotranspiration (PET) using temperature-based methods (Hargreaves, Thornwaite and Blaney-cridle), used in the calculation of RDI.

Applications of DrinC include:

1. Drought monitoring
2. Investigation of climatic and drought scenarios.
3. Assessment of the spatial distribution of drought

Required input data for DrinC per index are as shown in the table 2.1 below:

Table 2.1: DrinC Input Data Requirements

Index	Required Input Data
Deciles	Precipitation
RDI	Precipitation, PET (or temperature)
SPI	Precipitation
SDI	Streamflow

Source: (Dimitris Tigkas, Vangelis, & Tsakiris, 2015)

2.1.5 Reconnaissance Drought Index

The Reconnaissance Drought Index (RDI) has been used in Greece by Tigkas et al to characterise drought. Tigkas et al expressed RDI in three forms; Initial form, Normalised expression and Standardised form. Equations 1, 2 and 3 were used by D Tigkas, (2008) in their studies. They determined the initial form of the index ($a_k^{(i)}$) for a particular i-th year and for a reference period of k months using equation 1:

Equation 1: Initial form of RDI

$$a_k^{(i)} = \frac{\sum_{j=1}^{j=k} P_{ij}}{\sum_{j=1}^{j=k} PET_{ij}}, i = 1(1)N \ and \ j = 1(1)k$$

Where:

k – reference period
P_{ij} – total precipitation of j^{th} month of the i-th year
PET_{ij} – Potential Evapotranspiration of j^{th} month of the i-th year
N – total number of years of available data

The values of ($a_k^{(i)}$) are said to sufficiently fit both the gamma and lognormal distributions for majority of the locations and time scales for which they were tested but in most cases, the gamma distribution gave better results (Tsakiris, Nalbantis, Pangalou, Tigkas, & Vangelis, 2008). The PET can be calculated using Hargreaves, Thornwaite or Blaney-cridle method but according to Vangelis, Tigkas, & Tsakiris, (2013), the method of calculation of PET, seems to have no impact on results of RDI.

The second form of Reconnaissance Drought Index which is a normalised expression of the index (RDI_n), was calculated by equation 2 below:

Equation 2: Normalised expression of RDIn

$$RDI_n(k) = \frac{a_k}{\bar{a}_k} - 1$$

Where $\bar{a}_k$ is the long-term average of a_k.

Tsakiris & Vangelis, (2005) assumed that the values of a_k follow the log-normal distribution, and determined the standardised form of the index (RDI_{st}) by equation 3 as shown below:

Equation 3: Standardized form of RDIst

$$RDI_{st}(k) = \frac{y_k - \bar{y}_k}{\hat{\sigma}_k^k}$$

Where: y_k is equal to $\ln(a_k)$, while $\bar{y}_k$ is its average and $\hat{\sigma}_k^k$ is its standard deviation, respectively.

Tigkas et al noted that the above approach for the calculation of RDI_{st} cannot be used in case of zero precipitation sums ($a_k = 0$) and thus other methods were proposed by Tsakiris et al., (2008).

Since the gamma distribution gave better results in most places and times in Greece according to Tsakiris et al., (2008), it was noted that the calculation of RDI_{st} is best done by fitting the gamma probability density function (pdf) to the frequency distribution of a_k. This approach also solved the problem of zero precipitation sums ($a_k = 0$) over short periods which is the norm in arid and semi-arid areas and hence it is possible to evaluate RDI_{st}. The gamma probability density function is defined as in equation 4 below:

Equation 4: Gamma probability density function

$$g(x) = \frac{1}{\beta^{\gamma}\Gamma(\gamma)} x^{\gamma-1} e^{-x/\beta}, for\ x > 0$$

Where:

γ – is the shape parameter
β – is the scale parameter
x - is the precipitation amount
Γ(γ) - is the gamma function.

The parameters γ and β vary spatially and temporally and are estimated by equations 5:

Equation 5: Equations for determination of γ and β

$$\gamma = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \beta = \frac{\bar{X}}{\gamma}\ , where\ A = ln(\bar{x}) - \frac{\sum \ln(x)}{n}$$

n = number of observations

When the γ and β parameters are determined, it is also possible to establish the cumulative probability of a_k.for a given time and place which is given by equation 6 below:

Equation 6: Equation of cumulative probability of a_k

$$H(x) = q + (1 - q)G(x)$$

Where:

q - is the probability of zero precipitation
G(x) is the cumulative probability of the incomplete gamma function.

Thus, q can be evaluated by m/n if m is the number of zeros in an α_k time series enabling the transformation of the cumulative probability H(x) into the standard normal random variable z with variance of one and mean of zero which is the value of RDI_{st}. D Tigkas, (2008) characterised drought in Greece using drought severity classes based on the RDI_{st} values, as described in Table 2.2 below.

Table 2.2: Drought characterisation based on RDI values

RDI_{st} value	**Drought class**
> 2.00	Extremely humid
1.50 to 1.99	Severely humid
1.00 to 1.49	Moderately humid
-0.49 to 0.99	Normal conditions
-0.99 to -0.50	Mild drought
-1.49 to -1.00	Moderate drought
-1.99 to -1.50	Severe drought
< -2	Extreme drought

Tsakiris & Vangelis, (2005) had proposed the calculation of the original RDI on hydrological year basis, i.e., using reference periods starting from the first month of the hydrological year (typically October for Mediterranean conditions). This approach leads to a rational assessment of water deficits, useful in hydrological applications, early-warning systems and drought monitoring (D Tigkas, 2008).

Tigkas also argued that agricultural drought is mostly associated to the crop development period rather than to the hydrological year period. Further, each crop may be more vulnerable to drought episodes during specific development stages, depending also on the climate of the region and other environmental factors. Therefore, the selection of the appropriate reference periods for the calculation of eRDI should take into account the above considerations.

A principal criterion for this selection is the aim of each drought analysis. For instance, if the objective is to have an overall assessment of agricultural drought in a region, it is recommended to focus on the major crop of the area (Kumar & Panu, 1997). In case of agricultural drought monitoring or if an early estimation of drought impacts is attempted, the selected reference periods can use the month of seeding as the base (or the previous month, if the level of soil moisture is critical for germination) and evolve from this starting point to 1-month, 2-month, etc. periods.

Emphasising on reference periods corresponding to critical development stages of the plants could also provide interesting insights supporting early warning systems. However, if the objective is a post-event impact evaluation (e.g., to establish drought relief measures), the ideal is to select the reference period that corresponds to the entire crop development period (Dimitris Tigkas & Tsakiris, 2015).

2.1.6 The Effective Reconnaissance Drought Index (eRDI)

It is a modification of the RDI proposed by Dimitris Tigkas, Vangelis, & Tsakiris, (2016) whereby the total precipitation is replaced by effective precipitation in order to represent more precisely the amount of water that is productively used by the crop.

2.1.6.1 Estimation of Effective Precipitation (P_e)

Patwardhan, Nieber, & Johns, (1990) argued that the definition of effective precipitation (P_e) is always defined based on the objectives of a particular study. It could be the percentage of the precipitation that contributes to groundwater recharge, the total amount of the precipitation that enters into a reservoir or the amount of water that can be used productively by the root system in contributing to plant development.

For the purposes of this research Pe is considered as a factor that contributes to agricultural production. Therefore, Pe is considered as the part of total precipitation that contributes directly or indirectly to crop development. Effective precipitation (P_e) is the portion of total precipitation that is available to be consumed directly or indirectly for crop development. Soil water storage in the root zone is defined as below:

Equation 7: Expression of soil water storage in root zone

$$\Delta V = P + IR - (I + Q + ET + DP)$$

Where:

ΔV - is the change of soil water in the root zone
P - is the precipitation
IR - is the irrigation water depth
I - represents the interception losses
Q - is the runoff
ET - is the evapotranspiration and
DP - is the deep percolation.
*All units are expressed in mm and refer to a time period of Δt.

The Pe is defined as the percentage of the total precipitation that enters into the soil (root zone), but it is not lost due to deep percolation (Patwardhan et al., 1990):

Equation 8: Effective precipitation (Pe) equation

$$P_e = P - (I + Q + DP)$$

Portion of total P that becomes Pe depends on many factors based on local conditions and characteristics, topography, main soil types, etc. Food and Agriculture Organisation (FAO) has proposed the below method for the estimation of Pe (Brouwer & Heibloem, 1986):

Equation 9: Equation of Estimation of Pe suggested by FAO

$$\left\{ \begin{array}{ll} P_e = 0 & \text{for } P \leq 17mm \\ P_e = 0.6 \cdot P\text{-}10 & \text{for } 17\text{mm} < P \leq 70mm \\ P_e = 0.8 \cdot P\text{-}25 & \text{for } P > 70mm \end{array} \right\}$$

The method below in equation 10 was suggested by U.S. Bureau of Reclamation (USBR) and is said to be suitable for arid and semi-arid areas (Dimitris Tigkas et al., 2017):

Equation 10: USBR equation for estimation of Pe

$$\left\{ \begin{array}{ll} P_e = P \cdot (125\text{-}0.2 \cdot P) \big/ 125 & \text{for } P \leq 250\ mm \\ P_e = 0.1 \cdot P + 125 & \text{for } P > 250\ mm \end{array} \right\}$$

The above equations translate to the graph given below in figure 2

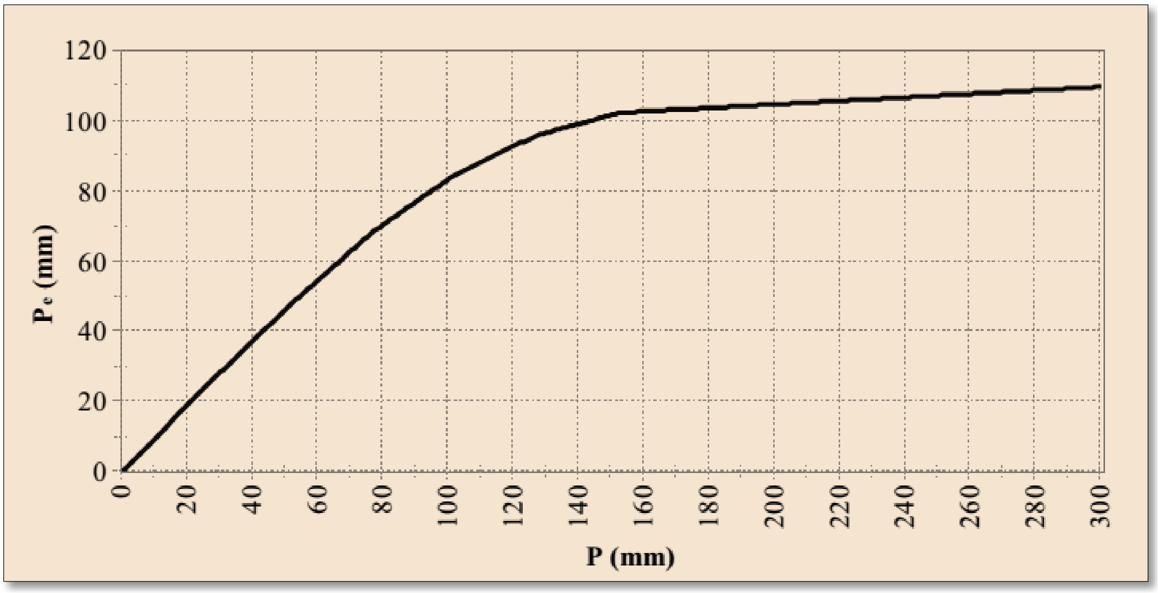


Figure 2: USBR graph of monthly Pe

2.1.6.2 Effective Reconnaissance Index (eRDI)

Dimitris Tigkas et al., (2017) determined the modified initial form of the index (α_e) as shown:

Equation 11: Effective Reconnaissance Index (eRDI) equation

$$a_{e(k)} = \frac{\sum_{j=1}^{j=k} P_{ej}}{\sum_{j=1}^{j=k} PET_j}$$

in which P_{ej} is the monthly effective precipitation of the jth month.

For the above formula, Dimitris Tigkas et al., (2017) stressed that the estimation of P_e is always based on the respective monthly values of total precipitation and not on the values of the entire reference period that is used. The normalised (eRDIn) and the standardised (eRDIst) forms of the eRDI are calculated and characterised with similar procedures, as of the RDI.

2.1.7 Remote sensing and Agricultural Drought

In Indonesia and other parts of the world, the Vegetative Health Index has been used to spatially characterise drought (Sholihah et al., 2016). Traditional drought analysis and monitoring methods in the entire world are based on precipitation, temperature, and soil moisture data collected from meteorological stations. The coarse spatial resolution of these stations and incomplete data coverage on a temporal scale pose a great challenge with these methods. Traditional methods don’t monitor drought accurately and in timely fashion.

Remote sensing offers a synoptic view of the earth surface and ability to spatially and temporally analyse drought in vast areas. Continuous spatial and temporal data which can be provided by remote sensing are therefore key to drought monitoring (Sholihah et al., 2016).

Some of the existing sensors are shown in the table 2.3 below:

Table 2.3: Examples of remote sensors and conveyor satellites

Remote Sensor	Conveyor Satellite (s)
1. MODIS - Moderate Resolution Imaging Spectroradiometer	1. TERRA and AQUA satellites
2. AVHRR - Advanced Very High-Resolution Radiometer	2. National Oceanic Atmospheric Administration (NOAA) satellites
3. Vegetation sensor (VGT)	3. Satellite Pour l'Observation de la Terre (SPOT)

From remotely sensed data, it is possible to characterise a drought event by establishing its duration, severity, intensity and spatial extent. The above examples of sensors have been used for drought monitoring at large scale (Kogan, 2001). Some of the indices that can be derived from remotely sensed data include:

1. NDVI-Normalized difference vegetation index
2. VHI-Vegetation health index
3. LST-Land surface temperature
4. VCI-Vegetation condition index
5. CWSI-Crop water stress index
6. VTCI-Vegetation temperature condition index

According to Bhuiyan, Singh, & Kogan, (2006) and Choi, Jacobs, Anderson, & Bosch, (2013), VHI showed a better ability to detect drought as compared to other vegetative drought indices. VHI combines VCI and TCI for a given time series and location. MODIS data that consists of Enhanced Vegetation Index (EVI) and Land Surface Temperature (LST), have been used by Sholihah et al., (2016) to calculate VCI and TCI, respectively.

In Indonesia, time series data of the appropriate target periods (1998-2015) were used to calculate the minimum and maximum values of VCI and TCI. The calculation of Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) was done using the equations 12-14 below:

Equation 12: Vegetation Condition Index (VCI) equation

$$VCI = 100 \times \frac{E - E_{min}}{E_{max} - E_{min}}$$

where E is EVI value of a given month. Emin and Emax denote the maximum and minimum EVI values, respectively, for the month from multiyear time series.

Equation 13: Temperature Condition Index (TCI) equation

$$TCI = \frac{L_{max} - L}{L_{max} - L_{min}}$$

where L is LST value of a given month. Lmin and Lmax denote the maximum and minimum LST values, respectively, for the month from multiyear time series. VHI are calculated based on VCI and TCI value using equation below.

Equation 14: Vegetation Health Index (VHI) equation

$$VHI = (0.5 \times VCI) + (0.5 \times TCI)$$

2.2 Crop modelling

According to Oteng-Darko et al, (2013), modeling is the general use of one or more equations individually or combined for the purpose of mimicking a system and goes further to describe Crop Modelling as use of computer programmes to mimic the growth and development of crops. Mimickry of growth and development of crops takes into account the plant components i.e leaves, roots, stems and grains. The models mimic the reactions and interactions between tissues and organs and finally it is able to predict crop yields. Some of the modelling softwares available include WOFOST and DSSAT.

Table 2.4: Desired attributes of crop models

Desired attribute	Explanation
Daily step simulation	Simulation of daily crop growth and development based on weather, soil, and crop physiological attributes
Flexibility to simulate management practices	Key management practices include: sowing date, plant density, cultivar maturity
Simulation of fundamental physiological processes	Simulation of key physiological processes such as crop development, net carbon assimilation, biomass partitioning, crop water relations, and grain growth
Crop specificity	Should reflect crop-specific physiological attributes for respiration and photosynthesis, critical stages and growth periods that define vegetative and grain filling periods, and canopy architecture
Minimum requirement of crop ‘genetic’ coefficients	The model should have a low requirement of crop-site ‘genetic’ coefficients, preferably only a limited number of phenological coefficients
Validation against data from field crops that approach Yp and Yw	Comparison of model outcomes (grain yield, aboveground dry matter, crop evapotranspiration) against actual measured data from field crops that received management practices conducive to achieve Yp (irrigated) or Yw (rainfed crops)
User friendly	Models embedded in user-friendly interfaces, where required data inputs and outputs can be easily visualized, and with flexibility to modify default values for internal parameters
Full documentation of model parameterization and availability	Publicly available models, published in the peer-review literature, with full documentation and publicly available code, and with reference to data sources for internal parameter values

Source: (Martin K. Van Ittersum et al., 2013)

2.2.1 Decision Support System for Agro- Technology Transfer-DSSAT

Developed by the International Benchmark Sites Network for Agro-technology Transfer-IBSNAT starting in 1982.DSSAT has been used for both research and teaching and has reduced the challenges posed by traditional agronomic experiments which are conducted at specific points in time and space, making their results site- and season-specific, time consuming and expensive.

The necessity to combine soil, climate, crop and management knowledge for sound decision making in production technology transfer between locations with different soils and climate was the key driver of the development of DSSAT (Tsuji, Hoogenboom, & Thornton, 1998)

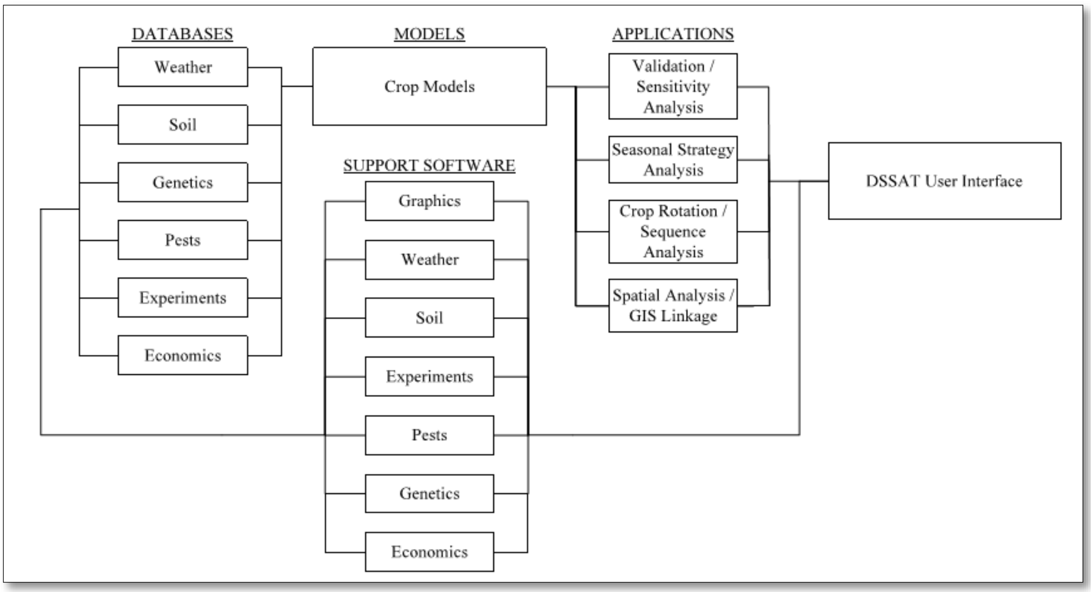


Figure 3: DSAAT model conceptual framework
Source: (Jones J.W. et al, 2003)

It consists of data base management system for soil, weather, genetic coefficients, management inputs, Crop simulation models, series of utility and weather generation programs and strategy evaluation program to evaluate options including choice of variety, planting date, plant population density, row spacing, soil type, irrigation, fertilizer application, initial conditions on yields, water stress in the vegetative or reproductive stages of development, and net returns.

According to Jones J.W. et al, (2003), the core of DSSAT is the DSSAT-CSM which is a cropping system model using a single soil model to incorporate all crops as modules. This is achieved by incorporating all crop models in one set of code. DSSAT-CSM has the following key functions:

1. Simulation of single crop production systems by considering: soil carbon, nitrogen, management, genetics, weather and soil water in single or multiple seasons.
2. Avail an environment for incorporation of biotic and abiotic factors like soil phosphorus and plant diseases.
3. Platform enabling users to make comparisons of modules
4. Create possibility of introducing CSM into other programmes in a modular and well documented way.

DSSAT has helped in reducing the time and cost of field experiments and evaluation of new cultivars and management systems has been made easy.

2.2.1.1 Model evaluation and testing

Evaluation involves comparing simulated results and observed data and determining the model’s suitability (accuracy) for a specific purpose. To carry out evaluation, minimum requirements include: all data required to operate the model and observed data on the aspects for which the model is being validated. The data must be different from the ones used for calibration and be representative of the target area (Jones J.W. et al, 2003)

2.2.1.2 Data requirements

The minimum data requirements for operation and evaluation of the DSSAT models include data on: site, weather, soil, initial conditions and Management practices. The detailed list is as shown in Table 2.5 below.

2.2.1.3 Limitations of DSSAT

DSSAT-CSM was created by bringing together CERES-maize model, SOYGRO-soybean model and PNUTGRO-peanut model amongst others under one platform and to achieve this, original codes for the pre-existing models were modified in order to incorporate all the models in one new platform (DSSAT-CSM). Code modifications are done for every release of a new version and it affects the consistency of the models. To solve this problem, DSSAT developed a software which automatically compares results between various versions of the DSSAT models and further modifications are made to the code and updates released. Despite this challenge, DSSAT has been used in Africa, North-South-Cenral America, Asia and Europe for Yield forecasting, Climate Variability studies and Education (Jones J.W. et al, 2003)

Table 2.5: DSSAT-CSM Data Requirements

(a) For operation of model	
Site	Latitude and longitude, elevation; average annual temperature; average annual amplitude in temperature Slope and aspect; major obstruction to the sun (e.g. nearby mountain); drainage (type, spacing and depth); surface stones (coverage and size)
Weather	Daily global solar radiation, maximum and minimum air temperatures, precipitation
Soil	Classification using the local system and (to family level) the USDA-NRCS taxonomic system Basic profile characteristics by soil layer: in situ water release curve characteristics (saturated drained upper limit, lower limit); bulk density, organic carbon; pH; root growth factor; drainage coefficient
Initial conditions	Previous crop, root, and nodule amounts; numbers and effectiveness of rhizobia (nodulating crop) Water, ammonium and nitrate by soil layer
Management	Cultivar name and type Planting date, depth and method; row spacing and direction; plant population Irrigation and water management, dates, methods and amounts or depths Fertilizer (inorganic) and inoculant applications Residue (organic fertilizer) applications (material, depth of incorporation, amount and nutrient concentrations) Tillage Environment (aerial) adjustments Harvest schedule
(b) For evaluation of models	
	Date of emergence Date of flowering or pollination (where appropriate) Date of onset of bulking in vegetative storage organ (where appropriate) Date of physiological maturity LAI and canopy dry weight at three stages during the life cycle Canopy height and breadth at maturity Yield of appropriate economic unit (e.g. kernels) in dry weight terms Canopy (above ground) dry weight to harvest index (plus shelling percentage for legumes) Harvest product individual dry weight (e.g. weight per grain, weight per tuber) Harvest product number per unit at maturity (e.g. seeds per spike, seeds per pod) Harvest product number per unit at maturity (e.g. seeds per spike, seeds per pod) Soil water measurements vs. time at selected depth intervals Soil nitrogen measurements vs. time Soil C measurements vs. time, for long-term experiments Damage level of pest (disease, weeds, etc.) infestation (recorded when infestation first noted, and at maximum) Number of leaves produced on the main stem N percentage of economic unit N percentage of non-economic parts

2.2.2 WOFOST

WOFOST version 7.1.7 was developed in Wageningen by the Wageningen University & Research Centre. According to Laar, Diepen, Rötter, Cabrera, & Van, (2014), it is a computer model that simulates the growth and production of annual field crops. Simulations can be setup and run through its GUI-Graphical user interface called the WOFOST Control Centre version 2.1 (WCC). WCC enables a user to select the production level, and input data sets on crop, soil, weather, crop calendar, hydrological field conditions, soil fertility parameters and choose the output options.

2.2.2.1 Theoretical background of WOFOST

WOFOST simulates an annual crop that is growing in a specific physical environment through the approach of Systems, Models and Simulations (Laar et al., 2014). A system refers to a finite section of the real world that accommodates reticulate components while a model implies a comprehensible depiction of the system and Simulation is the developing of numerical models and the analysis of their performance in reference to the system they mimic (Rabbinge & De Wit, 1989).

According to Laar et al., (2014), models can be broadly classified into:

1. Mathematical models
    a. Descriptive Models
        i. Statistical Models
        ii. Stochastic Models
    b. Explanatory Models
        i. Deterministic Models
        ii. Process Models
2. Non-Mathematical Models e.g Maps and Scale Models of Buildings.
3. Dynamic Models – include time as a variable
4. Static Models – Do not include time as a variable

Descriptive Models: use the analysis of statistical relatonships between studied variables in a system without delving much into the processess in the system to mimic the system behaviour in a simple manner.

Explanatory model: quantitatively describe the key processes in a system. Interrelation between the processess exists within these models and is based on the understanding of how they relate. For example, the low-level processes like photosynthesis-light response curve of a single leaf is connected to higher level processes such as crop growth to expalin system behaviour.

As much as there are processes in WOFOST that are descriptive and/or static, it can be classified as a **Dynamic-Explanatory Model** i.e it simulates crop growth on daily time steps based on the understanding of the low level interartions at the plant level.

WOFOST employs the State-Rate Variable approach assuming that its possible to quantify the state of a system at any moment and that any changes in the system can be described by mathematical equations. To understand this type of system, there are three key variables:

1. **State Variables:** measurable quantities e.g biomass or soil water
2. **Driving Variables:** define the impact of external factors such as weather on the system and include macro-meteorological variables such as air temperature, radiation and precipitation.
3. **Rate variables:** denote the frequency at which the state variables are varying.

By rectangular numerical integration, the equation 15 below is used to calculate new values of state variables after calculating the values of rate variables.

Equation 15: State equation

$$STATE(t+\Delta t) = STATE(t) + RATE(t).\Delta t$$

Where:

$STATE(t+\Delta t)$: *New state of variable*
$STATE(t)$:*Initial state of variable*
$RATE(t).\Delta t$: *Change in the state of variable*

State variables and driving variables at time (t+Δt) are used to determine rate vaeiables at time (t+Δt) which are inturn used to calculate state variables at time (t+2Δt). In WOFOST and many other models, Δt is taken to be one day. Rate is thus calculated according to equation 16 below:

Equation 16: Rate equation

$$RATE(t) = STATE\ (t) \times constatnt$$

Where:

$RATE(t)$: *Rate at time t*
$STATE(t)$: *State at time t*

Based on eco-physiological processes such as phenological development, light interception, CO_2-assimilation, transpiration, respiration, partitioning of assimilates to the various organs, and dry matter formation, WOFOST simulates crop growth as depicted in figure 4 below.

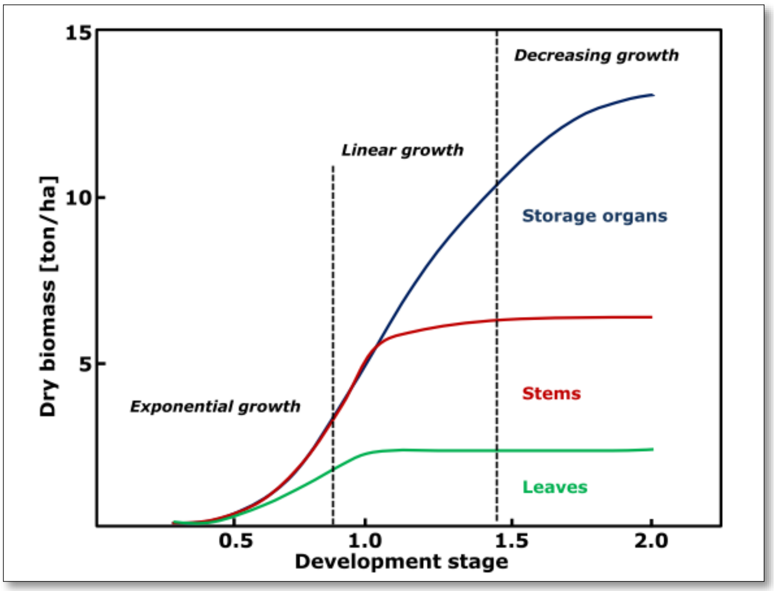


Figure 4: WOFOST model simulations
Source: (Laar et al., 2014)

2.2.2.2 Limitations of WOFOST

WOFOST is just a model and like any other model, the quality of the output is entirely dependent on the input data. Thus best quality data should always be used for modelling. A model merely elucidates the consequences of the users opinions and data.

Experimentation is very important for cropgrowth modelling as we obtain specific parameter values used to calibrate and validate the model outcomes.

During validation, we compare observed data versus simulated results and tune the parameters whenever there are differences inorder to make the results similar but we also use independent set of observations to again check the model. While doing all these, there are three main issues that arise:

1. There are many parameters in the model but only a few can be validated at a time.
2. Calibration improves the model results but compromises the models aplicability(spatially and temporally).
3. Some parameters are fixed while in reality they are known to vary e.g those concerning the relationship between development stage and partitioning (Laar et al., 2014) This problem arises when the processes at a lower integration level are insufficiently known.

2.2.2.3 WOFOST Control Center – WCC

This is the Graphical User Interface of WOFOST that enables one to edit and view the input data for WOFOST, run WOFOST, and view and analyse the output data in table or in graphical form.

2.2.2.4 Input data for WOFOST

WCC provides a graphical user interface with the following tabs: General, Crop, Weather, Timer, Soil, Nutrients and Reruns for loading input data. In order to load input data for a particular study area that is currently not in WCC database, one has to prepare the files outside and store them in the correct directories within WCC.

General Data: allows a user to select simulating Potential crop growth, water limited crop growth or nutrient-limited crop growth depending on objectives.

Weather Data: Data from the appropriate weather station i.e weather station within thae study area should be used in WOFOST. The data includes: dates, irradiation (kJ m^{-2} d^{-1}), minimum temperature (degrees Celsius), maximum temperature (degrees Celsius), vapour pressure (kPa), mean wind speed (m s^{-1}), precipitation (mm d^{-1}). This files are stored in the WCC under folder named METEO and can be loaded into WOFOST for simulations.

Timer Data: Timer data needed by WCC includes: start of the simulation, the number of years to simulate and the options for starting and ending the crop.

Soil Data: the physical soil characteristics of the study area are to be loaded as a .NEW file from the SOIL Directory. The physical characteristics are listed in the table 2.6 below:

Table 2.6: WOFOST model Soil data requirements

Soil water retention Data	**Hydraulic conductivity Data**	**Soil workability parameters**
1.Vol. Of soil moisture content as a funtion of pf [log (cm); cm^3 cm^{-3}]	1.10-log hydraulic conductivity as function of pf [log (cm); log (cm/day)]	1.1st topsoil seepage parameter deep seedbed
2.Soil moisture content at wilting point [cm^3/cm^3]	2.Hydraulic conductivity of saturated soil [cm day^{-1}]	2.2nd topsoil seepage parameter deep seedbed
3.Soil moisture content at field capacity [cm^3/cm^3]	3.Maximum percolation rate root zone[cm day^{-1}]	3.1st topsoil seepage parameter shallow seedbed
4.Soil moisture content at saturation [cm^3/cm^3]	4.Maximum percolation rate subsoil [cm day^{-1}]	4.2nd topsoil seepage parameter shallow seedbed
5.Critical soil air content for aeration [cm^3/cm^3]		5.Required moisture deficit deep seedbed

Crop Data:

Table 2.7: Crop Data Requirements

Crop Emergence Temperature Data (^{O}C)	**Phenological Data**	**Initial Crop conditions Data**	**Green Area Data**	**CO$_2$ Assimilation Data**	**Assimilates Conversion into Biomass**	**Partitioning Data**	**Death Rates Data**	**Water use Data**	**Rooting Data**	**Nutrients data**
1.Lower threshold temperatures for emergence	1.Whether pre-anthesis depends on temperature	1.Initial total crop dry weight (Kg/ha)	1.Specific leaf area (ha/Kg)	1.Extinction coefficient for diffuse visible light	1.Efficiency of conversion into leaves (Kg/Kg)	1.Fraction of dry matter to roots (Kg/Kg)	1.Max. death rate of leaves (Kg/Kg/d)	1.Correction factor transpiration rate	1.Initial rooting depth (cm)	1.Max. and Min. conc. of Nitrogen (N)
2.Max. effective temperatures for emergence	2.Optimum daylenth for development (hr)	2.Leaf Area Index (LAI)at emergence (ha/ha)	2.Specific pod area (ha/Kg)	2.Max. Leaf CO$_2$ assimilation rate	2.Efficiency of conversion into storage organs (Kg/Kg)	2.Fraction of dry matter to leaves (Kg/Kg)	2.Max. death rate of roots (Kg/Kg/d)	2.Crop growth number for soil water depletion	2.Rooting depth max increase (cm/d)	2.Max. and Min. conc. of Potassium (K)
3.Temperature sum from sowing to emergence	3.Critical daylenth for development (hr)	3.Max. Relative increase in LAI (ha/ha/d)	3.Specific stem area (ha/Kg)		3.Efficiency of conversion into stems (Kg/Kg)	3.Fraction of dry matter to stems (Kg/Kg)	3.Max. death rate of stems (Kg/Kg/d)	3.Air ducts present in roots	3.Max. rooting depth (cm)	3.Max. and Min. conc.of Phosphorus (P)
	4.Temperature sum from emergence to anthesis		4.Lifespan of leaves growing at 35^{o}C		4.Efficiency of conversion into roots (Kg/Kg)	4.Fraction of dry matter to storage organs (Kg/Kg)				
	5.Temperature sum from anthesis to maturity		5.Min.Temperature for ageing leaves							
	6.Daily increase in Teperature									
	7.Initial Development stage									
	5.Development stage at harvest									

Nutrients Data: as explained in Laar et al., (2014), Data required by WCC is generally on the fertility of the soil. WCC uses data on how much nutrients the soil can provide a plant without fertilizer use in order to simulate the nutrient-limited growth. The amount of nutrient in unfertilized soil that is potentially available for uptake by a standard crop in a growing season of 120 days is refferred to as the **Basic Soil Supply.**

Table 2.8: WOFOST Soil Nutrient data requirements

Basic Soil Supply Data (0-100Kg/ha)	**Apparent Recovery Fraction (0-1)**
1.Nitrogen (N)	1.Nitrogen (N)
2.Phosphorus (P)	2.Phosphorus (P)
3.Potassium (K)	3.Potassium (K)

Reruns Data: the tab provides user with a chance to change input variables and make several runs in WCC. This is useful in studying the impact of various variables on crop growth.

Assessment of crop production potential is arrived at by determining potential yield and water limited yields as the benchmarks for crop prodcution under irrigated and rainfed conditions respectively. Yield Gaps are thus determined from the difference between theoritical yields and actual yields. Knowledge of the spatial distribution of the gaps informs decision making on policy, research, development and investment that aim to affect future crop yield and land use, and to inform on-ground action by local farmers through their knowledge networks (Martin K. Van Ittersum et al., 2013)

2.3 Mitigation strategies of drought impacts

According to Vogt & Somma, (2000), drought mitigation options can be broadly grouped into three; drought impact minimisation, demand reduction and supply-increase and emphasizes on the importance of proactive rather than reactive approaches to drought mitigation since it’s a phenomenon with economic, physical and societal impacts.

Multicriteria decision making methods have also been proposed as a method for assessing the performance of various mitigation options and choosing the most suitable. Both water supply and demand-oriented measures are geared towards risk reduction while impact minimisation measures are focused on minimising the environmental, economic and social impacts of drought.

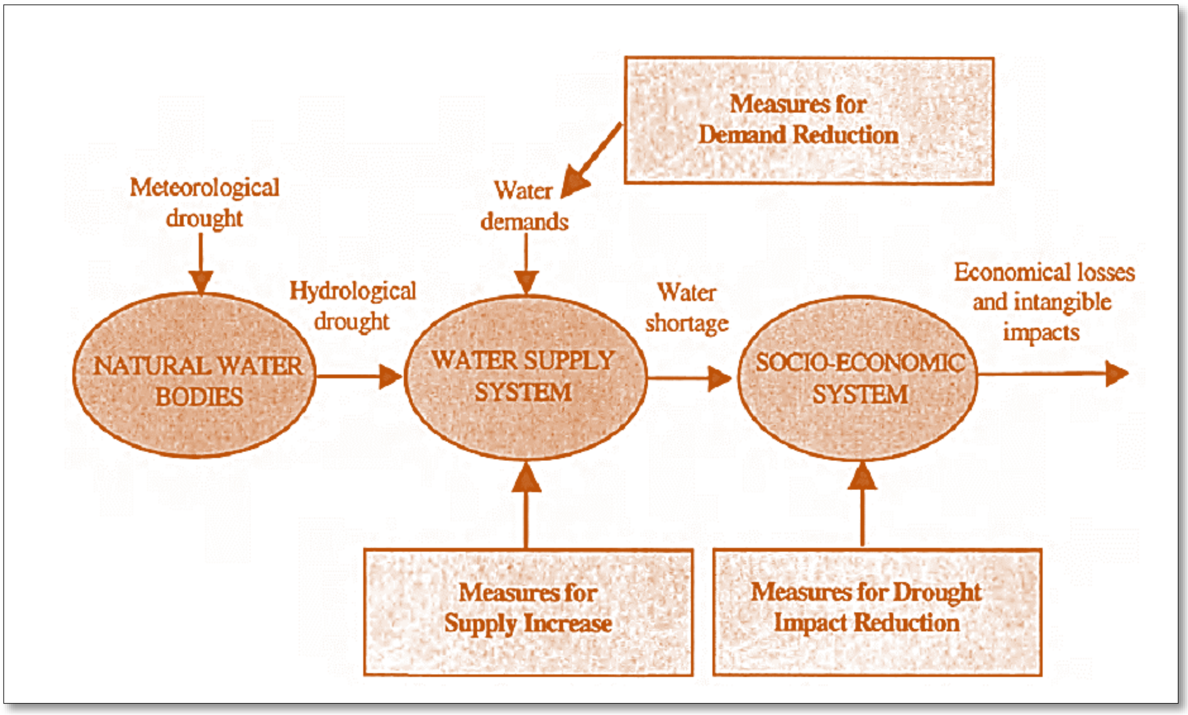


Figure 5: Drought impact process and role of mitigation measures
Source: (Vogt & Somma, 2000)

Drought mitigation options can also be classified as either *reactive* or *proactive*. *Reactive* approaches are implemented once drought begins and its impacts are known. These measures can be described as "crisis management" strategies. This approach is still common and has high economic cost and social impact. *Proactive* refers to measures and plans that are made and implemented before the beginning of a drought. These approaches reduce vulnerability of sectors that might be affected.

Drought mitigation options can also be classified as; long-term actions or short-term actions. Long-term actions are geared towards reducing vulnerability of water supply systems to drought thus improve reliability using a set of appropriate institutional and structural measures while short-term actions combat incoming drought events using existing framework of management policies and infrastructure.

Drought mitigation options can thus be represented in three dimensions as shown in figure 6 below.

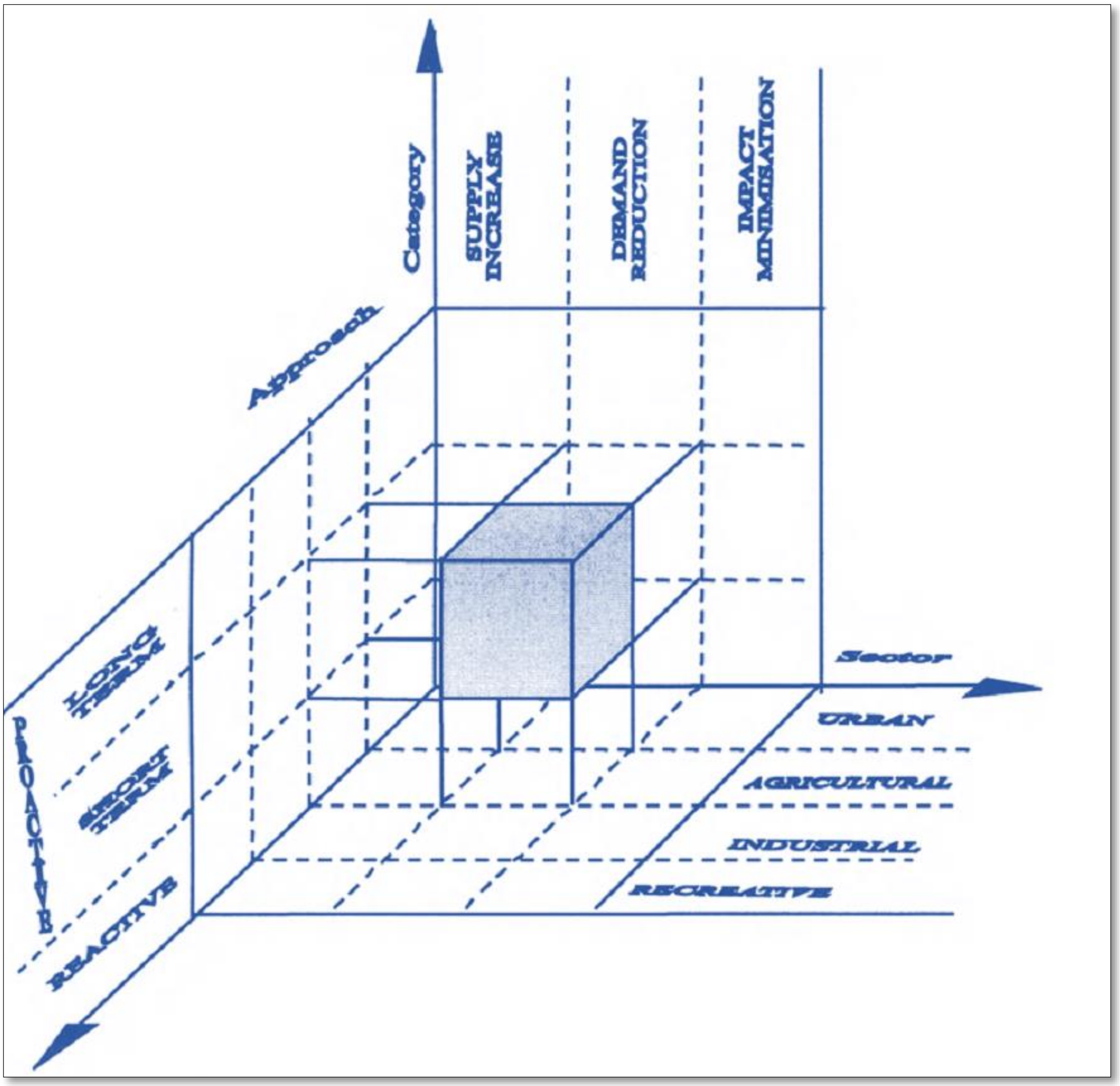


Figure 6:Three-dimensional representation of the potential drought mitigation measures
Source: (Vogt & Somma, 2000)

Some of the challenges in the implementation of the drought mitigation measures as discussed by Vogt & Somma, (2000) include:

i)Natural and man induced aspects of drought are not properly understood by all.
ii)Low temporal and spatial resolutions of drought forecasts.
iii)Quantification of drought impacts on various sectors of society and economy is difficult.
iv)Conflicts amongst political decision makers.
v) preparedness for drought is of low priority to decision makers.
vi) legal constraints in implementation of some strategies.
vii) weak decision support systems for water resource managers.
viii)Low appreciation of proactive approaches to drought mitigation.
ix)Lack of skills and authority to ensure horizontal co-ordination among water supply organisations and vertical coordination among local, regional, national and international levels.

2.3.1 Multi Criteria Decision Making (MCDM) and Multi Criteria Decision Analysis(MCDA)

According to Majumder, (2015) MCDM and MCDA is one way of assessing options and being able to make choices amongst an array of options. This tool provides decision makers with a way of making decisions and has two main types i.e. Compensatory method and Outranking method. In compensatory methods, "trade offs" are made since one attribute in an option can compensate for lack of the same attribute in another option while in Outranking methods, some criterias are given more weight such that these criterias have more influence on the final result. Generally, decision making is said to take the following steps:

1. Establishing objective of decision making process
2. Choosing criteria(s) of assessment and selecting options
3. Defining a weighing method
4. Aggregating the performances of options based on chosen method
5. Choosing options based on the Aggregation results

2.4 Agricultural insurance

According to Jie, Li, & Sijia, (2013), Agricultural Insurance aims at protecting farmers against economic losses in Agricultural production and occurs in three main forms listed in the table 2.9 below:

Table 2.9: Agricultural Insurance types

Agricultural Insurance Type	Challenges
i)Traditional agricultural insurance (Single rate Insurance)	• Presence of adverse selection • Difficulty of determining premium rate and assessing the claims
ii)Crop area yield index insurance	• Compensation is available when the average yield of the region is less than the insured yield
iii)Weather index insurance	

The Weather index insurance considers Agricultural disasters such as drought and floods as the subject and then determines the losses and claims using actual meteorological data and thus it's an improvement from the traditional agricultural insurance. Weather index insurance has been implemented in several countries such as: Mexico and South Africa where a rainfall index has been designed for transferring risks of drought and floods. In Canada, the weather index insurance protects farmers from losses due to high temperature in planting corn and forage while South Africans have designed the apple frost weather index insurance transferring the risk of frost damage to the apples during growth. The Chinese use the citrus frost damage index insurance in the Zhejiang Province to disperse the risk of damage to citrus by frost.

The weather insurance index contracts designed by Jie et al., (2013) include; type of contract, the contract period, the official weather station data, weather insurance index, insurance rates, trigger value and the amount of the compensation.

According to Silvestre & Lansigan, (2015), advantages of Index insurance products include; absence of adverse selection problems since premiums and indemnities are not dependent on individual risk, low administrative costs(no inspections of farms), no moral hazard problems (farmers cannot influence triggers of payments),affordable and thus suits low-income farmers, it has a standardised and open structure and thus is solid in most currencies, show the insured party how payouts are calculated and enables rapid payouts since it uses weather station data and not field verification.

The disadvantages of index insurance products is the basis risk which refers to the difference between the payout triggered and loss experienced by the farmer. When the correlation between the losses and the index is not very high, the farmer could experience high yield loss without receiving payout or he would receive a payout without having made any losses.

The design of this cover should be comprehensive and include; cover period, trigger, measurement site in order to reduce basis risk. Lack of quality and quantity weather data is also another challenge. Need of stable re-insurance for the insurance companies is also a concern. Index insurance is also not a comprehensive product and covers only related to chosen index. This has to be communicated to farmers for them to be aware of the capabilities and limitations of the insurance.

2.5 Gaps and need for this study

Several researchers have worked on phenomenon related to drought and crop yields in Burkina Faso.

Researchers such as Thornton et al., (1997) carried out studies in the 30 administrative units of Burkina Faso on the millet production by using both ground data and satellite data to come up with a prototype system that would predict the millet yields based on remotely sensed satellite data. They used CERES-Millet model and found that their mid-season estimates were 15% of the real end of season values and concluded that more work is needed to be able to more accurately estimate the end of season yields and provide decision makers with more information needed for decision making.

Other researchers such as Abdoulaye, Bruno, Bétéo, & Hamma, (2017) worked on the Impact of climate change on cotton production in Burkina Faso and concluded that the future changes in rainfall would affect cotton production but at a lesser scale compared to effects of temperature changes.

According to Some et al., (2014) who analysed crop water requirements for major crops in Burkina Faso such as Sorghum, maize, groundnut, millet, cowpea and cotton, rainfall increases soil water reserve and that the general soil water holding capacity is low in Burkina Faso. They also found out that water requirements for cereal crops are met by rainfall and in the Sudano-Sahelian and Sahelian zones, water deficits are experienced towards the end of the rainy season. They proposed supplemental irrigation as a solution to enable crops complete their cycle.

Using remote sensing, Hountondji, Sokpon, & Ozer, (2006) analysed vegetation trends in Burkina Faso for the monitoring of desertification and concluded that the desertification phenomenon hasn’t strongly manifested in Fada N’Gourma.

The above researchers have worked in areas related but have not carried out an analysis of drought in Gourma and its relationship with agriculture. The relationship between drought and yields is still a grey area and more work needs to be done on it. The researchers also have worked on the whole Burkina Faso as a study area which comes with low resolution spatially and temporally in some cases. Since the earth is a system that is complex and is made up of subsystems, it is always better to work on relatively small areas in order to better understand natural phenomenon.

This study seeks to delve into the relationship of drought and agriculture in the case of Gourma province with an aim of coming up with sustainable solutions to mitigate the impacts of drought in the province.

CHAPTER 3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Location of Burkina Faso and Gourma Province

Burkina Faso is a West African nation that lies within the latitudes 9^{o} and 15^{o} N and longitudes 6^{o} W and 3^{o} E and covers a total area of 274,200Km^{2}. Burkina Faso is surrounded by Mali, Niger, Cote d'Ivoire, Ghana, Benin and Togo.

Fada N’Gourma is the administrative headquarters of Gourma Province which is situated in the East region of Burkina Faso. The neighbouring provinces include: Komandjari and Gnagna to the North, Tapoa Province to the East, Boulgou and Kouritenga to the West, and Koulpelogo and Kompienga to the South. Gourma lies within latitudes 13°7' N and 11°55' N and longitudes 0°7' W and 1°25' E. It covers a total area of 11,217km^{2} and an average altitude of 280m. See location Map in Figure 7.

3.1.2 Hydrological Characteristics

There are several water courses in the northern part of the province including Bonsoaga and Sirba which are part of the Niger River Basin as well as in the southern part where Rivers Koulpéologo and Singou form part of the Pendjari watershed which is a tributary of River Nakambé. The three rivers within the province (see map on figure 7), drain the province.

3.1.3 Topography

The terrain in the province of Gourma is relatively uniform, with a mean altitude of 280m. Highest points are hills in Pama with elevations between 320m and 350m.

3.1.4 Agriculture (crop and animal production)

The main economic activity in the area is Agriculture where crops such as sorghum, millet and maize are grown. Inheritance and kinship are the common means by which people own agricultural land parcels. This is based on rights acquired by virtue of being part of a lineage that were first to settle on the piece of land. Agriculture is widely practised with fallow periods that change based on soil types and distance from residences. In the province of Gourma, it’s the Fulani herders that practice extensive animal breeding characterized by transhumance. For every herd owner, the average herd size is between 40 and 50 heads of livestock which have both economic and social functions.

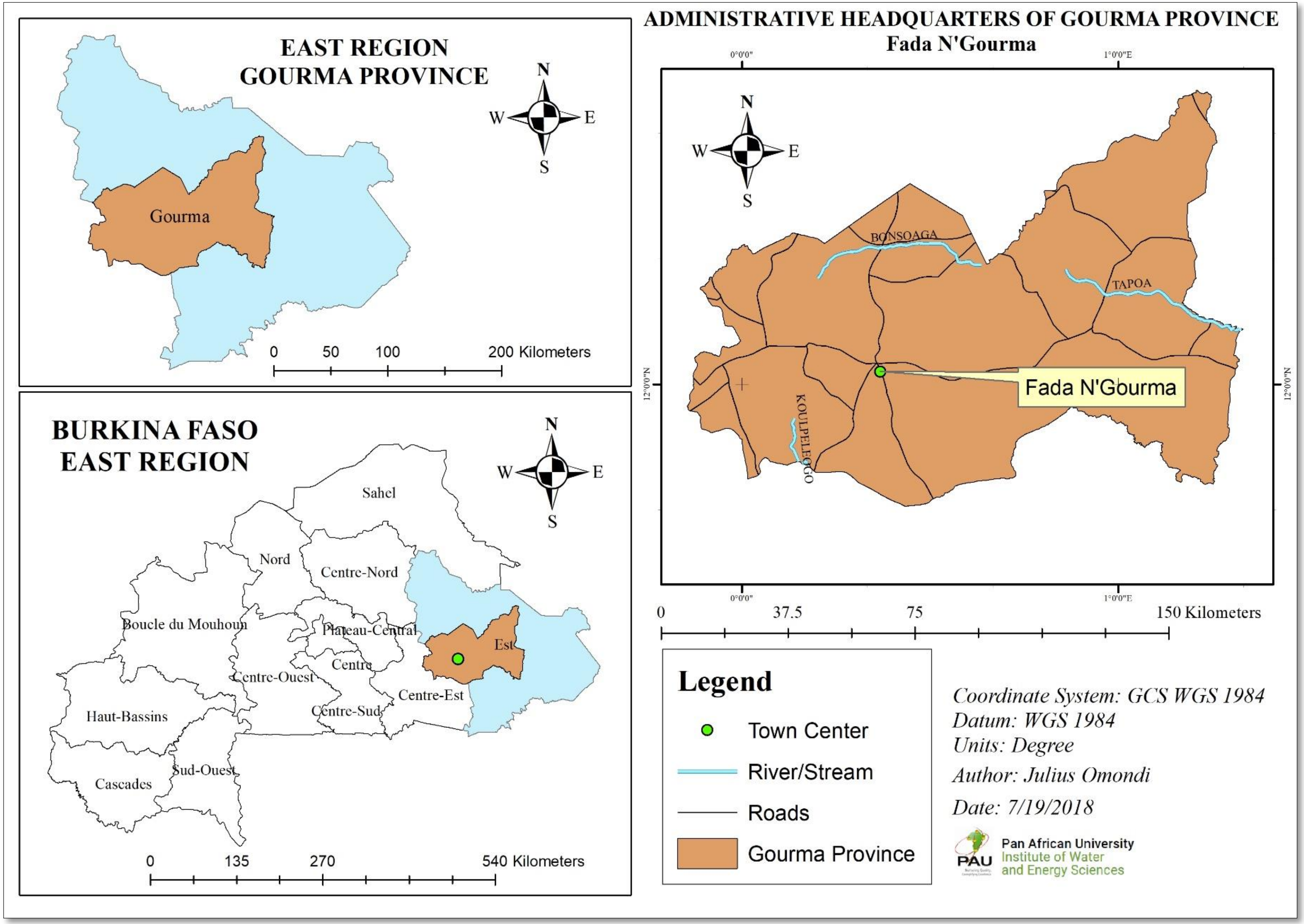


Figure 7: Location of Gourma Province

3.1.5 Climate

Gourma province lies within the Sudano-sahelian region which is situated within the 11°30' and 14°00'N parallels as shown in figure 8 below. An average annual rainfall of between 800 and 900 mm is experienced in this region within four to five months. In terms of vegetation, herbaceous cover is vast and continuous and forests are denser. This zone covers a huge part of the country (Abdoulaye et al., 2017).

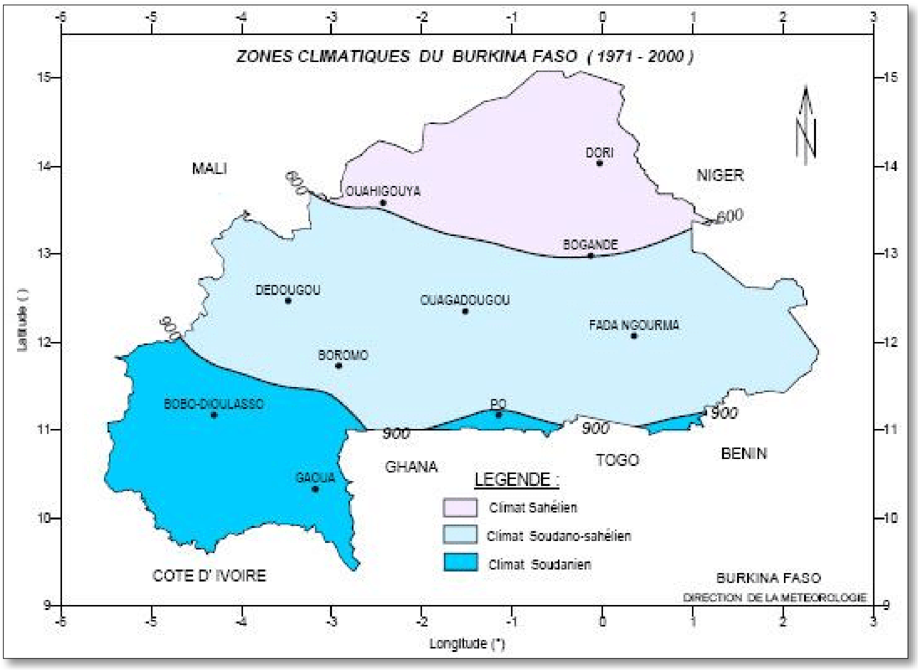


Figure 8: Climate zones of Burkina Faso

Source: (Abdoulaye et al., 2017)

3.1.5.1 Precipitation

Every year, mid-April marks the beginning of the rainy season accompanied with the start of monsoon winds, and continues until mid-September (Guèye & Sivakumar, 1992). Since 1963, there have been huge variations in annual rainfall. In the 1980s, a huge decline in rainfall was experienced with the values ranging between 709mm and 612mm. Some et al., (2014) reported that the average annual rainfall from 1963 to 2003 is 818mm.

3.1.5.2 Temperature

The maximum temperature between 1963 and 2003 ranges from 34 - 37.8^{o}C i.e. 4.8 ^{o}C difference while the minimum ranges from 20.5 - 23.6 ^{o}C i.e. difference of 3.1 ^{o}C. The mean minimum was 21.6 ^{o}C while the mean maximum was 34.4 ^{o}C and the mean temperature in this period was 28.6 ^{o}C according to Some et al., (2014).

3.1.5.3 Relative Humidity

From 1963 to 2003, maximum relative humidity ranged between 63 and 77%, with a mean of 68% while the minimum was between 29 and 36%, with a mean of 33% until 2003 when a dramatic drop to 18% took place(Some et al., 2014).

3.1.6 Soils

According to Rahman, Talaat, & Some, (2008), Vertisols, Gravelly soils, Brown soils and Ferruginous soils, are the four major soil types in the province.

Vertisols are frequently associated with the Ferruginous soils and has the following types: typical vertisols with a sandy or gravelly cover, gravelly vertisols on the surface and vertisols on river alluviums. Vertisols are clayey in texture and have weak internal and external drainage. They have a swelling tendency with a strong ECC and weak porosity and thus hard to be saturated and difficult to work with.

Gravelly soils are shallow (< 40cm) with a low fertility generally (i.e. low organic matter content, insufficient water-holding capacity, and phosphorus deficiency).

Brown soils are uncommon though they are normally associated with Vertisols with an average to thin structure on the surface and depth greater than 100cm. they have poor drainage at greater depths and a strong ECC.

Ferruginous soils are leached and sandy on the surface but also sandy/clayey at greater depths. They are moderately deep to deep with low fertility (i.e. low effective calcium carbonate (ECC), poor water retention, low permeability and porosity, organic matter content (<1%), quite dissaturated and vulnerable to erosion). These soils cover large area of the province.

3.1.7 Vegetation

Shrubby savannahs and arboreous vegetation cover most of the central and southern parts and becomes sparser in the north, where the vegetation has thorny species as well. Three natural reserves are found within the province i.e.: Pania (223,000ha), Singou park (182,800ha), Arly (76,000ha) and the comprising about 11.3% of protected area in the region.

3.1.8 Population

From 1975 to 1996, population of Gourma Province increased from 192,331 to 220,116 and by this time, about 49.3% of the population had less than 15 years of age. About 47.3% were between 15 and 64 years of age and were active. In 1991, Gourmatché ethnic group constituted 54.8%, Mossi ethnic group were 35.4%, Fulani ethnic group were 7.6% and others 22% (Bissa, Bobo, Gouin). of the total population.

3.1.9 Farming systems

Maize, millet, soybean, sorghum, rice, cowpea, groundnut and cotton are the main crops grown in the province. In the lowlands, Bossangri, Bassabiliga and Fonghin, market vegetables such as: tomato, eggplant and cabbage are cultivated. Sweet potatoes, maize, cassava and sorghum are also grown along water courses in the lowlands. There are three main types of fields in Gourma:

1. **Village fields** – anywhere between 500 and 1000meters from homesteads or village area. Crops grown in these fields include: the early and late maturing varieties of sorghum, groundnuts, millet (sometimes intercropped with cowpeas), maize and rice in lesser areas. Common rotations are sorghum/millet and groundnut/sorghum.
2. **Compound fields** – located around homesteads. Food crops, such as maize, short cycle sorghum varieties, vegetables (sorrel, okra, red sorrel) and tobacco are grown here.
3. **Bush fields** – situated a few kilometres from the village and are made up of fields scattered in the bush. They mark village borders and food crops monoculture and crop rotation of sorghum/millet are common. Sorghum and millet are normally intercropped with cowpea by planting the seeds in one hole.

3.1.10 Millet

Millet is considered as one of the critical drought-resistant crops and in world agricultural production of cereal crops, it is the 6th cereal crop. Apart from having a short growing season, millet can be produced under drought conditions and compared to the other major cereals, it is resistant to pests (Khairwal et al., 2007)

Millet has small seeds and some of its varieties include: pearl millet (*Pennisetum glaucum*), kodo millet (Paspalum setaceum), finger millet (Eleusine coracana), little millet (*Panicum sumatrense*), barnyard millet (*Echinochloa utilis*), foxtail millet (*Setaria italic*), and proso millet (*Penicum miliaceum*) (Saleh, Zhang, Chen, & Shen, 2013)

3.1.10.1 Pearl millet growth and phenology

Every crop has a particular growth rate and life cycle which determine its growth potential. Pearl millet is considered a short cycled and small seeded monocotyledon with three major growth phases (GS-I, GS-II and GS-III) as shown in figure 9 below.

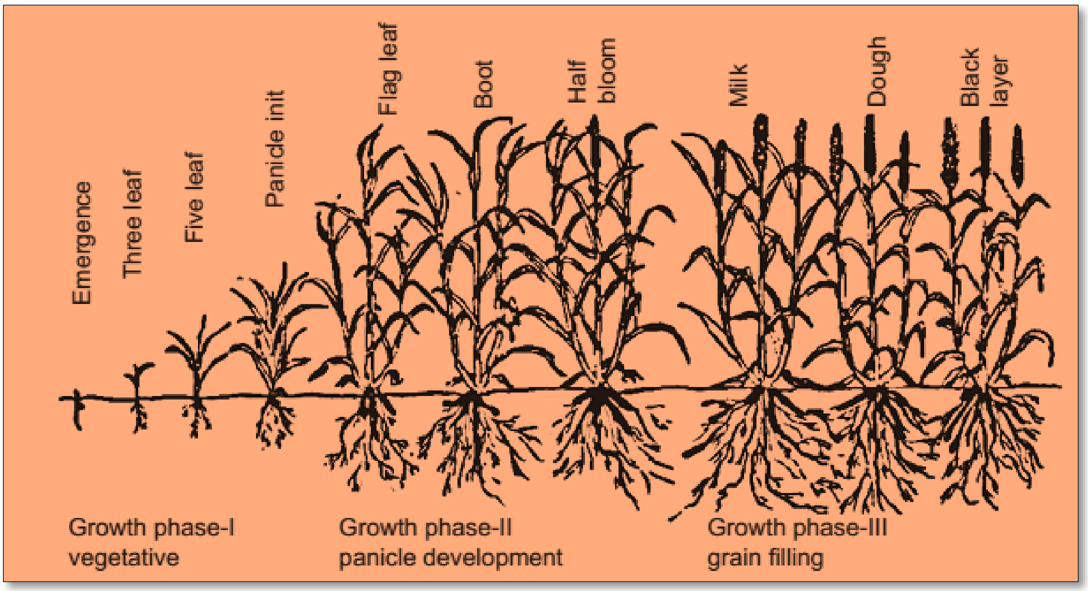


Figure 9: Pearl Millet growth phases

Source: (Khairwal et al., 2007)

Pearl millet can be grown in areas with low rainfall and infertile soils but it can as well be irrigated. The built-in short life cycle trait of pearl millet is a hereditary phenomenon from its wild seed (Ullah, Ahmad, Khaliq, & Akhtar, 2017).

3.1.10.2 Pearl Millet farming in Gourma province

The common pearl millet cultivars in Burkina Faso are: IKMP 2, IKMP 3, IKMP 5 and IKMV 8201. In Gourma province, the dominant millet cultivar grown is the **IKMP8201** which has a physiological maturity period of 90 days. This cultivar is normally sowed in the second half of July but the optimal sowing date is at the start of July. On average, 502,000 seeds of IKMP8201 cultivar are planted per hectare under a rain fed water regime with an actual yield of approximately 0.754 tonnes/hectare. Harvesting is done in the months of October and November (Ouattara, 2014).

In order to understand the impact of drought on the yield, the climatic conditions during the crop development period must be taken into account.

Table 3.1: Pearl millet phenology

Growth stage	Phenological Event(s)	Key dates and descriptions
Growth phase-I	<u>Vegetative</u> i. *Seedling formation with root and leaf* ii. *Initiation of panicle* iii. *Development of tiller*	Under optimum temperature and moisture, germination starts after 3-4 days but may change to 5-7 days in unsuitable conditions. A small shoot and root emerge when coat is broken. In a week, first roots die and new adventitious roots develop. Root penetration rates in sandy soils is between 3.5–4.5 cm d^{-1} (Azam-Ali, Gregory, & Monteith, 1984) which depends on cultivar genotype and crop season. (Vadez, Hash, Bidinger, & Kholova, 2012) observed 300 cm and 140 cm deep roots in long and short duration cultivars respectively. (Craufurd & Bidinger, 1988) observed that It takes 2-4weeks for seedling and stalk development while primary tillers appear after 20-25 germination days followed by secondary tillers at all stages of apical development.
Growth phase-II	<u>Panicle development</u> i. *Elongation of all leaves* ii. *Emergence of all tillers* iii. *Floral initiation in tillers* iv. *Stem elongation* v. *Elongation of the panicle* vi. *Formation of floral parts* vii. *Emergence of stigmas on the panicle*	In 45 and 59 days of germination, Panicle initiation and flowering occur respectively and the flag leaf becomes visible after 50 days of germination. Seed setting/grain formation starts from 60–65 days after germination and are completed within 9–10 days.
Growth stage-III	<u>Grain filling</u> i. *Fertilization of florets* ii. *Accumulation of dry matter in grain formation and also in enlargement of stems and leaves of the tillers.* iii. *Physiological maturity marks the end and is depicted by a dark layer development at the bottom of the grain.*	Pearl millet accomplishes its physiological maturity between 90–95 days after germination depending upon weather conditions.

3.2 Methodology

In order to achieve the overall objective of this master thesis research work, each of the specific objectives were approached systematically as summarised in figure 10 below.

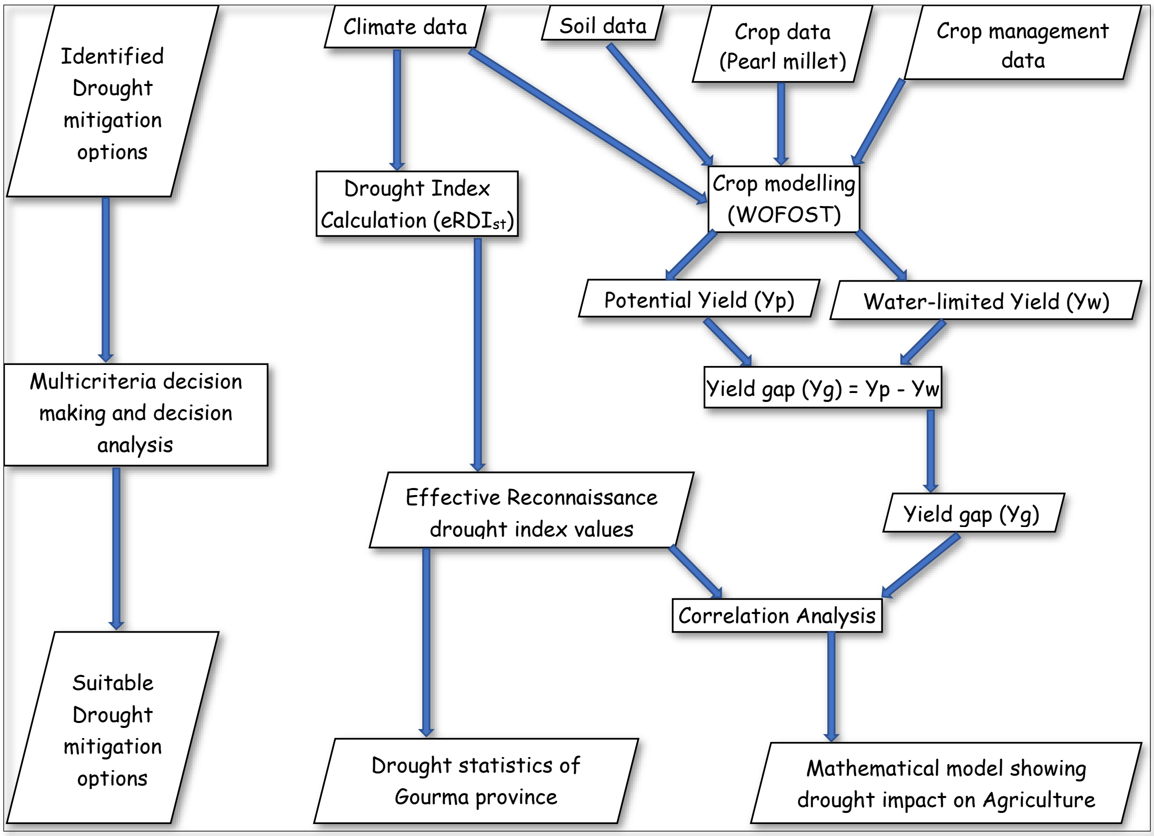


Figure 10: Summarised Methodology

3.2.1 Calculation of Drought Indices

Data used for calculation of the drought indices included temperature (^{o}C) and precipitation (mm). Climate data was obtained from NCEP-CFSR research data archives in a SWAT file format. The CFSR archives contain global and high-resolution climate data for 36-years starting from 1979 to 2014 including precipitation, wind, relative humidity, and solar radiation data (National Centers for Environmental Prediction (NCEP), 2016). Climate data with the Fada N'Gourma weather station coordinates (Longitude 0.367^{o}E and Latitude 12.033^{o}N) were chosen and taken to be representative of the climate of Gourma province. This provided 35-years of daily climate data which is recommended by (Svoboda & Fuchs, 2017) for calculation of many indices. The data was then checked for missing values and averaging by interpolation used to fill the gaps. The daily temperature data was converted into mean monthly temperature data and using the Hargreaves method, the PET-Potential Evapotranspiration was determined using DrinC calculator.

Vangelis et al., (2013) recommended temperature-based methods as sufficient to determine PET for RDI calculations. The Hargreaves method used maximum and minimum temperatures as well as latitude of the station and duration of the data to determine PET. PET results were then used to determine the effective reconnaissance drought index for each year starting June and July for up to 4 and 5 months for the 34 years of available data. The Brouwer & Heibloem, (1986) method was used to determine effective rainfall as shown below:

$$\begin{aligned} P_e &= 0 && for\ P \leq 17mm \\ P_e &= 0.6 \times P - 10 && for\ 17mm < P \leq 70mm \\ P_e &= 0.8 \times P - 25 && for\ P > 70mm \end{aligned}$$

Where: Pe-Effective rainfall (mm)
P-Precipitation (mm)

The eRDI was determined using equation shown below:

$$a_{e(k)} = \frac{\sum_{j=1}^{j=k} P_{ej}}{\sum_{j=1}^{j=k} PET_j}$$

Where: P_{ej}-the monthly effective precipitation of the jth month (mm)
PET_j-the monthly potential evapotranspiration of the jth month (mm)

The results of the $eRDI_{st}$ calculations were used to characterise the drought's intensity and severity. For the spatial characterisation, data from NOAA / NESDIS Center for Satellite Applications and Research (NOAA, 2018a) were downloaded and used to spatially characterise the drought. VHI data starting from starting from 1981 to 2017 was also accessed from (NOAA, 2018b) in ASCII format and used for the correlation analysis with yield gaps.

3.2.2 Crop Yield Modelling

WOFOST model was used to simulate the annual crop yields of pearl millet (*Pennisetum glaucum*) starting from 1979 to 2013. It is a generic model that can be used to simulate yields of any annual crop so long as its growth properties are known. WOFOST considers a plant as a system and goes ahead to simulate its reaction to the necessary growth inputs and thus estimate the yields. The dominant crop grown in Gourma Province is Millet and thus using WOFOST crop simulation model v7.1.7, the Potential Yield (Y_P) and the Water-Limited Yield (Y_W) were simulated for each year starting from the year 1979 to 2013.

WCC provides a graphical user interface with the following tabs: General, Crop, Weather, Timer, Soil, Nutrients and Reruns for loading input data. In order to load input data for a particular study area that is currently not in WCC database, one has to prepare the files outside and store them in the correct directories within WCC.

In order to simulate the crop yields, WOFOST was fed with weather, crop and soils data as the input files which were drawn from various sources.

3.2.2.1 Weather Data

Daily weather data for Fada N'Gourma weather station (1979-2013) used to determine the eRDI (National Centers for Environmental Prediction (NCEP), 2016) was used to prepare the input weather files for WOFOST. The data was first checked for gaps and estimation by interpolation used to fill gaps. The data was then arranged in the WOFOST CABO-format where theres is a file for every year and this resulted in 35 files for 1979-2013. A sample file is included in annex 1. These files were stored in the WCC under the folder named METEO and were loaded into WOFOST for simulations.

Data needed in each file included: dates, irradiation (kJ m^{-2} d^{-1}), minimum temperature (degrees Celsius), maximum temperature (degrees Celsius), vapour pressure (kPa), mean wind speed (m s^{-1}), precipitation (mm d^{-1}).

Since the data from National Centers for Environmental Prediction (NCEP), (2016) did not contain values for vapour pressure, the Arden Buck equation shown below was used to determine the vapor pressures since it has minimum data needs i.e temperature only.

Equation 17: Arden Buck's Equations

$$P_S(T) = 0.61121 \times \exp\left(\left(18.678 - \frac{T}{234.5}\right) \times \left(\frac{T}{257.14+T}\right)\right), \text{ over liquid water, T>0}^{\circ}\text{C}$$

$$P_S(T) = 0.61115 \times \exp\left(\left(23.036 - \frac{T}{333.7}\right) \times \left(\frac{T}{279.82+T}\right)\right), \text{ over ice, T<0}^{\circ}\text{C}$$

Where:

Ps(T) is the saturation vapour pressure in kPa
exp(x) is the exponential function
T is the air temperature in degrees Celsius

The Angstrom's coefficients a and b for Burkina Faso were adopted from Baldy & Stigter, (1997) and used in the weather file preparation.

Table 3.2: Angstrom's Coefficients (*a* and *b*)

Country	*a*	*b*
Guadeloupe	0.27	0.47
Malaysia	0.34	0.52
India	0.31	0.44
Burkina Faso	0.27	0.49
Singapore	0.26	0.46
Kenya	0.26	0.57
Brazil	0.28	0.50
Uganda	0.24	0.47
Trinidad	0.27	0.49

Source: (Baldy & Stigter, 1997)

3.2.2.2 Soils data

Input soil files were created using data from ISRIC-WISE database and SPAM results. Both the ISRIC-WISE raster and the SPAM model results are 5 by 5 arcminute datasets.

ISRIC-WISE data

The soils data was obtained from the ISRIC-WISE and the chosen product was the WISE derived soil properties on a 5 by 5 arc-minutes global grid, version 1.2 (ISRIC, 2012) This dataset comes from a combination of the Soil parameter estimates derived from ISRIC's WISE database and Spatial data from the 1:5 million scale FAO-UNESCO world soil map. It contains 106 soil units of the world at steps of 20cm up to a depth of 100cm.

Metadata of this product was accessed through Batjes, (2012) where all the soil properties contained in this database are explained. ISRIC-WISE data was downloaded as a database file and a GeoTiff file.

The downloaded ISRIC-WISE dataset contained 6698 soil mapping units covering the entire world. Within each soil mapping unit there is a maximum of 8 soil units based on FAO-UNESCO, (1977). From the database, only the mapping units within Gourma province were chosen, specifically the regions within the province where pearl millet is cultivated. See map of Gourma soils below:

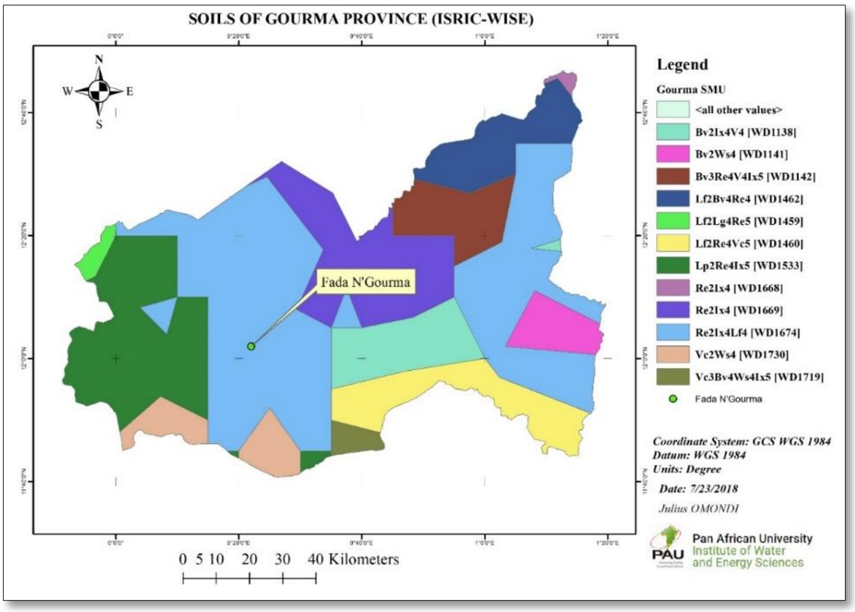


Figure 11: Soils of Gourma province

SPAM (Spatial production allocation) model results

SPAM model uses data from international agricultural organizations such as FAO, national agriculture ministries of countries, regional agricultural departments within countries and other available sources to generate plausible agricultural production patterns data.

The SPAM Model results on pearl millet production were downloaded from You, L., U. Wood-Sichra, S. Fritz, Z. Guo, L. See, (2017) in form of a raster file and a geodatabase containing harvested area data for 42 crops grown worldwide in 47 countries broken down into two administrative levels in the specific countries. From the SPAM results, the below map shows the areas where pearl millet is grown in the province:

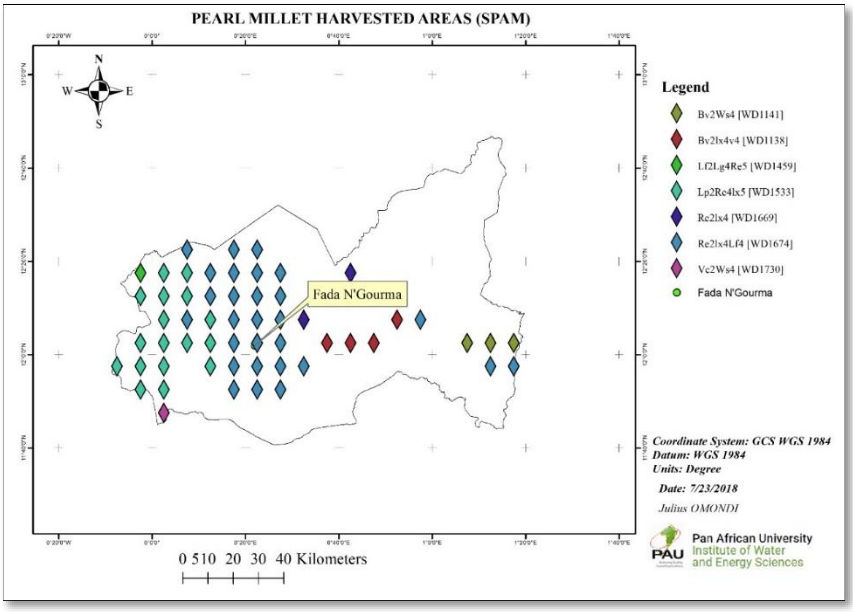


Figure 12: Pearl Millet harvested areas

Superimposing harvested area on to the soils map produced the resulting map below:

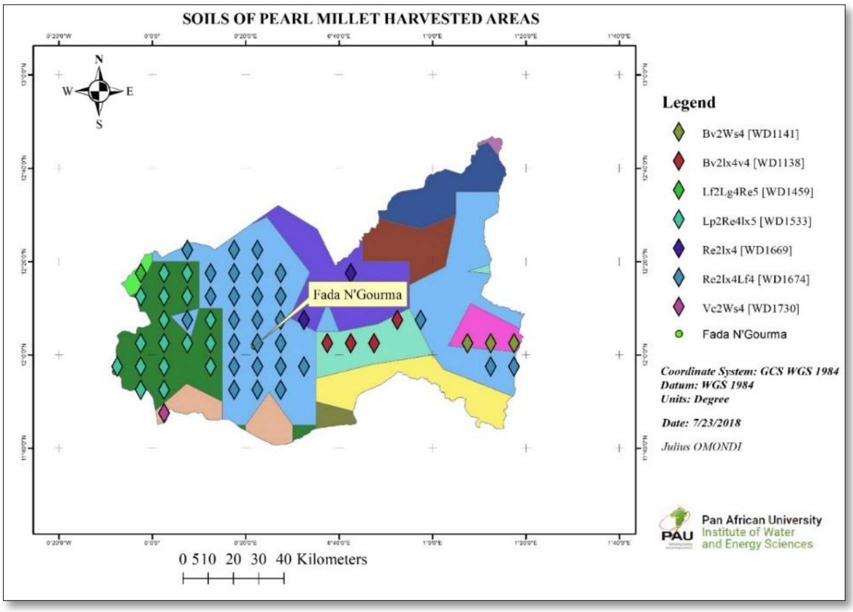


Figure 13: Soils of pearl millet harvested areas

By overlaying the results of the modelled Harvested areas from SPAM on the ISRIC-WISE raster dataset, and then joining the two attribute tables of the separate raster data, the following soil mapping units were identified to be the soils occurring within the harvested areas of rainfed pearl millet in Gourma Province.

Table 3.3: Soils of pearl millet growing areas

Soil Mapping Unit	Harvested Area (Ha)	Harvested Area (% of Total)
Re2lx4Lf4 [WD1674]	21223	47.14
Lp2Re4lx5 [WD1533]	16344	36.30
Bv2lx4v4 [WD1138]	3498	7.77
Bv2Ws4 [WD1141]	2045	4.54
Re2lx4 [WD1669]	1174	2.61
Vc2Ws4 [WD1730]	741	1.65
Total	**45025**	**100**

According to (FAO-UNESCO, 1977), the above soil units are named as below:

Table 3.4: Complete soil names

FAO Soli Unit	Complete name
Re	Regosols
Lx, Lf, Lp	Lithosols
Bv	Cambisols
V, Vc	Vertisols
Ws	Planosols

Table 3.5: Percentage composition of the SMUs

WISE-Soil Mapping Unit	Percentage Composition of the different FAO Soil Units		
Re2lx4Lf4 [WD1674]	60	20	20
Lp2Re4lx5 [WD1533]	60	30	10
Bv2lx4v4 [WD1138]	60	20	20
Bv2Ws4 [WD1141]	70	30	
Re2lx4 [WD1669]	70	30	
Vc2Ws4 [WD1730]	70	30	

From the above percentage compositions of the various WISE-Soil Mapping Units, the textures were retrieved from the database and the two major FAO soil Texture groups that were arrived at were the Medium and Fine texture and these were taken to be representative of the respective areas.

Table 3.6: Dominant soil units by Area

FAO-UNESCO (1974) Legend code	Harvested Area (Ha)	Texture Class-SPAW	FAO Texture group
Re	18458.8	Sandy Loam	Medium-2
Lf	4244.6	Sandy Clay Loam	Medium-2
Lp	9806.4	Sandy Clay Loam	Medium-2
lx	6930.8	Loam	Medium-2
Ws	835.8	Sandy Clay	Fine-4
Bv	3530.3	Clay	Fine-4
Vc	518.7	Clay	Fine-4
V	699.6	clay	Fine-4
Total Area (Ha)	**45025**		

In summary, the areas covered by the two major soil texture groups were determined as shown in the table below:

Texture group	**Medium**	**Fine**	**Total**
Harvested Area (ha)	39440.6	5584.4	**45025**

Soil physical characteristics (SPAW)

Soil physical properties were determined using SPAW v6.02.75 model which uses a wide range of Pedo-transfer equations to estimate soil physical characteristics (Saxton & Rawls, 2006). This was done for all the 8 FAO soil units and then the properties averaged into the two major texture groups of fine and medium textures.

The data below in table 3.10 was acquired from ISRIC-WISE database after selecting the soils in the zones where pearl millet is grown and was used to prepare physical soil characteristics of soil files for input in the WOFOST model. Firstly, the SPAW equivalents of the soil properties provided in the ISRIC-WISE database were determined. The respective equivalents are as shown in table 3.7 below:

Table 3.7: ISRIC-WISE Database data and their respective SPAW Model Equivalents

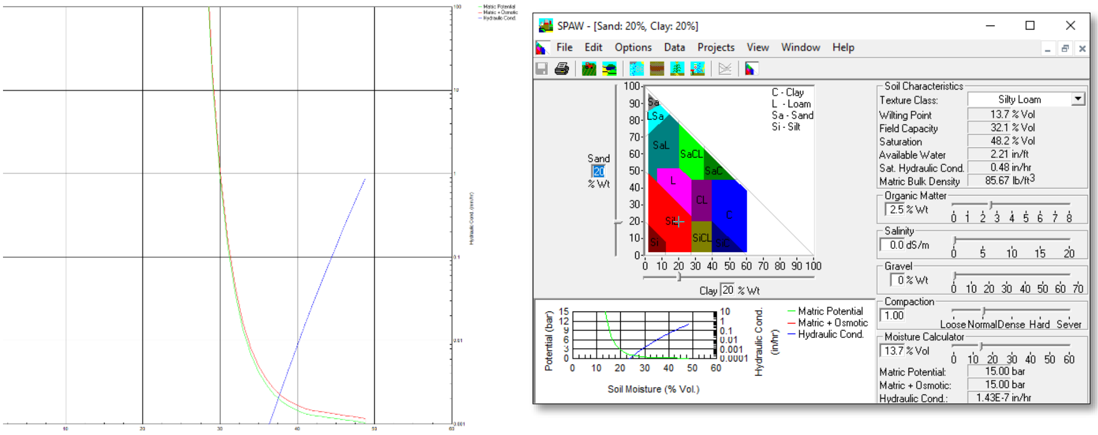
ISRIC-WISE Database	**SPAW Model Equivalent**
SDTO-Sand Mass %	Sand % Wt
CLPC-Clay Mass %	Clay % Wt
TOTC-Organic Carbon Content gC/Kg	Organic Matter % Wt
ELCO-Electrical Conductivity (dS/m)	Salinity dS/m
CFRAG-Coarse fragments (Vol.% > 2mm)	Gravel % Vol.

Note: TOTC *is the soil organic carbon concentration and OM is soil organic matter concentration. To convert TOTC into OM, we use the below relationship:*

Organic Matter (% Wt) = (TOTC/(0.58*10)) (Perie & Ouimet, 2008)

Using the Sand, Clay, Organic matter, Salinity and Gravel content data of each soil, the physical properties were determined in the Soil-water characteristics tab in SPAW.

Figure 14: SPAW outputs



Soil Characteristics
Texture Class: Silty Loam
Wilting Point 13.7 % Vol
Field Capacity 32.1 % Vol
Saturation 48.2 % Vol
Available Water 2.21 in/ft
Sat. Hydraulic Cond. 0.48 in/hr
Matric Bulk Density 85.67 lb/ft^3
Organic Matter 2.5 % Wt
Salinity 0.0 dS/m
Gravel 0 % Wt
Compaction 1.00
Moisture Calculator 13.7 % Vol
Matric Potential: 15.00 bar
Matric + Osmotic: 15.00 bar
Hydraulic Cond.: 1.43E-7 in/hr

Source: SPAW

Physical soil characteristics of the FAO soil units and the results are shown in table 3.11 and a summary of the two major categories of FAO soil textures is given in the table 3.8 below:

Table 3.8: Physical soil properties summary

	Medium-2	Fine-4
SMW (cm3/cm3)	0.159	0.293
SMFCF (cm3/cm3)	0.264	0.414
SMO (cm3/cm3)	0.421	0.489
AWC (mm/m of soil)	75.000	110.000
KO (cm/day)	20.124	2.400
CRAIRC (cm3/cm3)	0.157	0.076
SOPE (cm/day)	20.124	2.400
KSUB (cm/day)	20.124	2.400
TAWC (20cm)	10	15.5
Maximum initial moisture content in initial rooting depth (-)	0.264	0.414

From the above physical soil properties, the soil files were prepared for use in WOFOST simulations of Water Limited Yields (Yw). The used crop files are attached in annex 2.

Runoff estimation by use of Slope of Gourma province.

Six tiles of ASTER GLOBAL Digital elevation models (DEM) covering Gourma province were downloaded from USGS (https://earthexplorer.usgs.gov/) and merged in ArcGIS to form one layer which was then corrected by filling the gaps and defining the projections. The resulting DEM was then clipped using the Gourma province polygon and the slope of the resulting layer determined. The average slope of the province was found to be **3.233%,** see the map below in figure 15. Apart from the physical soil characteristics, WOFOST also needs information on the portion of precipitation that is converted to runoff.

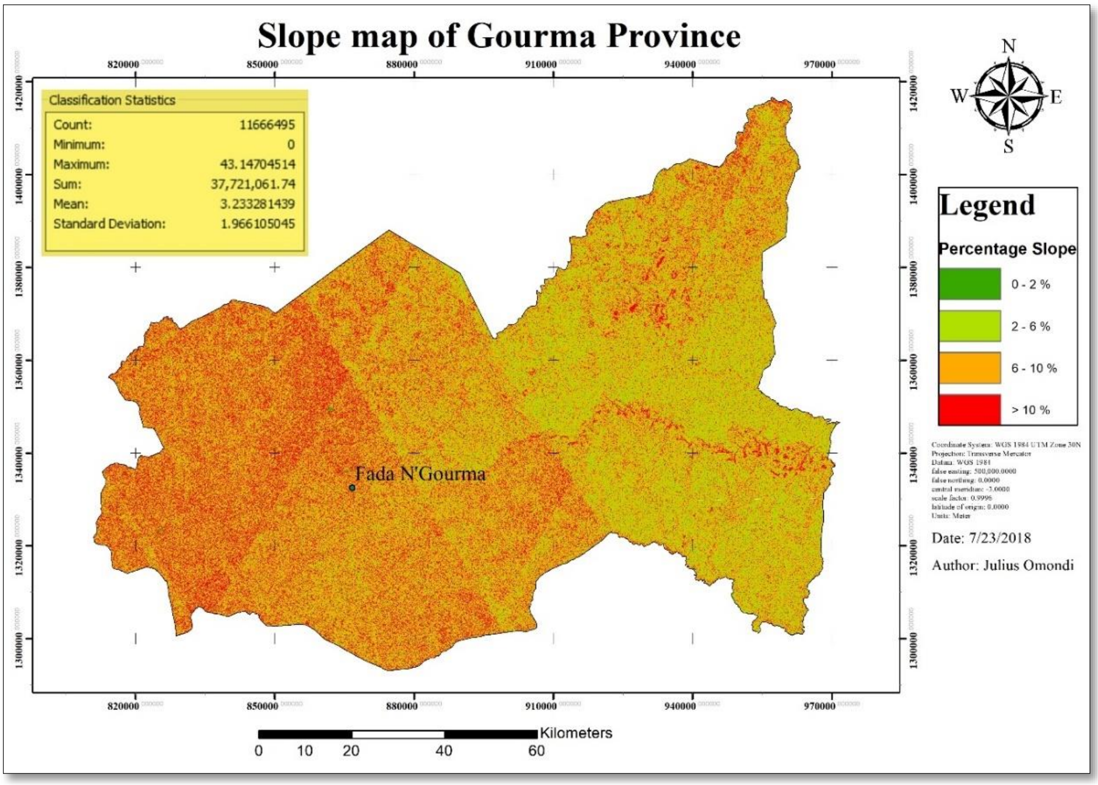


Figure 15: Slope of Gourma Province

To avoid the assumption that all the precipitation will infiltrate the soil and be available to the plant, this slope value was used to determine the percentage fraction of precipitation that is converted to runoff using table 3.9 below. It was assumed that a fixed fraction of precipitation is lost to surface runoff. According to ISRIC-WISE data, the soils of Gourma are dominated by Sand and thus the soils can be classified as well drained. This is supported by opinions of soil scientists in Burkina Faso such as Dr Korodjouma Ouattara – INERA (Institut de l'Environnement et de Recherches Agricoles). Also the province is situated on a plateau that is the source of some tributaries of Niger and Volta basin Rivers such as Bonsoaga, Dyamongou, Tapoa and Ouale Rivers (DIRH, 1993). Since the soils of Gourma are well drained and with a slope of 3% from above, the runoff fraction of total rainfall is **3.3%.** this value was used for water limited yield simulations where it was assumed that the soils are cultivated with cereals and mulched.

Table 3.9: Surface runoff fraction of total rainfall (in %)

Slope angle, in %	Drainage class	Very poor	Insufficient	Moderate	Well drained	Extremely well drained
0-2		10	6.7	3.3	0	0
2-6		13.3	10	6.7	3.3	0
6-10		16.7	13.3	10	6.7	3.3
>10		20	16.7	13.3	10	6.7

Source: (Ouattara, 2014) (for soil cultivated with cereals and mulching)

Table 3.10: ISRIC-WISE soil properties (At Rooting Depth of 80 cm):

CLAF	PRID	Drain	CFRAG	SDTO	STPC	CLPC	PSCL	BULK	TAWC (80cm)	ELCO	Salinity	TOTC	OM	TAWC (20cm)
Re	WD-Re	S	29	68	19	13	M	1.41	12	0.18	0.18	2.16	0.37	12
Lf	WD-Lf	W	15	53	13	34	M	1.51	8	0	0	3.06	0.53	8
Lp	WD-Lp	M	41	50	19	31	M	1.65	12	0	0	2.73	0.47	8
Ix	WD-Ix	S	24	47	30	23	M	1.34	12	1.74	1.74	20.88	3.60	12
Ws	WD-Ws	I	8	48	16	36	F	1.77	12	0.65	0.65	2.56	0.44	17
Bv	WD-Bv	M	6	23	29	48	F	1.38	18	0.42	0.42	3.98	0.69	16
Vc	WD-Vc	M	9	15	28	57	F	1.79	13	0.65	0.65	4.53	0.78	14
V	WD-V	M	8	19	24	57	F	1.59	15	0.55	0.55	5.26	0.91	15

Table 3.11: Physical soil properties determined by Pedo-Transfer functions

	Medium-2	Medium-2	Medium-2	Medium-2	Fine-4	Fine-4	Fine-4	Fine-4
SMW (cm3/cm3)	0.08	0.206	0.188	0.16	0.218	0.285	0.334	0.335
SMFCF (cm3/cm3)	0.16	0.311	0.298	0.285	0.329	0.415	0.455	0.455
SMO (cm3/cm3)	0.393	0.414	0.413	0.462	0.422	0.488	0.527	0.519
AWC (mm/m of soil)	60	90	60	90	100	120	110	110
KO (cm/day)	47.928	5.064	4.536	22.968	4.224	2.112	1.896	1.368
CRAIRC (cm3/cm3)	0.233	0.103	0.115	0.177	0.093	0.073	0.072	0.064
SOPE (cm/day)	47.928	5.064	4.536	22.968	4.224	2.112	1.896	1.368
KSUB (cm/day)	47.928	5.064	4.536	22.968	4.224	2.112	1.896	1.368
TAWC (20cm/m)	12	8	8	12	17	16	14	15
Maximum initial moisture content in initial rooting depth (-) (20cm)	0.16	0.311	0.298	0.285	0.329	0.415	0.455	0.455

3.2.2.3 Crop file

To develop the crop file used for simulating pearl millet growth in the province, some growth parameters of the original millet file provided by WOFOST version 7.1.7 were modified according to experiments carried out in the country by other researchers. This was done following the procedures laid out by Laar et al., (2014). This crop file was designed to represent a high yield variety that is grown under optimal conditions and thus produces the highest possible yields (Yp).

The standard crop growth parameters required for crop growth simulation were adopted from Van Heemst, (1988) and the site specific parameters such as life span of leaves at 35°C and maximum leaf CO_2 assimilation rate were adopted from GYGA reports (Ouattara, 2014). All the crop growth parameters and their values were used as presented in the crop file sample in annex 3.

3.2.2.4 Calibration of WOFOST model

After preparing the weather, soil and crop files as described above, these files were loaded into their respective folders under the WCC (WOFOST Control Centre) graphical user interface in preparation for calibration. According to Wit & Wolf, (2010), experimental data on crop, soil and weather conditions are needed. The needed experimental data sets are given in table 3.12 below.

Table 3.12: Data needed for WOFOST Calibration

Crop Data	Soil Data	Weather Data
Planting date	Slope and % surface runoff	Minimum temperature (^{0}C);
Dates of emergence, anthesis and maturity	Soil moisture content in rooted soil	Maximum temperature(^{0}C);
Leaf area index	Ground water level	Daily global irradiation (kj.m^{-2}. d^{-1});
Total biomass	Moisture content at field capacity, wilting point and porosity	Precipitation (mm.d^{-1});
Total Biomass	Rooting depth	Mean wind speed at 2 m above ground level (m.s^{-1});
Distribution of biomass over plant organs		Vapour pressure (early morning, kPa)
Crop composition at harvest		Minimum temperature (^{0}C);

The data below in table 3.13 was adopted from GYGA reports (Ouattara, 2014) and used to check for the quality of the simulations.

Table 3.13: Data used for WOFOST calibration

Crop characteristic/Parameter	Acceptable Range for Burkina Faso
Period from emergence to maturity (days)	85 - 105
Period fractions from emergence to flowering and from flowering to maturity (%)	62% - 38%
LAI-max (m^2 m^{-2})	2 - 7
Total biomass above-ground (kg dry matter per ha)	6750 - 14000
Yield (kg dry matter per ha)	2000 - 4200
Harvest index (yield / total biomass above ground)	0.25 – 0.35

In order to prepare the model for simulations of both the dry and wet conditions as well as with the different soil textures, the Reruns Tab in WCC was used to change the TSUM1(temperature sum from emergence to anthesis) and TSUM2 (temperature sum from anthesis to maturity) until the results were within the ranges shown above in table 3.13.

From table 3.13 the upper limits (UL) and the lower limits (LL) of the crop parameters were checked for calibration and the final values of TSUM1 and TSUM2 were chosen as 840°C and 600°C respectively. After these two values were chosen, they were fixed and all other simulations were done using these as the optimum temperatures. The calibration results were as presented in the figures 16-19 that follow below.

Calibration results:

From the calibration exercise, the following graphs were plotted to assess the readiness of the model.

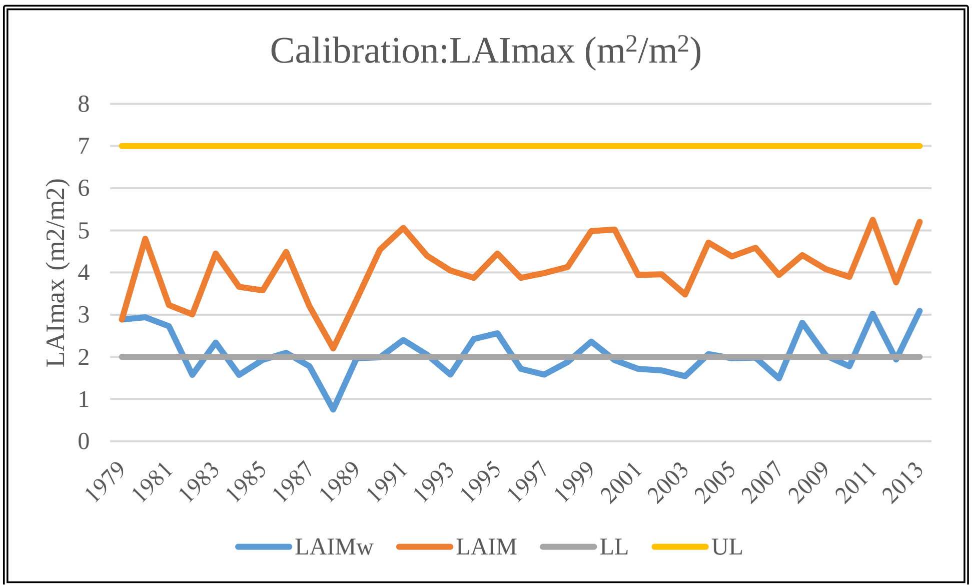


Figure 16: Calibration: LAImax (m^2/m^2)

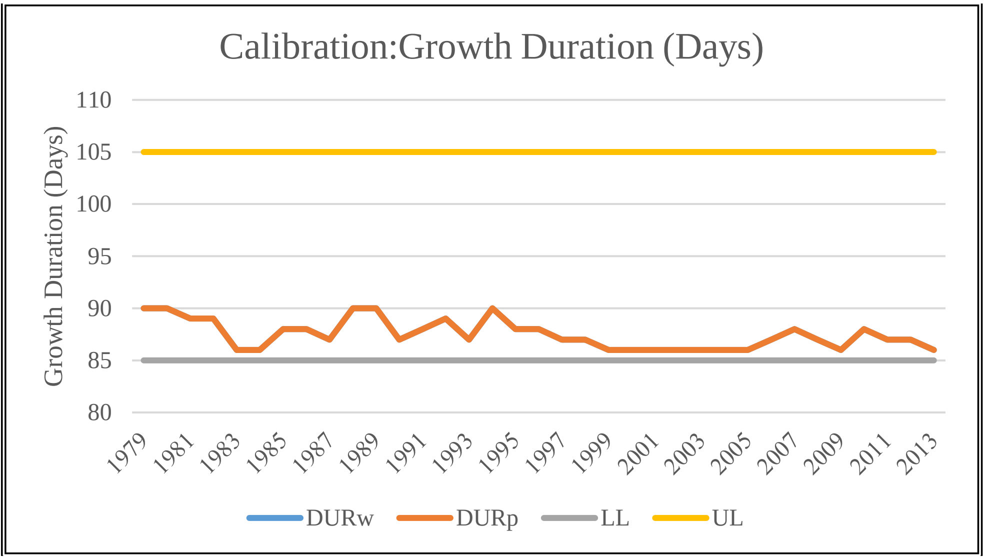


Figure 17: Calibration: Growth Duration (Days)

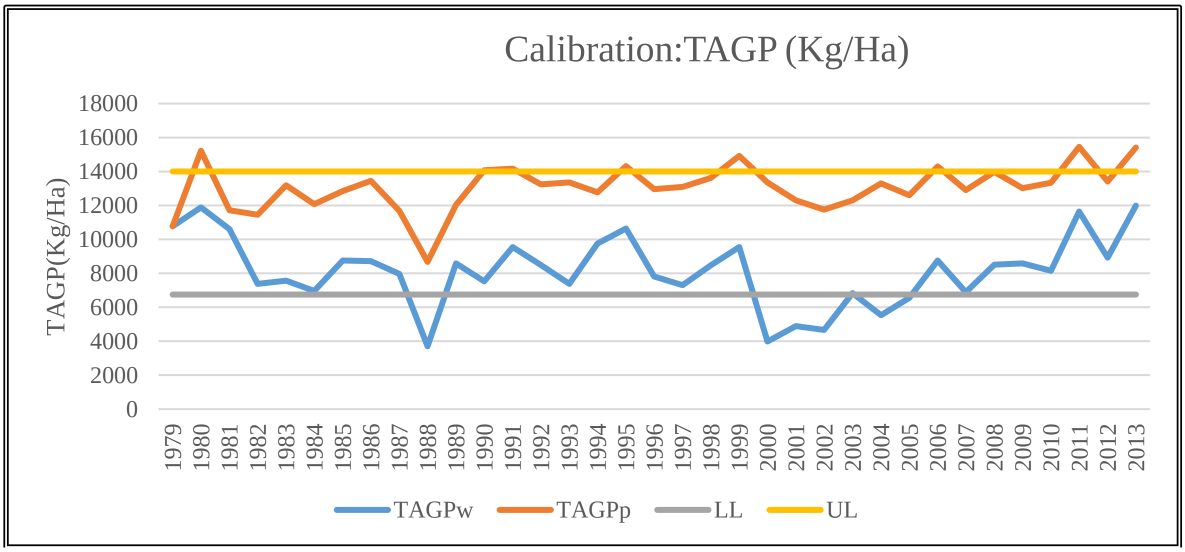


Figure 18: Calibration: TAGP (Kg/Ha)

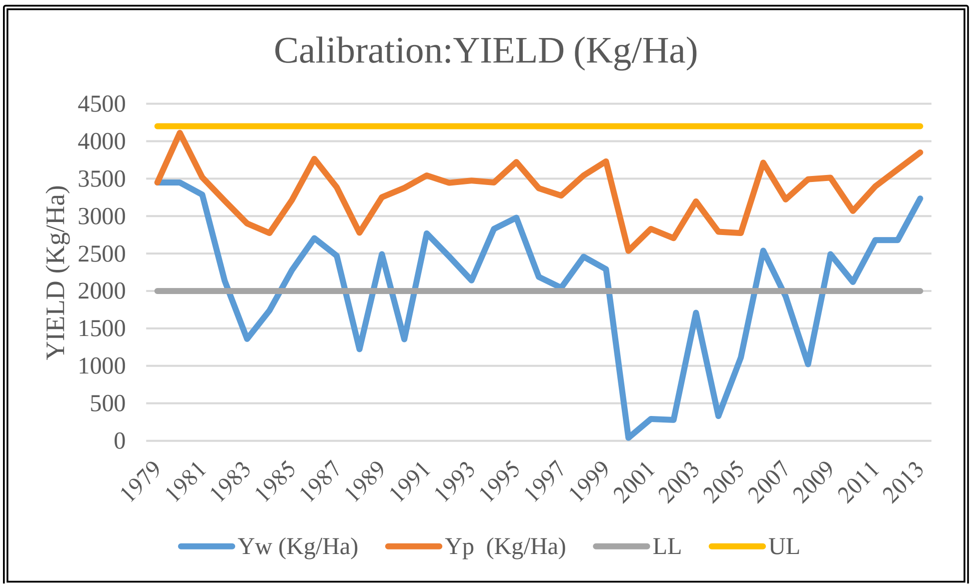


Figure 19: Calibration: YIELD (Kg/Ha)

Table 3.14: Calibrated values used in all simulations

Parameter	Value
TSUM1	840^{o}C
TSUM2	600^{o}C
Start date of water balance	Day 92 of the Year
Earliest sowing date	Day 182 of the Year
Ultimate sowing date	Day 212 of the Year
Maximum duration	90 Days
% of precipitation converted to runoff	3.3%

After the calibration process, the simulations were done for 35 years starting 1979 to 2014 and the data used to determine yield gaps. Simulations were done for the below conditions in table 3.15.

Table 3.15:Variations in Simulation conditions

Soil texture type	Yield type
i. Fine texture	*i.* Potential yield (Yp)
ii. Medium texture	*ii.* Water limited yield (Yw) a. Effects of drought b. Effects of drought and excess water

3.2.3 Determination of Yield Gaps

After determining the Potential Yield (Y_p) and the Water-Limited Yield (Y_w), the Yield Gap (Y_g) was then be determined for each year starting 1979 to 2014.

Equation 18: Yield Gap (Yg) equation

$$\mathbf{Yg = Y_P - Y_W}$$

Where:

Yg – Yield Gap (Kg/Ha)
Yp – Yield Potential (Irrigated) (Kg/Ha)
Yw – Water-limited yield potential (rainfed) (Kg/Ha)

3.2.4 Correlation Analysis and Empirical model development

To establish the relationship between and the yield gap (Yg) and drought level, the Yield gap (Yg) was plotted against the drought indices $eRDI_{st}$ and VHI. The drought level indices (eRDIst and VHI) were taken to be the independent variables while the yield gap (Yg)was taken to be the dependent variable. The datasets were then fitted into curves of the highest possible correlation coefficients while considering the physical meanings and explanations of the curves.

The resulting equations of the best fitted curves were taken to be the empirical model showing the relationship between drought and yields (Agriculture).

3.2.5 Determination of the losses in terms of money

Field interviews were carried out in the village of Kouare (12 Kilometres from Fada N’Gourma town centre) where pearl millet farmers provided information on cost of production and the returns on investment.

The criteria used for choosing the millet farmers were:

1. Must be farming within Gourma province
2. Must be growing pearl millet
3. Must have at least 1 hectare
4. Must be depending on rainfall for production

The cost of production/Ha was estimated by averaging the labour and fertilizer costs for 11 farmers (see summary of collected data in table 3.17 and samples of the questionnaires in annex 4).

The return on investment was estimated by multiplying the average price of pearl millet in the local market by the yield gap (Yg) resulting from a unity change in the 5MJL regression model (see table 3.16 below)

Table 3.16: Impact of unity change in 5MJL

	Yg (Kg/Ha)	5MJL	ROI ($/Ha)
MYgD (5MJL)	775	1	298
MYgDW (5MJL)	1980.79493	1	762

The total cost is the sum of return on investment and cost of production and consequently the total loss is given by equation 19 below:

Equation 19: Economic losses equation

Total losses = ROI ($/Ha) + COP ($/Ha)

Where:

ROI-Return on Investment ($/Ha)

COP-Cost of Production ($/Ha)

Table 3.17: Summary of Fieldwork data

Inputs (Unit)	Farmer 1	Farmer 2	Farmer 3	Farmer 4	Farmer 5	Farmer 6	Farmer 7	Farmer 8	Farmer 9	Farmer 10	Farmer 11
1.Labour (FCFA/par jour)	20000	17500	15000	10000	8000	8000	10000	15000	5000	15000	12500
Days	60	60	60	60	60	60	60	60	60	60	60
Total labour cost	1200000	1050000	900000	600000	480000	480000	600000	900000	300000	900000	750000
2.Fertilizer (Kg)	200	150	150	200	500	500	200	1000	350	2000	1750
Sacs	4	3	3	4	10	10	4	20	7	40	35
Cost	15000	1600			16000	15000			16000		15000
Total fertilizer cost	64000	48000	48000	64000	160000	160000	64000	320000	112000	640000	560000
3. Seeds (Kg)	H	H	H	H	H	H	H	H	H	H	H
4.Area (Ha)	2.5	2	2	3.5	5	2	3	5	10	9	7
5.Yield (Kg)	5000	5000	5000	5000	1200	1100	4000	3500	3500	6000	6000
Sacs	50	50	50	50	12	11	40	35	35	60	60
Kilo/sac	100	100	100	100	100	100	100	100	100	100	100
Sowing date	2-July	2-July	1-June	1-June	June	June	June	June	15-Mai	June	June
Harvesting date	Nov.	Nov.	Nov.	Nov.	Nov.	Nov.	Nov.	Oct.	Nov.	Nov.	Nov.
Market price of pearl millet (FCFA/Kg)	200	200	225	200	210	210	210	200	200	230	200
Willingness to be Insured	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Willingness to pay (FCFA)	15000	7500	2500	2000	1000		2500	1000	1000	500	500

H: Last season’s harvest is used for planting next season.

3.2.6 MCDM and (MCDA) for selecting Drought mitigation options.

MCDM and MCDA was used to asses and propose the suitable Drought Mitigation Options (DMO) for the province of Gourma. By scrutinising the current policy strategies employed by the Gourma administration as well as the national government of Burkina Faso, new DMOs geared towards protection of farmers against drought proposed.

Firstly, the drought mitigation options that are employed world over were identified for assessment in this case of Gourma province. The identified options are presented in table 3.20 below. The goal of this MCDM process was to propose options that can cushion the farmers against the impacts of drought. To assess these options, the criteria adopted was based on:

5.Cost of implementation of the option and,
6.Impact on Yield gap (Yg)

The two criteria were found to be independent, quantifiable, related with most of the options and were represented in the same scale of between 0 to 1.

Determination of cost of implementation

In order to determine the cost of implementing an option, an assessment of what already exists within the province of Gourma was done through interviews and literature review of reports by the water utility company of Gourma province which is in charge of the East Region of Burkina Faso. As reported in the water resources inventory report by DGAE, the sources of water are as presented in table 3.18 below.

Table 3.18: Water sources of East Region (Gourma)

Source	**Dams**	**Small dams *(Boulis)***	**Lakes**	**Ponds**
Number	3	2	5	66

Source: (KABORE, GAMENE, & HIEN, 2016)

In the KABORE et al., (2016) water resources inventory report, there exists the sources of water to both Niger and Nakambé basins as well as three major types of aquifers in the region namely:

i. Loose rock aquifers (*Les aquifères de roches meubles*)
ii. Cracked aquifers (*Les aquifères fissurés*)
iii. Karst aquifers (*Les aquifères karstiques*)

The information was further verified through field visits to the province and interviews with the Director of DGAE (Direction Générale de l'Agence de l'Eau du Gourma)

Eng. Madam Lationo Flora as well as the director of policy formulation at MAAH - Ministry of Agriculture and Water Resources *(Ministère de l'Agriculture et des Aménagements Hydraulique)* under DGESS – Directorate-General for Sectoral Statistiques *(Direction générale des statistiques sectiorielles)* of Burkina Faso Mr. Touré Adama (See questionnaires attached in annex 5).

From the interviews and other information collected, an inventory of the existing infrastructure necessary for implementation of the DMO was formed and used to determine the cost of implementation. (See inventory in table 3.21)

1. Cost of implementing DMO

The cost of implementing each DMO was arrived at as the cost of the infrastructure that is missing. Costs were awarded as values between 0 and 1 by comparing amongst the options. The higher the relative cost the closer the awarded score is to 0 and the lower the relative cost, the closer the awarded score is to 1.

2. Impact on Yield gap (Yg)

The impact of the DMOs on Yield gap (Yg) was assessed from the point of the ability of the technology to provide water at all times for the physical options while its ability to reimburse the farmer his/her losses resulting from drought were assessed for the monetary options. The reasoning behind this was that if the technology can keep more water in the root zone, then it can reduce the yield gap much more than the technologies that can't keep more water in the root zone. The higher the ability of the technology to reduce the yield gap, the higher the score was given. Here the scores were awarded as either 0, 0.5 or 1. Zero (0) being low, 0.5-medium and 1-high.

Aggregation of criteria

The final score was arrived at by aggregation of the two scores using a weighting formula where the two criteria were weighted at 50% each. The score was arrived at by adding the two values. (see performance results in table 3.22)

Equation 20: MCDM Aggregation equation

$$Final\ score = 50\%(Cost\ of\ implementation\ ) + 50\%(Impact\ on\ Yg)$$

Table 3.19: Classification of drought mitigation measures

	Short-term actions	**A.S.***	**Long-term actions**	**A.S.***
Supply increase	i)Use of additional sources of low-quality water and/or high exploitation costs ii)Over-exploitation of aquifers iii)Increase diverted waters by relaxing ecological or recreational use constraints (e.g. minimum instream flow, minimum lake level) iv)Improvement of existing water systems efficiency through leak detection programs, modified operation rules, etc.	U,A,I,R U,A,I U,A,I U, A,I	Augmentation of available resources through: i)New surface reservoirs ii)Inter-basin and within-basin water transfers iii)Conveyance network for bidirectional exchanges iv)Reuse of treated wastewater v)Control of evaporation losses vi)Use of aquifers as groundwater reserve vii)Rainfall augmentation	 U,A,I,R U,A,I,R U,A,I A,I U,A,I U,A,I U,A,I
Demand reduction	i)Restriction of some municipal uses (car washing, gardening) ii)Restriction of the irrigation of some crops (e.g. annual) iii)Pricing iv)Public information campaign for voluntary water saving v)Mandatory rationing	U A U,A,I U,A,I U,A.I	i)Dual distribution network for municipal use ii)Water recycle in industries iii)Use of less water consumptive crops iv)Agronomic techniques for reducing water consumption v)Sprinkler or drip irrigation vi)Shift from irrigated to dry crops vii)Economic incentives for private investments in water conservation	U I A A A A U,A,I
Impact minimization	i)Temporary reallocation of water resources (on the basis of assigned use priority) ii)Public aid to compensate loss of revenue iii)Tax relief (reduction or delay of payment deadline) iv)Rehabilitation programs	U,A,I U,A,I U,A,I U,A,I	i)Development of an early warning system ii)Reallocation of water resources on the basis of water quality requirements iii)Use of drought resistant plants iv)Development of a drought contingency plan v)Mitigation of economic and social impacts through voluntary insurance, pricing and economic incentives vi)Education activities for improving preparedness to drought	U,A,I U,A,I A U,A,I,R U,A,I U,A,I

*Affected Sector: U =Urban; A = Agricultural; 1= Industrial; R = Recreation. Source: (Vogt & Somma, 2000)

Table 3.20: Table of proposed DMOs

DMO-Drought Mitigation Option (DMO)
1. Use of additional sources of low-quality water and/or high exploitation costs
2. Over-exploitation of aquifers
3. Increase diverted waters by relaxing ecological or recreational use constraints (e.g. minimum instream flow, minimum lake level)
4. Improvement of existing water systems efficiency through leak detection programs, modified operation rules, etc.
5. New surface reservoirs
6. Inter-basin and within-basin water transfers
7. Reuse of treated wastewater
8. Mulching using crop residues, will enhance the organic matter content also besides reducing the evaporation
9. Mulching using polythene sheets
10. Shading
11. Subsurface drip irrigation
12. Use of aquifers as groundwater reserve
13. Rainfall augmentation
14. Restriction of the irrigation of some crops (e.g. annual)
15. Pricing
16. Public information campaign for voluntary water saving
17. Mandatory rationing
18. Water recycle in industries
19. Use of less water consumptive crops
20. Agronomic techniques for reducing water consumption
21. Sprinkler or drip irrigation
22. Shift from irrigated to dry crops
23. Economic incentives for private investments in water conservation
24. Temporary reallocation of water resources (on the basis of assigned use priority)
25. Public aid to compensate loss of revenue
26. Tax relief (reduction or delay of payment deadline)
27. Rehabilitation programs
28. Development of an early warning system
29. Reallocation of water resources on the basis of water quality requirements
30. Use of drought resistant plants
31. Development of a drought contingency plan
32. Mitigation of economic and social impacts through voluntary insurance, pricing and economic incentives
33. Education activities for improving preparedness to drought

Table 3.21: Inputs required to implement DMO

Inputs required to implement the DMO	Availability of the Inputs required to implement the DMO
1. WSN, WWCS	0%
2. Aquifer, Pumps, Reservoirs	67%
3. River, WSN	50%
4. WSN, Leak detection system	0%
5. River, Stream, WSN	67%
6. IB-WTS	0%
7. WSN, WWCS, WWTP	0%
8. Crop residues	100%
9. Polythene sheets	100%
10. Trees	100%
11. Subsurface drip kits	100%
12. Aquifer, Injection wells & Equipment, Additional water source	33%
13. Rainfall Augmenter	0%
14. Law restricting irrigation of some crops during drought	0%
15. Pricing Policy-high prices to encourage efficient water use	100%
16. Sensitization campaigns	100%
17. Water rationing Policy	100%
18. Policy requiring all industries to have recycling plants	0%
19. Crop seeds	100%
20. Conservation Agriculture/Tillage machines	100%
21. Sprinkler Irrigation kits	100%
22. Crop seeds	100%
23. Tax holidays for Irrigation equipment, cheap loans	100%
24. Temporary reallocation policy	100%
25. Donations by well wishers	100%
26. Tax holidays for production inputs	100%
27. Rehabilitation plans for drought hit areas	100%
28. DEWS	100%
29. Reallocation policy	100%
30. Crop seeds	100%
31. Consultation of all stakeholders in water sector	100%
32. Willingness of farmers to protect themselves against drought	100%
33. Farmer sensitization	100%

Table 3.22: DMO performance table

DMO(Number)	Cost of implementing the DMO (0-1)	Impact of implementing DMO on yield gap (0,0.5,1)	Performance (%)
1	0.4	0.5	0.45
2	0.6	0.5	0.55
3	0.7	0	0.35
4	0.5	0	0.25
5	0.7	0.5	0.6
6	0.6	0.5	0.55
7	0.3	0.5	0.4
8	1	1	1
9	0.9	1	0.95
10	0.8	0.5	0.65
11	0.4	1	0.7
12	0.4	0.5	0.45
13	0.4	0.5	0.45
14	0.9	0.5	0.7
15	1	0	0.5
16	1	0	0.5
17	1	0	0.5
18	1	0	0.5
19	0.8	1	0.9
20	0.2	1	0.6
21	0.3	1	0.65
22	0.8	1	0.9
23	1	1	1
24	1	0.5	0.75
25	1	0	0.5
26	1	0	0.5
27	1	0	0.5
28	1	0.5	0.75
29	1	0	0.5
30	0.8	1	0.9
31	0.8	0.5	0.65
32	1	1	1
33	0.9	0.5	0.7

Note: *Cost of implementing is higher towards zero (0) and lower towards (1)
*Impact is given as:

0: Low impact
0.5: Average impact
1: High impact

3.2.7 Development of *Le Guardien de l'espoir* Insurance Scheme

This was a system designed for the low-income farmers, to be managed by them and to protect themselves from the harsh reality of drought. This insurance regime is similar to a net single premium (NSP) which is normally a premium paid in lump sum to the insurer and doesn't comprise contingencies, management and other expenses such as taxes and operating expenses. In this case, the villagers are the insurers and they contribute each month to help protect themselves from drought.

In order to arrive at the amount of money that each farmer needs to contribute every month, the opportunity cost resulting from droughts were calculated for the three experienced drought levels in the province since 1979-2013 as shown below:

Table 3.23: History of losses

Drought class	**Frequency**	**eRDIst value**	**Losses ($/Ha) MYgD (5MJL)**
Mild drought	9%	-0.990	1711
Moderate drought	11%	-1.490	2230
Severe drought	6%	-1.990	2963

The present value of $1 was determined using an annual interest rate of 4.5% as reported in ("Burkina Faso Interest Rate | 2010-2018 | Data | Chart | Calendar | Forecast," 2018).The annual premium was then determined as the product of the present value, the insured amount and the probability of drought for each of the drought levels.

Equation 21: Annual premium equation

Annual premium ($) = Probability of drought × Insured amount × Present value ($1)

Equation 22: Monthly premium equation

Monthly payable amount ($) = Annual premium ($)/12months

CHAPTER 4. RESULTS

4.1 Analysis of Drought

Starting 1979 to 2014, eRDIst results show that there were 3 agricultural drought events in the province of Gourma which started in the years 1983, 1999 and 2008 but with different durations. The 4month, 5month and 6month analysis of the farming season starting June and July show that 1979 was the wettest year while 2000 was the driest year in Gourma province. From the eRDIst results, considering the 4, 5 or 6-month time scales gives the same number of drought events. (see figures 20-23)

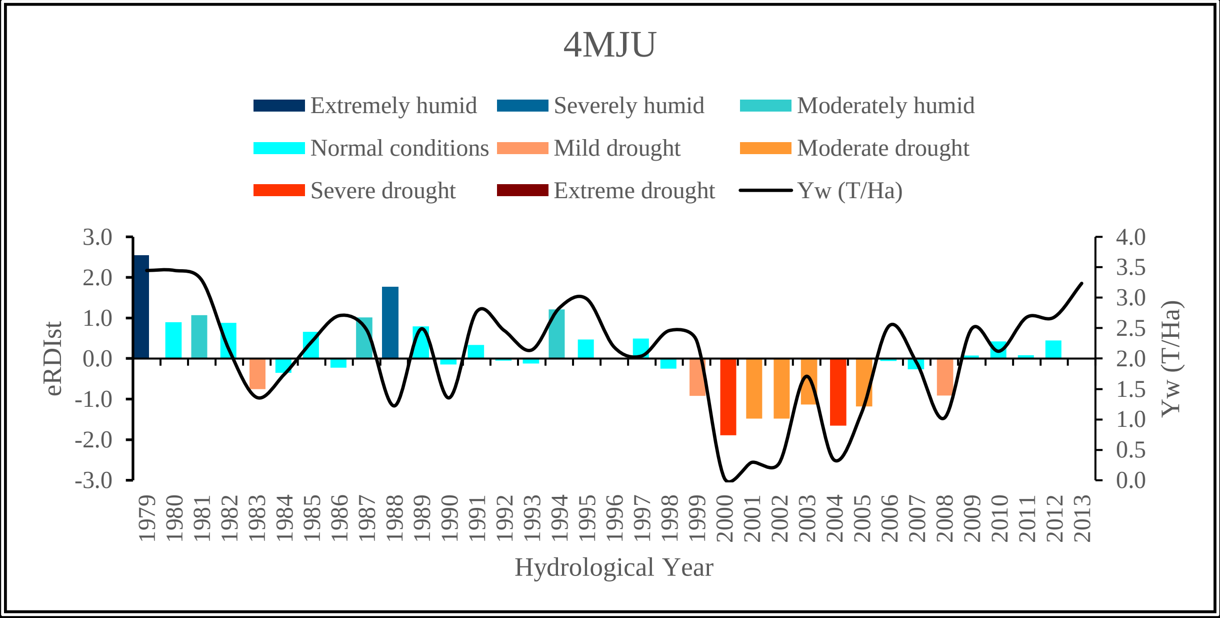


Figure 20: 4MJU Drought conditions from 1979-2013 in Gourma province

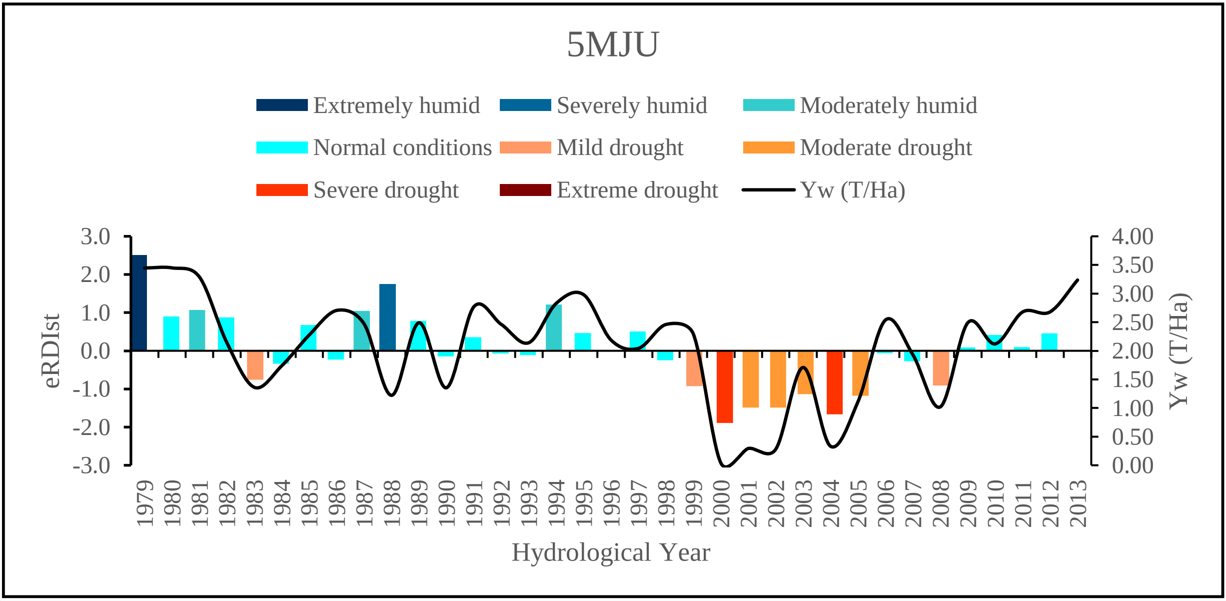


Figure 21: 5MJU Drought conditions from 1979-2013 in Gourma province

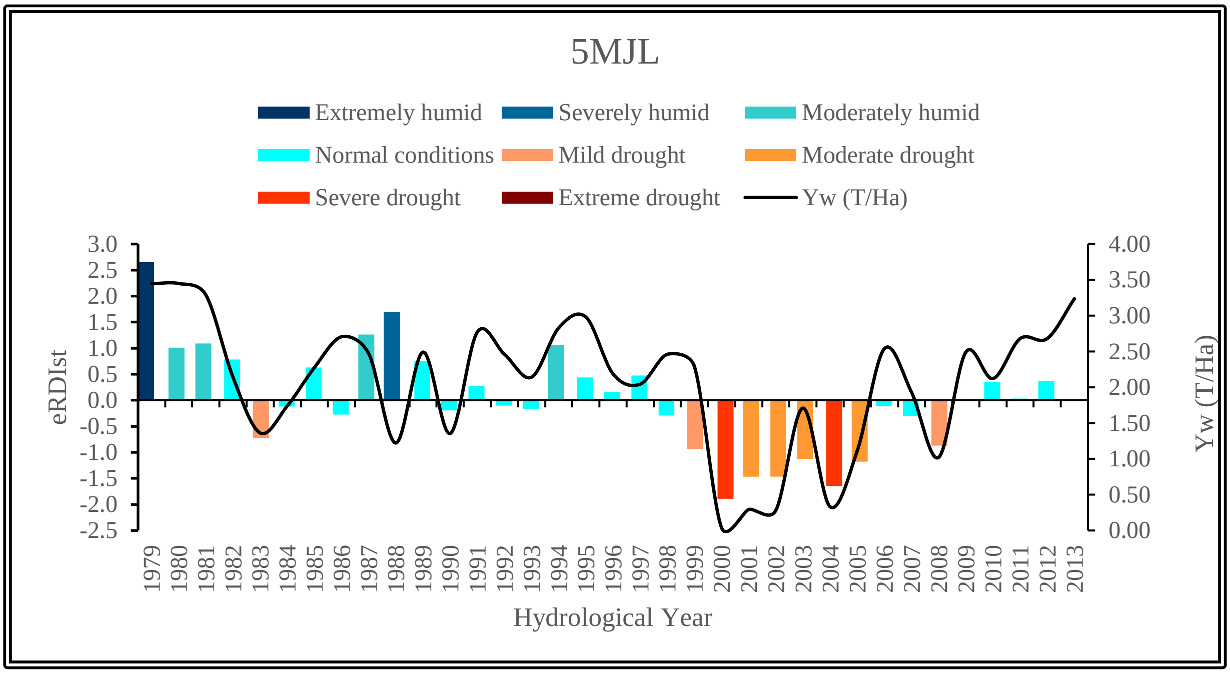


Figure 22: 5MJL Drought conditions from 1979-2013 in Gourma province

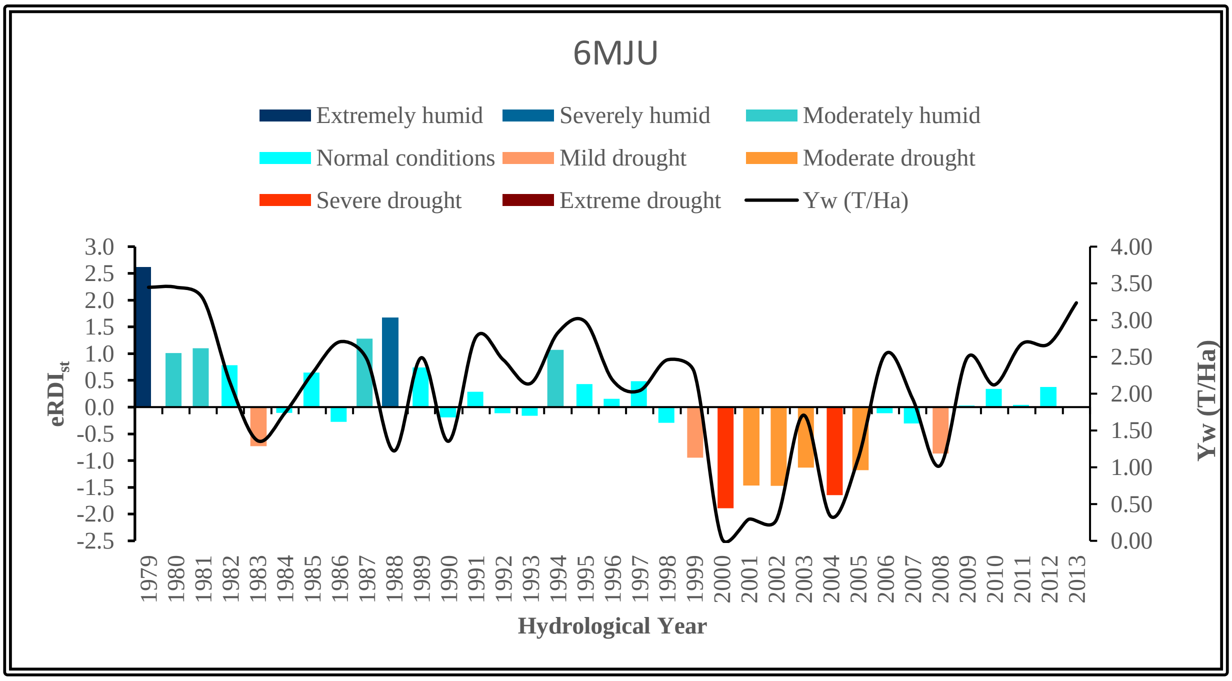


Figure 23: 6MJU Drought conditions from 1979-2013 in Gourma province

4.1.1 Severity, Intensity and duration of drought

Severity of the drought events as per eRDIst, evidently show that there were 3 years of Mild drought, 4 years of moderate drought and 2 years of severe dought. The most severe drought occurred in 2000 with an eRDIst value of -1.89 and the least severe drought in 1983 with an eRDIst value of -0.75. In terms of intensity, the period between 1999 and 2005 was the most intense with continuous drought conditions throughout the period. For the durations, the shortest events were in 1983 and 2008 while the longest was between 1999 and 2005 lasting at least 6 months each year. (See figures 24, 25 and table 4.1)

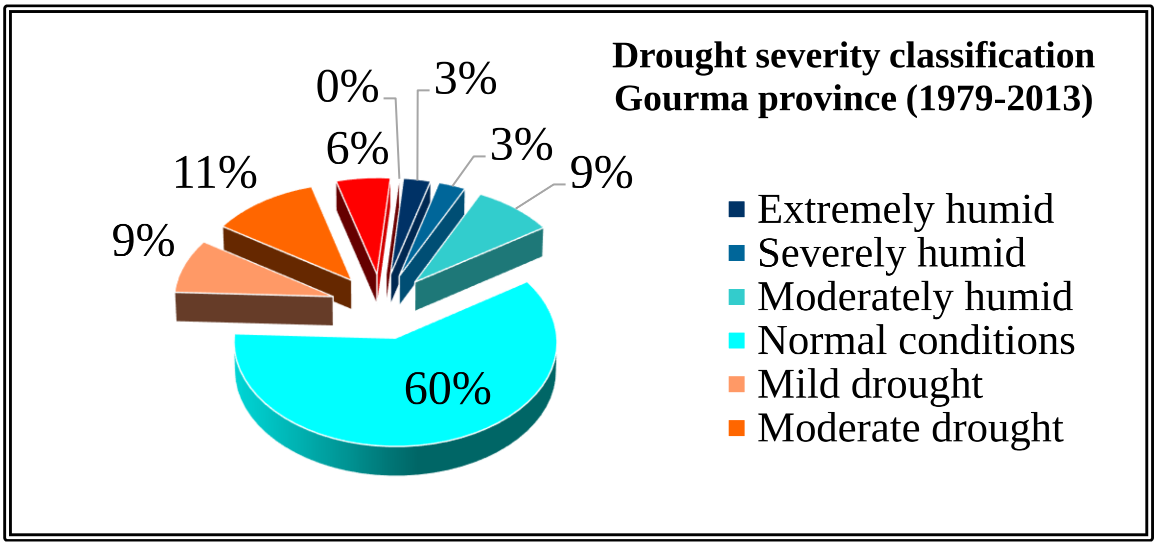


Figure 24: Drought severity 1979-2013 in Gourma province

Table 4.1: Drought frequency in Gourma province

Drought level	**No. of Events (x)**	**Frequency (x/35)**	**Frequency (%)**
Extreme drought	0	0.00	0.00
Severe drought	2	0.06	5.71
Moderate drought	4	0.11	11.43
Mild drought	3	0.09	8.57

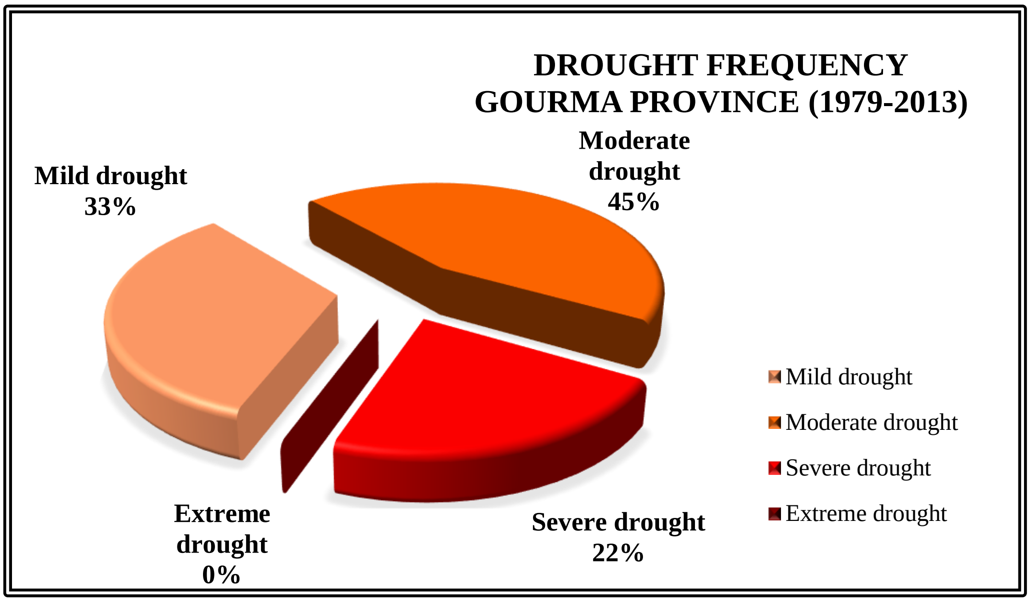
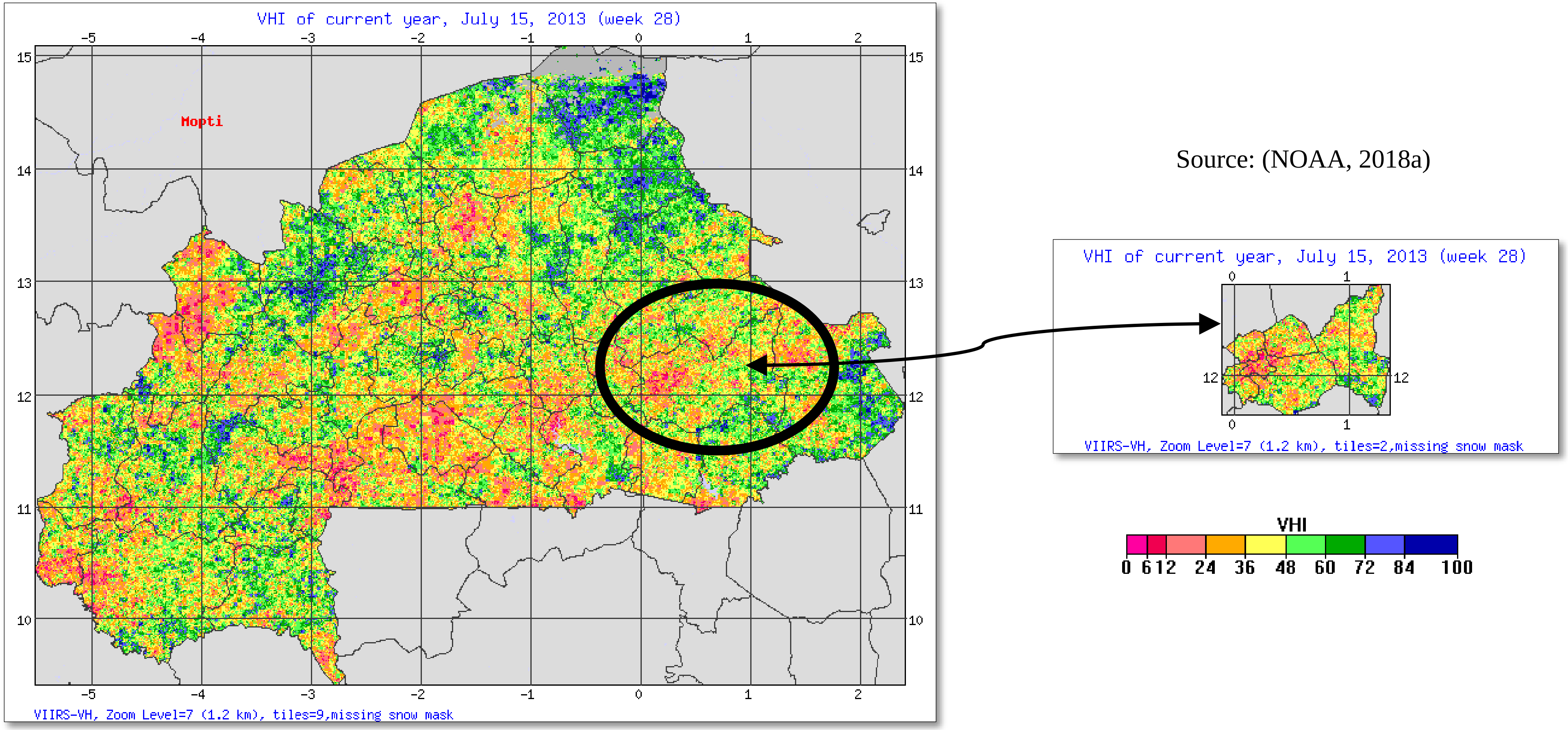


Figure 25: Drought frequency pie chart

4.1.2 Spatial characterisation using VHI

Satellite images of Burkina Faso from 2013 to 2018 show that Gourma province is amongst one of the provinces that is drought prone. From the satellite images, 2018 shows that the entire East Region was the worst hit by the drought conditions in the country. Within Gourma province, the area around Fada N'Gourma city centre is the worst affected by the dry conditions. See figures 26-31.

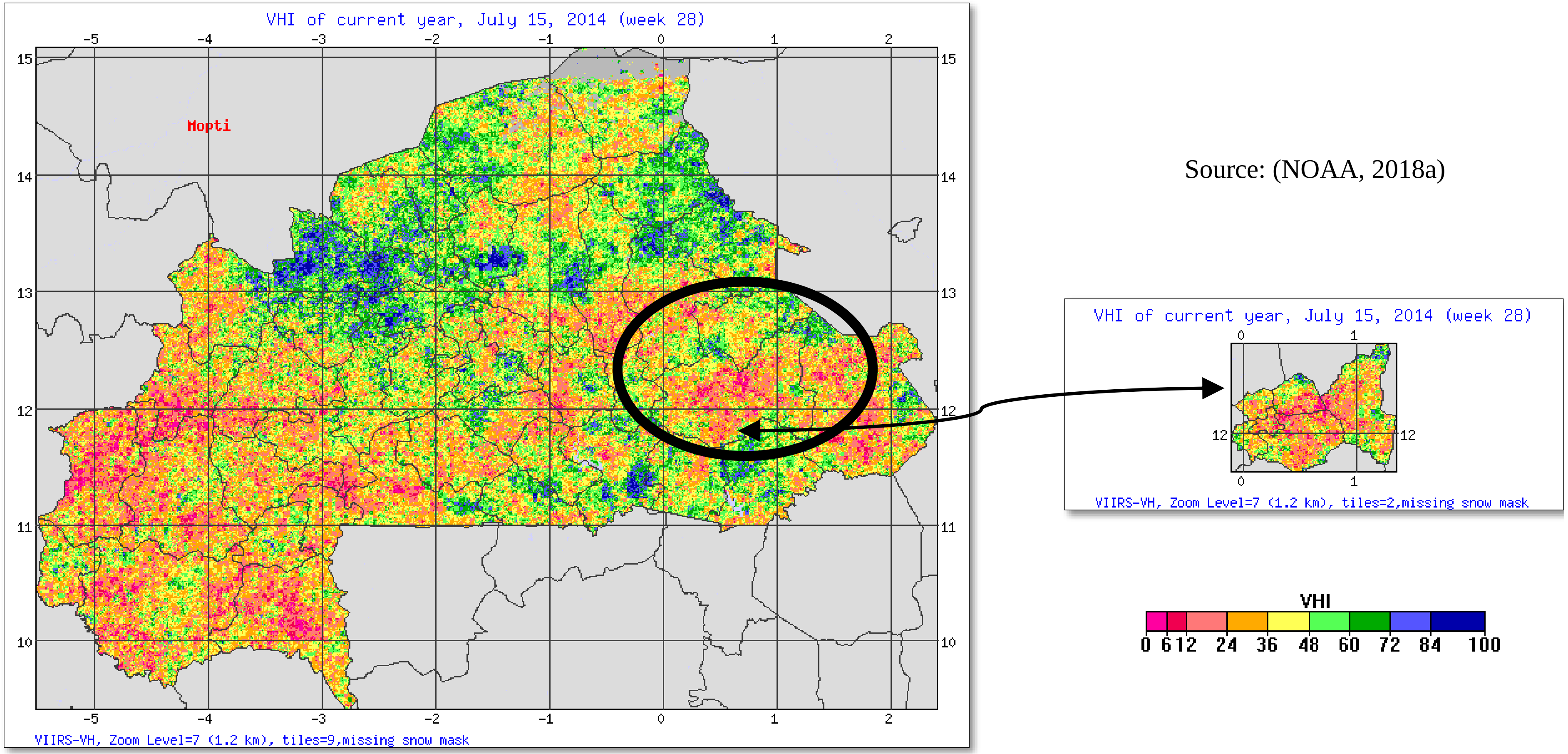
2013



Source: (NOAA, 2018a)

Figure 26: VHI 2013

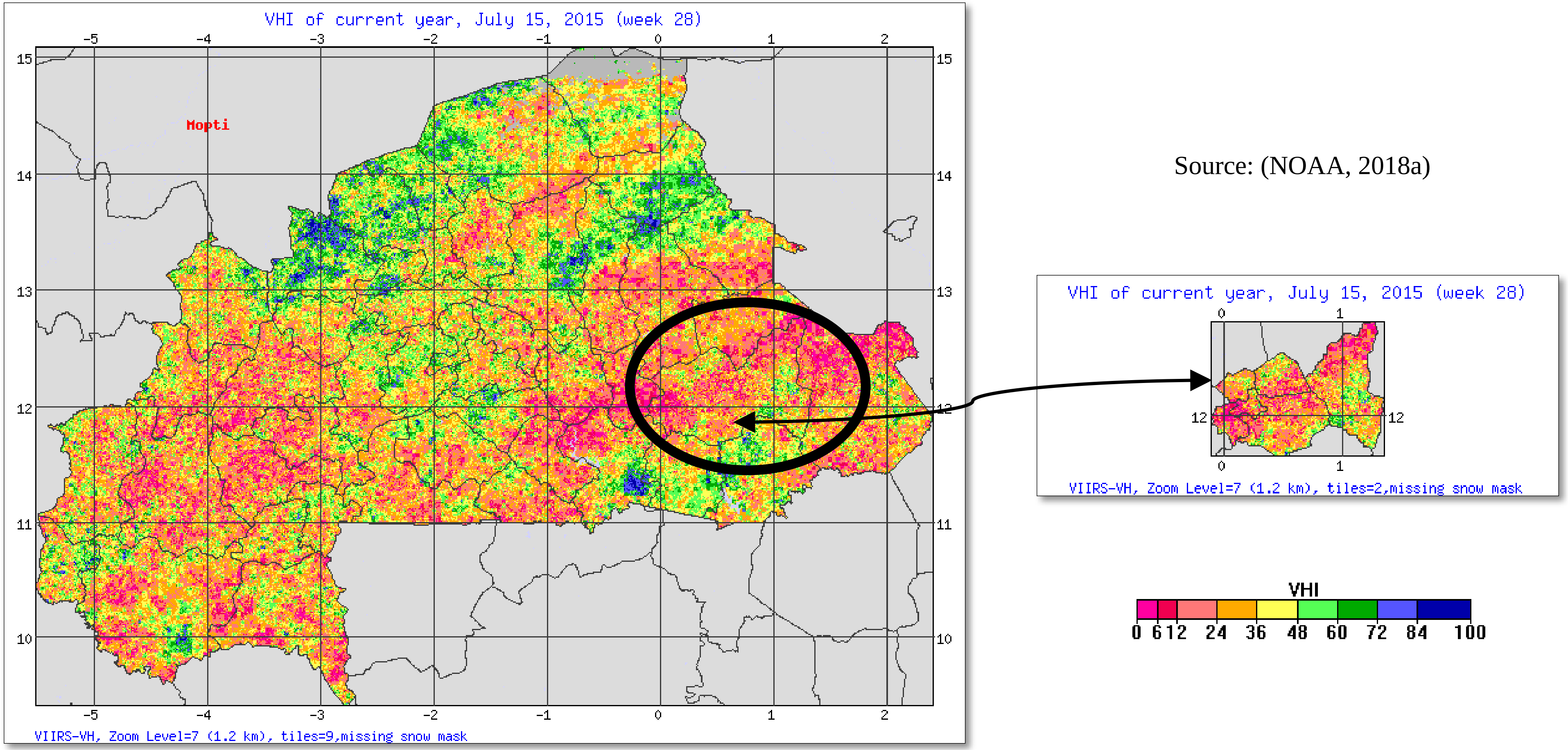
2014



Source: (NOAA, 2018a)

Figure 27: VHI 2014

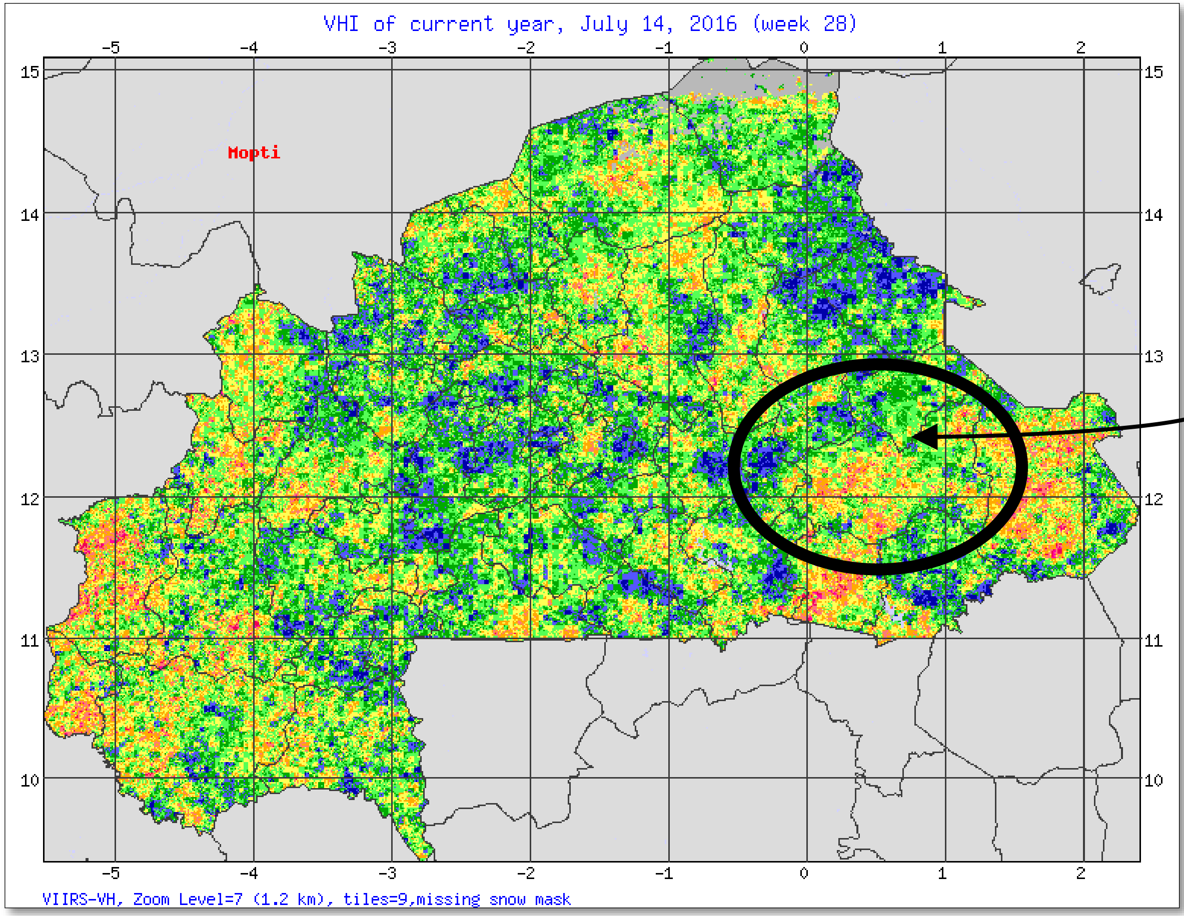
2015



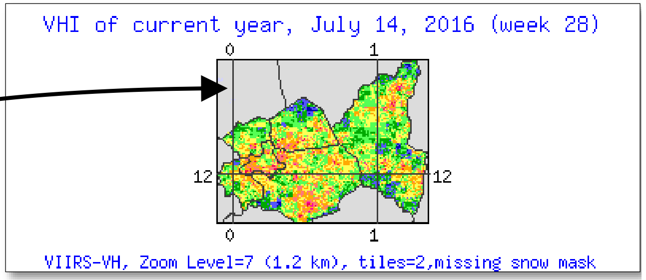
Source: (NOAA, 2018a)

Figure 28: VHI 2015

2016



Source: (NOAA, 2018a)



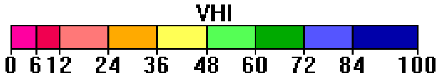
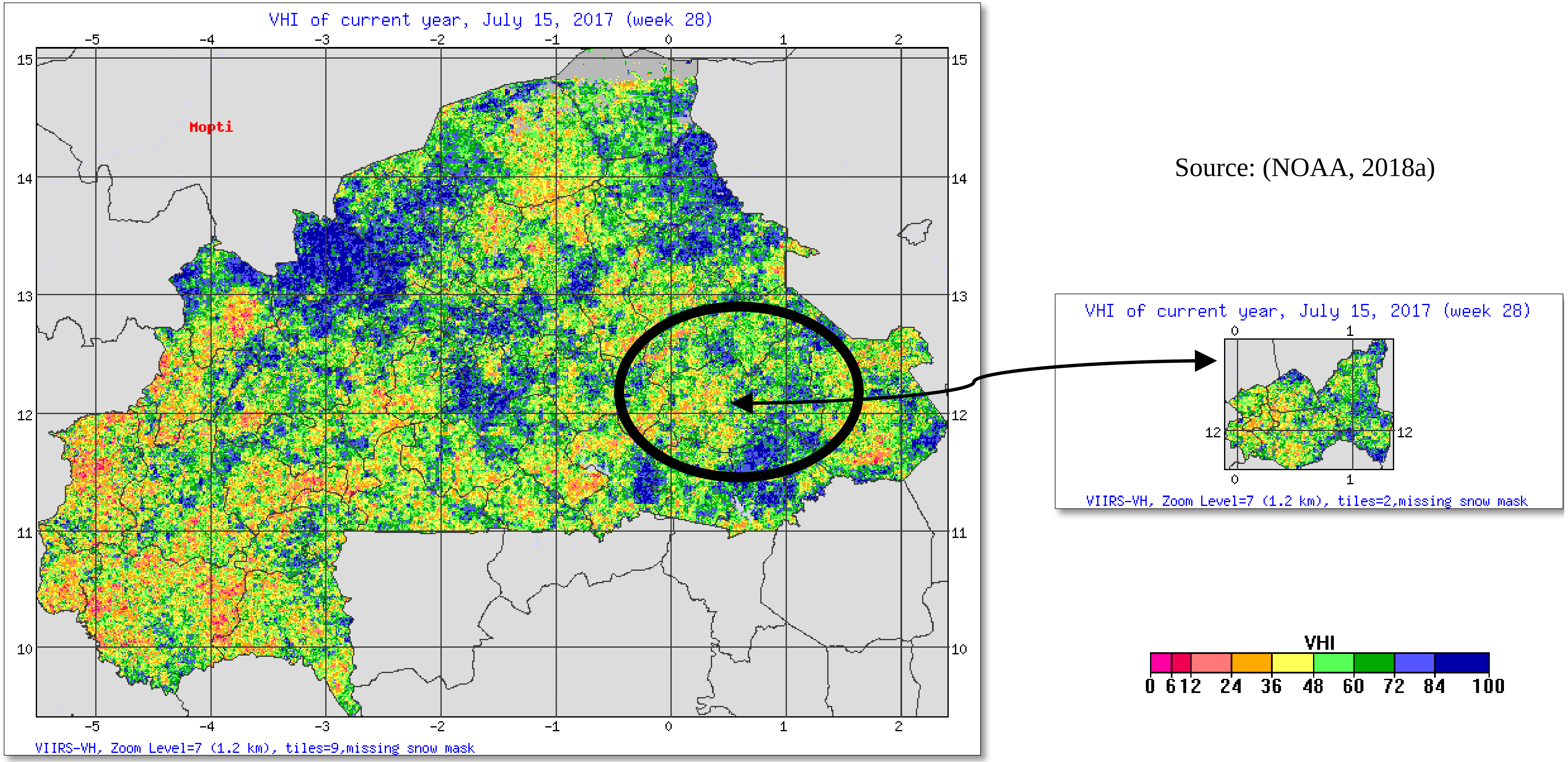


Figure 29: VHI 2016

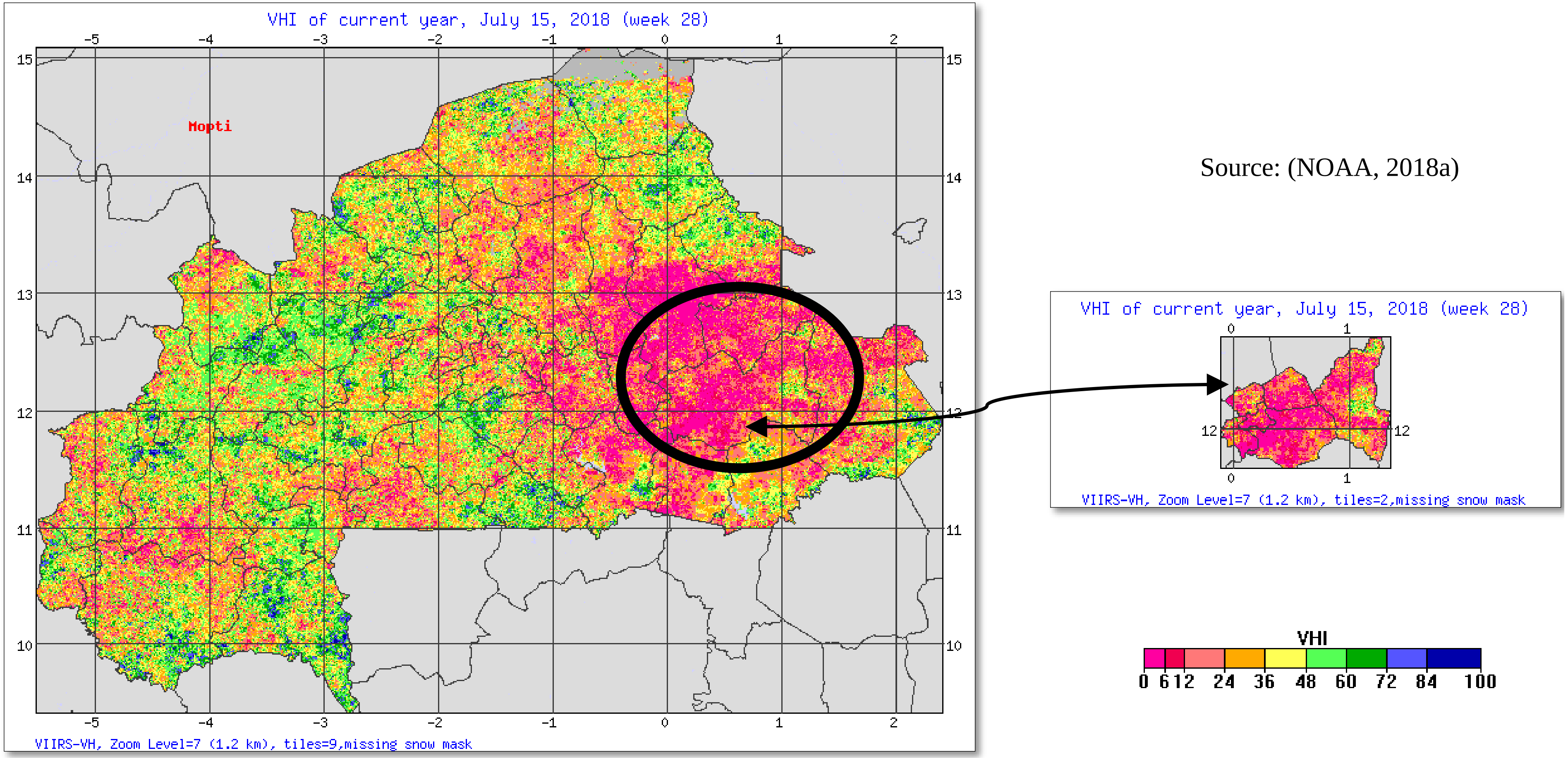
2017



Source: (NOAA, 2018a)

Figure 30: VHI 2017

2018



Source: (NOAA, 2018a)

Figure 31: VHI 2018

4.2 Crop Yields

WOFOST uses the weather data only to simulate Yp and from the table 4.2 below, the Yp is constant for all soil types. The mean growth duration (DUR) is 88 days while the total above ground production (TAGP) for the Yw varies. The medium texture soils produce more pearl millet with TAGP of more than 7000 Kg/Ha. The harvest index (HINDEX) is approximately 0.25 which translates to the medium soils producing the highest yield in Kg/Ha at about 1905 Kg/Ha simulated under drought conditions only. Lowest yield is from the fine textured soils simulated under drought and low oxygen conditions. The table 4.2 below summarises the crop yield results between 1979 – 2013. A sample of the results file is given in annex 6.

Table 4.2: Table of crop yield results summary (Averages)

	DUR	TAGP	LAIM	HINDEX	Yield (Kg/Ha)
FYpDW	88	12720	4.01	0.25	3180
FYwDW	88	5737	1.36	0.25	1434.25
FYpD	88	12720	4.01	0.25	3180
FYwD	88	6669	1.58	0.26	1733.94
MYpD	88	12720	4.01	0.25	3180
MYwD	88	7939	2.09	0.24	1905.36
MYpDW	88	12720	4.01	0.25	3180
MYwDW	88	7306	1.82	0.24	1753.44

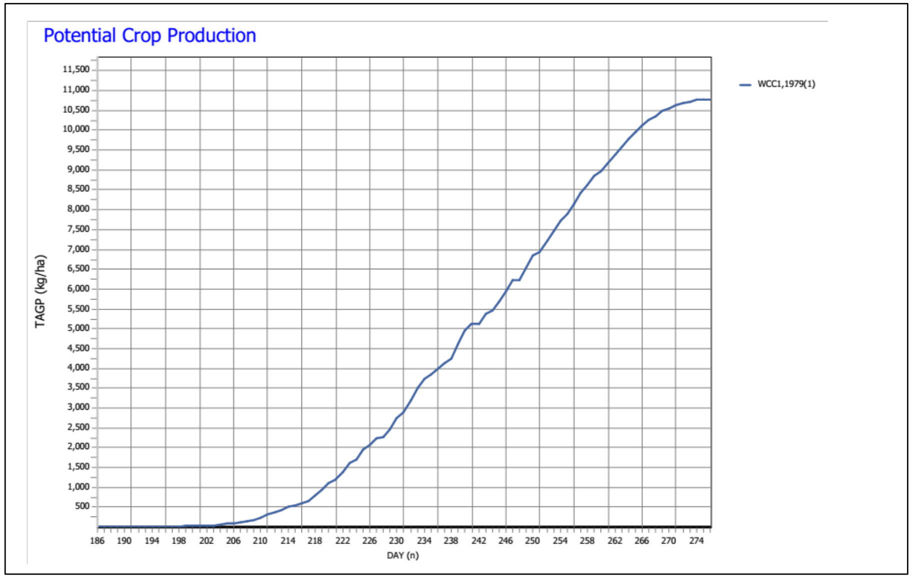
From the above crop yields summary, it’s observed that the potential yield is not affected by the soil type and thus the averages are the same for all the varying conditions. The highest yields are from medium texture soils simulated under drought only conditions while lowest yield is from the fine textured soils under drought and low oxygen conditions.

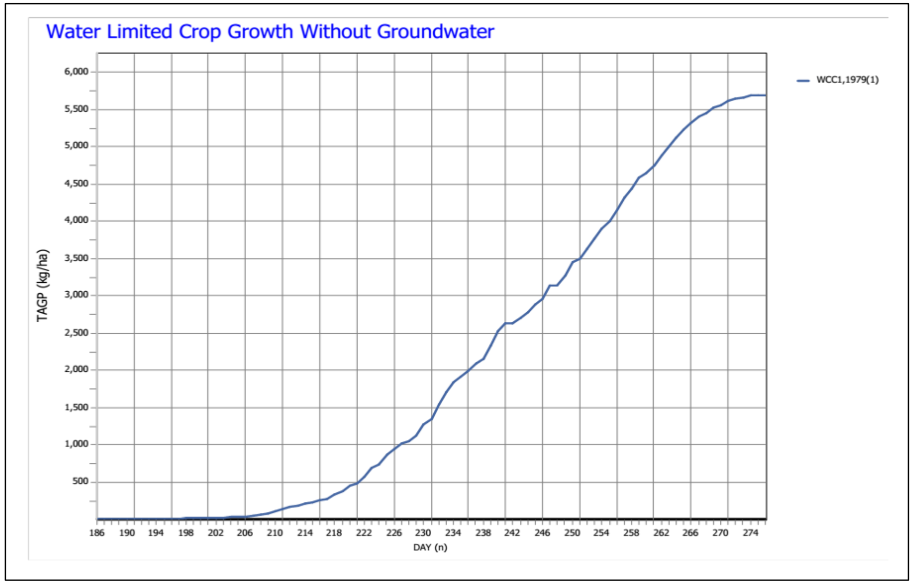
It is also evident that extremely wet conditions affect the yields, this is seen in the case of 1979 which is the wettest year. The Yg in fine soils is 2.9t/Ha while for medium soils its 1.5t/Ha. This further shows that the fine texture soils hold water in the relatively lesser air spaces available hence denying the crop of proper aeration while the medium texture soils are well drained and provide the much-needed aeration for the crop.

From figure 32 below, the pearl millet growth depicts the sigmoid growth curve consisting of exponential growth, linear growth and decreasing growth. In the wettest year, the water in the soil is coming from precipitation and while part of it is used up in the root zone, the rest is lost through leaching into deep soils, surface runoff and transpiration.

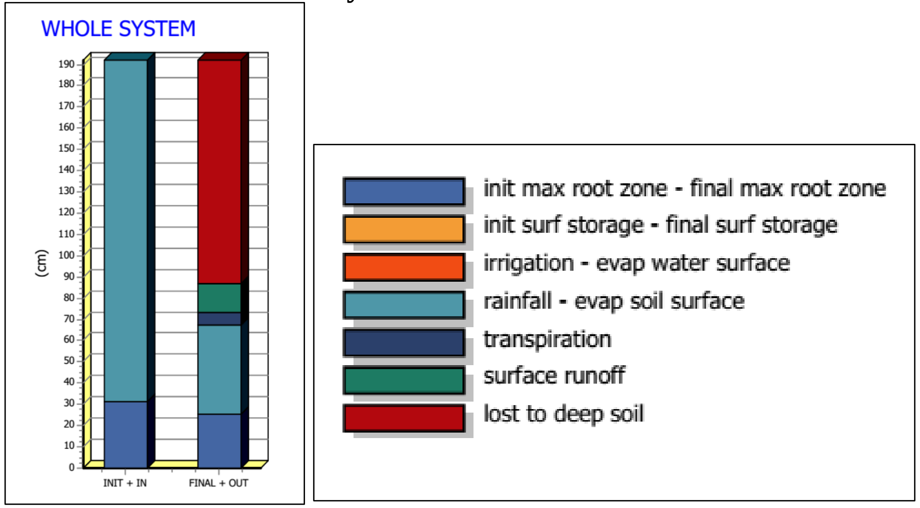
Figure 33 shows the Yg in the driest year that is 2000 where for fine soils, the Yg is at 2.4t/Ha while for medium soils, Yg is at 2.5t/Ha. The moisture in the root zone is mainly added by the crop’s transpiration.

Figure 32: Sample crop yield results - WETTEST YEAR: 1979





Water balance – Whole system



Water balance – root zone

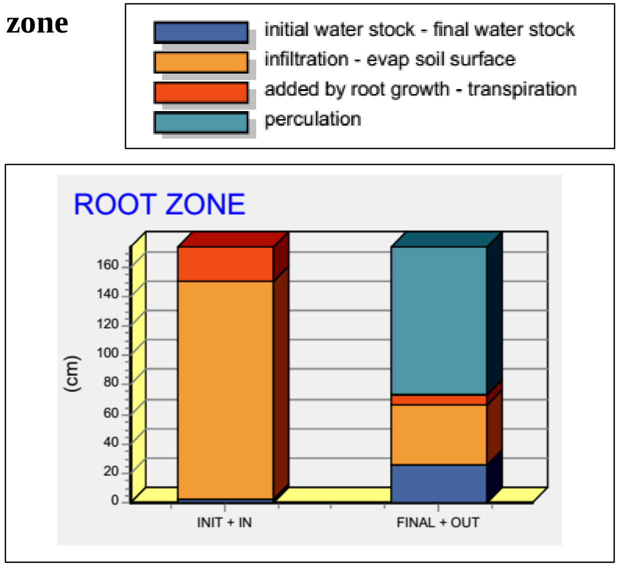
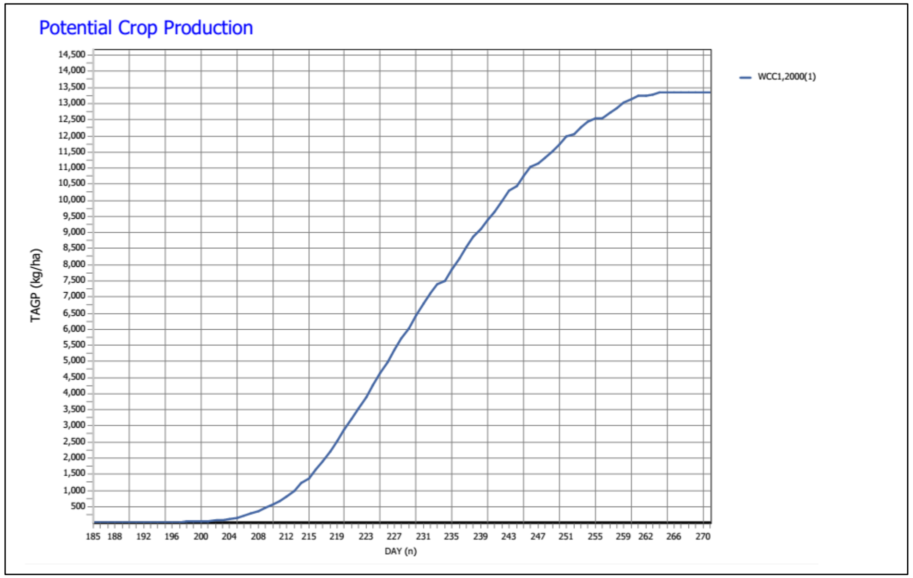
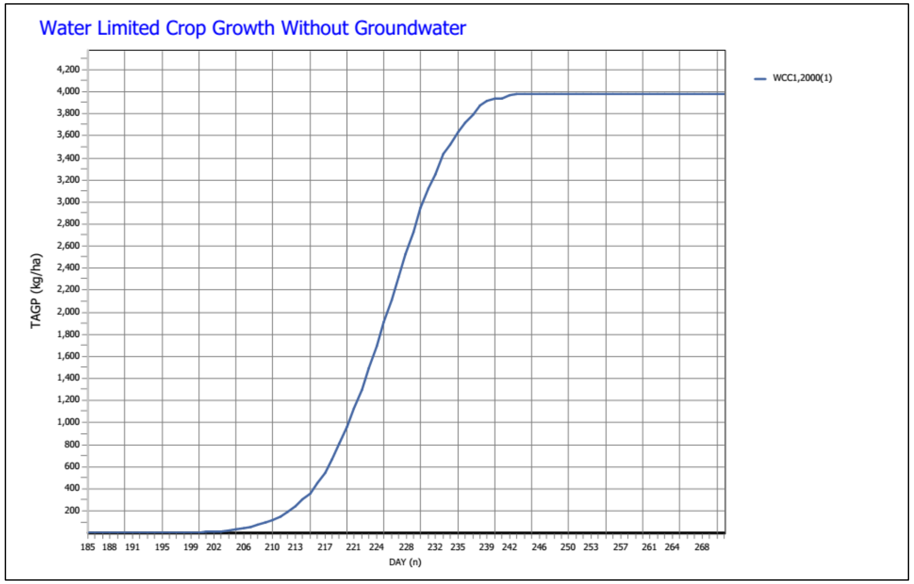
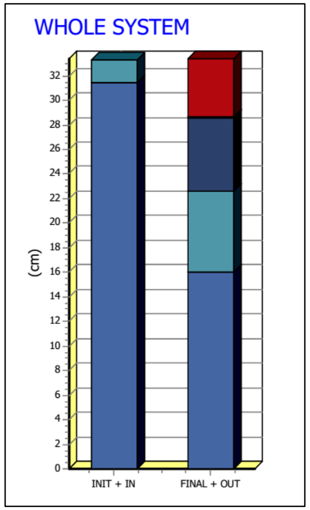


Figure 33: Sample crop yield results - DRYEST YEAR: 2000





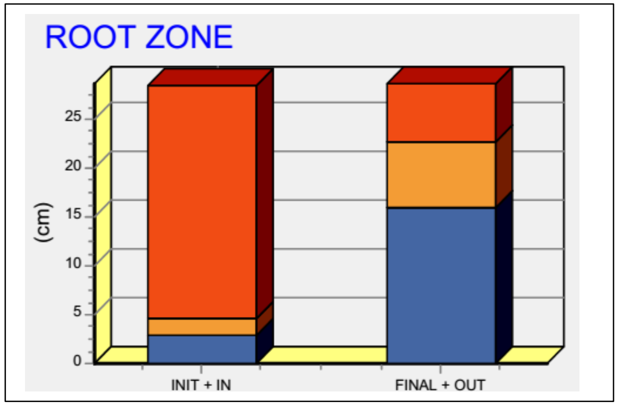
Water balance – Whole system



🟦 init max root zone - final max root zone
🟧 init surf storage - final surf storage
🟥 irrigation - evap water surface
🟦 rainfall - evap soil surface
🟦 transpiration
🟩 surface runoff
🟥 lost to deep soil

Water balance – root zone

🟦 initial water stock - final water stock
🟧 infiltration - evap soil surface
🟥 added by root growth - transpiration
🟦 perculation



4.3 Relationship between drought and yield gap (Y_g)

The relationship between drought and Agriculture is established by use of the eRDIst, VHI and Yg. It is evident that the higher the drought level the higher the Yg as well as the when there is excess precipitation.

4.3.1 VHI and Yg

From figure 34 below, the correlation coefficient between VHI and Yg is less than 0.1 thus it is very weak and thus cannot show the impact of drought on Agriculture in Gourma province neither in fine nor medium texture soils.

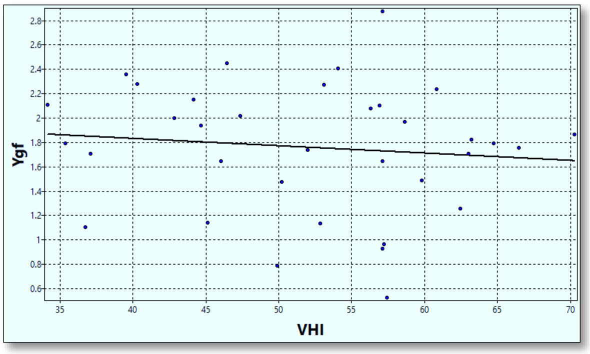
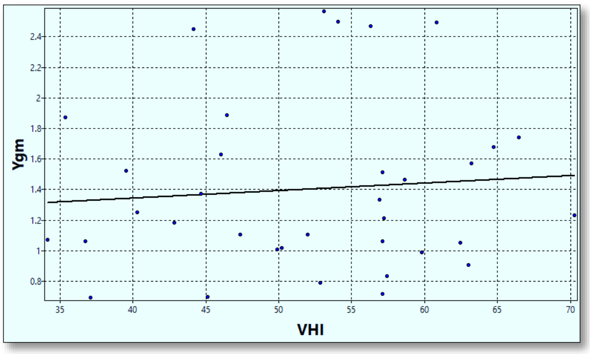
FYgDW	MYgDW
	
$R^2=0.011955$	$R^2=0.007218$
$Ygf=2.1-(6.01\times10^{3}\times VHI)$	$Ygm=1.1+(0.005\times VHI)$

Figure 34: VHI and Yg

4.3.2 eRDI_{st} and Yg

In table 4.3 below, it is clear that eRDIst has a stronger relationship with Yg in medium texture soils as compared to fine textured soils. The regression coefficient is highest between the 5month eRDIst starting July and the Yg simulated in medium texture soils for both drought and low oxygen conditions. The weakest relationship is between the 6month eRDIst starting June and Yg simulated in fine texture soils for both drought and low oxygen conditions. The MYgDW and the MYgD have the strongest relationship and can be used to demonstrate the impact of drought in Gourma province.

Table 4.3: R^2 values for all fitted curves

	4MJL	**5MJL**	**5MJU**	**6MJU**
FYgDW	0.338422	0.3356515	0.316728	0.270914
FYgD	0.452351	0.460347	0.491763	0.492672
MYgDW	0.702547	0.717585	0.685451	0.686343
MYgD	0.706128	0.706266	0.705183	0.705214

For the fine soils, there is a stronger relationship between the FYgD and Yg as compared to FYgDW and Yg as shown in figure 35 below.

In the medium soil's category, MYgDW has a higher regression coefficient of 0.72 as compared to MYgD which is at 0.70 see figure 36 below.

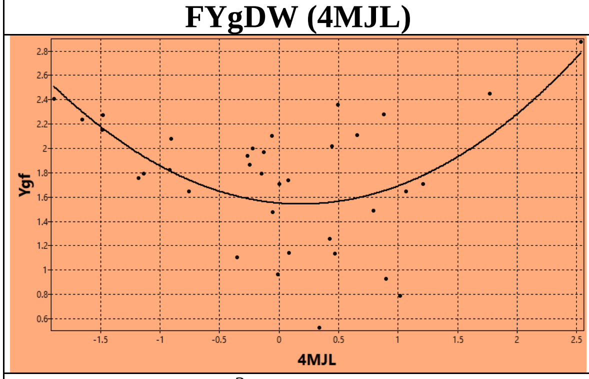
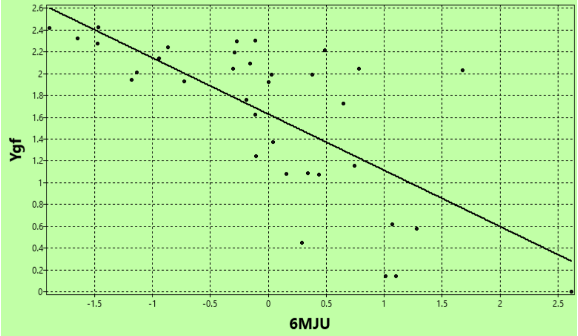
FYgDW (4MJL)	FYgD (6MJU)
	
R^2=0.338422	R^2=0.492672
$Ygf = 1.55 + (0.22 \times 4MJL^2) - (0.083 \times 4MJL)$	$Ygf = 1.63 - (0.52 \times 6MJU)$

Figure 35: FYgDW vs FYgD

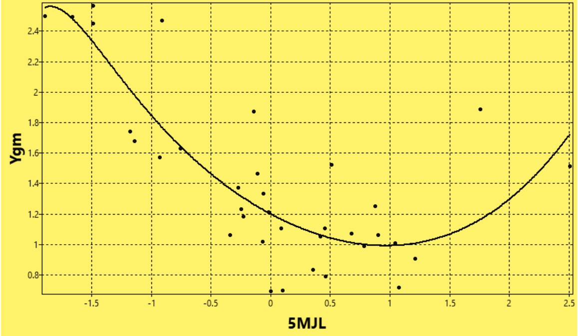
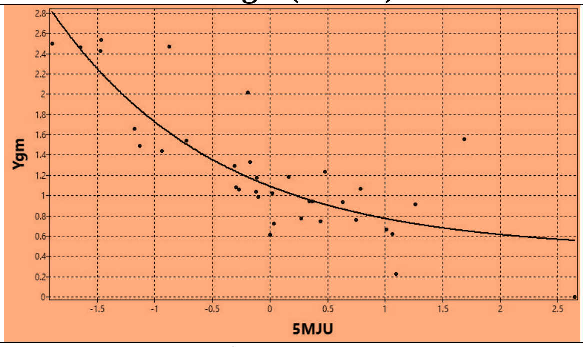
MYgDW (5MJL)	MYgD (5MJU)
	
R^2=0.717585	R^2=0.706266
$Ygm = 0.78 + (0.42 \times \exp(5MJL)^{-1}) + (0.06 \times 5MJL^3) - (0.000325 \times \exp(5MJL)^{-4})$	$Ygm = 0.46 + (0.63 \times 0.5^{5MJU})$

Figure 36: MYgDW vs MYgD

4.3.3 Economic Impact of drought

From the interviews with the farmers, the major inputs for pearl millet production include fertilizer and labour which cost approximately 378 $/Ha (see table 4.4 on cost of production). This excludes crop management inputs such as pesticides which highly vary from one farmer to another.

Economically, the total losses accrued by the farmer include the ROI and the COP. From the analysis, as a result of drought only, the farmer loses a minimum of 676 $/Ha while as a result of both dry and extremely wet conditions, the farmer loses a minimum of 760 $/Ha (see details in table 4.5 below)

Table 4.4: Cost of production

				Price of Pearl Millet (FCFA)/Kg
	Labour	**Fertilizer**	**Area (Ha)**	
1. Ouedraogo Haruna (+22662300851)	1,200,000	64,000	3	200
2. Zibgo Salamata	1,050,000	48,000	2	200
3. Pima Ramata	900,000	48,000	2	225
4. Ouedraogo Madi (+22673306218)	600,000	64,000	4	200
5. Kabore Anré (+22671722031)	480,000	160,000	5	210
6. Kompaoré Paul	480,000	160,000	2	210
7. Ouedraogo Togonogo (+22651382409)	600,000	64,000	3	210
8. Thiombiano Talardia (+22670435195)	900,000	320,000	5	200
9. Sina Bejerome (+22671067267)	300,000	112,000	10	200
10. Sana Fati (+22670886168)	900,000	640,000	9	230
11. Kouraogo Hanirata (+22661636187)	750,000	560,000	7	200
Sub-total (FCFA)	8,160,000	2,240,000	51	208
Total (FCFA)	10,400,000			
COP (FCFA/Ha)	**203,922**			
COP ($/Ha)	**378**			

Table 4.5: Economic impact of drought

	Yg (Kg/Ha)	5MJL	ROI ($/Ha)	COP ($/Ha)	Total Losses ($/Ha)
MYgD (5MJL)	775	1	298	378	676
MYgDW (5MJL)	995	1	383	378	760

*Taking 1$=540 FCFA

4.4 DMOs suitable for the province of Gourma

Out of 33 DMOs, the six best performing options were found to be exploitation of the aquifers (55%), reduction of evaporation losses by mulching (100%), controlled irrigation during drought (70%), economic incentives that encourage water conservation (100%), reallocation of water during drought (75%) and insurance services (100%) as shown in figure 37 and table 4.6 below.

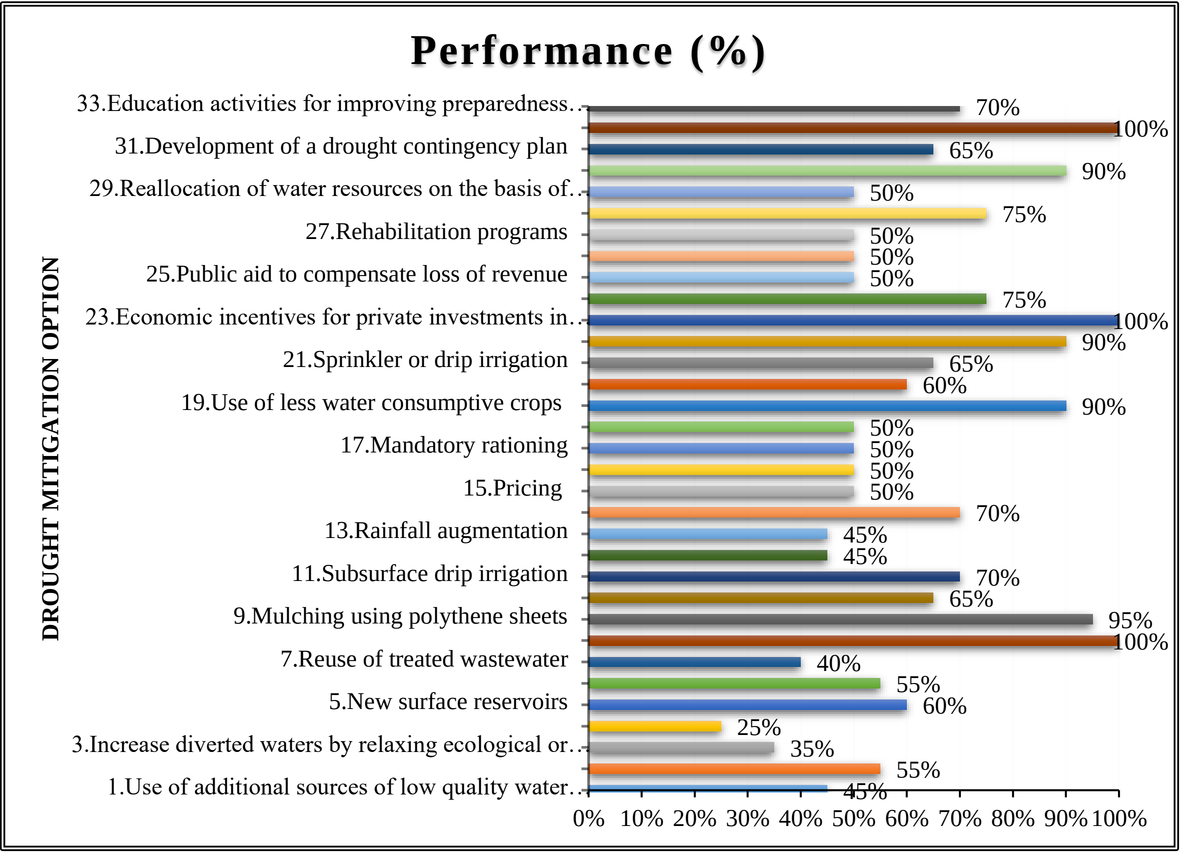


Figure 37: Suitability Analysis of Drought Mitigation Strategies

4.4.1 List of Identified Drought Impact Mitigation Strategies

The 3×2 matrix below gives the most suitable combination of DMOs for mitigation of drought impacts in Gourma province based on the MCDA process.

Table 4.6: List of Identified Drought Impact Mitigation Strategies

	Short-term actions	Long-term actions	A.S.*
Supply increase	Over-exploitation of aquifers	Mulching using crop residues, will enhance the organic matter content also besides reducing the evaporation	A
Demand reduction	Restriction of the irrigation of some crops (e.g. annual)	Economic incentives for private investments in water conservation	A
Impact minimization	Temporary reallocation of water resources (on the basis of assigned use priority)	Mitigation of economic and social impacts through voluntary insurance, pricing and economic incentives	A

***Affected Sector: U =Urban; A = Agricultural; 1= Industrial; R = Recreation**

4.5 *Le Guardien de l'espoir* Insurance Scheme

From the analysis, each farmer will have to pay at least 12$/month, 14$/month and 20$/month as premiums for mild, severe and moderate drought events respectively (see details in table 4.7 below)

Table 4.7: Le Guardien de l'espoir monthly premiums

	Drought class	**Mild drought**	**Moderate drought**	**Severe drought**
Probability of drought	**Frequency**	9%	11%	6%
	eRDIst value	-0.99	-1.49	-1.99
Insured Amount	**MYgD (5MJL)**	1711	2230	2963
Present value	**Present value of $1 at 4.5%**	0.957	0.957	0.957
	Annual premium ($)	140	244	162
	Monthly payments ($)	12	20	14

The triggers for payment

In order for any payments to be start being carried out, the below values in table 4.8 have to be experienced in order to declare mild, moderate or severe drought.

Table 4.8: Le Guardien de l'espoir payment triggers

Drought class	**Mild drought**	**Moderate drought**	**Severe drought**
eRDIst value	-0.99	-1.49	-1.99

Monitoring system

Le Guardien de l'espoir insurance scheme shall be run by a monitoring system based on the below mathematical model which determines eRDIst for the farming season starting June to November based on historical data.

The system is capable of estimating the drought indices for present periods after learning from historical climatic data of the area. It is assumed that the present climatic characteristics of period monitored and historical times are constant. The mathematical model used in the monitoring system is described below:

Equation 23: Drought monitoring equation

$$eRDI_{st} = c \times ln(\alpha_n) + b$$

Where:

α_n is the initial value of eRDIst for n-months period

c and b are constants calculated from the available historical data for the corresponding n-months period.

For Gourma province, **c = 1.521099** and **b = 2.15093** for 5MJL

CHAPTER 5. DISCUSSIONS

Obtained results show that Gourma province has experienced 3 drought events between 1979 and 2013 with different intensities and severity based on the eRDIst. The most frequent severity level is the Moderate drought which occurred four times in thirty-five years.

The results show that the time series considered be it 4MJU, 5MJU, 5MJL or 6MJL for calculating eRDIst in Gourma province resulted in the same drought trends for the thirty-five years of climate data.

The similarity in the eRDIst trends for the thirty-five years of climate data shows that the effective rainfall and potential evapotranspiration in the province of Gourma between June and December have the same trends over the years. This is further explained by the method of calculating eRDIst which divides the sum of effective rainfall with the sum of potential evapotranspiration for the chosen time series.

From this research work, the new findings from this work include the fact that there is no relationship between VHI and Yg in the province of Gourma. Findings of this work confirm the assertions of Hountondji et al., (2006) who used the Normalized Difference Vegetation Index (NDVI) to analyze vegetation trends in Burkina Faso and concluded that desertification as a phenomenon hasn’t strongly manifested in Gourma province. This therefore makes it clear that remote sensing methods are not suitable methods for assessing drought impacts on Agriculture in the province of Gourma and this is supported by this new study which has found out that there is no relationship between VHI and Yg.

Studies by Dembélé & Zwart, (2016) show that between 2001 and 2014, there were only two Agricultural drought events in the province of Gourma one in 2002 and another in 2013 that were also accompanied by rainfall anomalies in the said years. The findings of this study are different as it is shown that within the same period, there were droughts in the years 2001, 2002, 2003, 2004, 2005 and 2008. This is as a result of the difference in the drought types under study as well as the methodology used in the studies. Dembélé & Zwart, (2016) combined Precipitation Condition Index (PCI) and VHI to establish an Agricultural drought index (in Burkina Faso) which was used to declare whether there was a drought event or not while in this study, the effective precipitation was determined and used to determine the agro-meteorological index (eRDIst) which was used to declare whether there was a drought or not in Gourma province.

Also of keen interest is the fact that Dembélé & Zwart, (2016) firstly identified vegetation stress by using VHI before proceeding to determine the PCI and ultimately establish the Agricultural drought indices of the provinces. This is another reason for the difference in the declaration of the events as from the VHI products, it is already indicated not to be a good indicator of drought impacts on Agriculture and thus an indicator of Agricultural drought.

The other finding from this work is that impact of drought on Agriculture in Gourma province can be sufficiently demonstrated by use of the eRDIst. This study shows that there is a strong relationship between eRDIst and Yg in the province of Gourma. The higher the drought level, the higher the yield gap and vice versa. A unity change in eRDIst would result in 775Kg/Ha yield gap. The highest drought levels are reported in the period between 1999 and 2005 and again in 2008 consequently, it is the same periods showing high yield gaps (Yg).

Dembélé & Zwart, (2016) also found out that in the years 2001, 2002 and 2008, the millet yields suffered penalties in the country. In 2008, Dembélé & Zwart, (2016) noted that no vegetation stress was reported by VHI but there was a meteorological drought and the 2008 yields suffered penalties. This is proof that eRDIst which is an agro-meteorological index is a better method of assessing the impact of drought on agriculture.

A new finding from this study is that the yield gaps also increase as a result of insufficient oxygen in the plant root zone. The results of curvilinear regression modelling have shown that apart from droughts, excess water also increases the yield gap and from this model, a unity change in the eRDIst results in 995 Kg/Ha yield gap. These are drawn from the fact that the WOFOST model also provides an option of modelling the impacts of low oxygen and drought at the same time.

From the results, the relationship between Yg and eRDIst is influenced by the soil texture such that soils of fine texture show a weaker relationship as compared to soils of medium texture. This is explained by the fact that fine soils have a higher clay content and thus the available water in their root zones is not influenced by drought or wet conditions in the same manner as it is influenced in the medium textured soils. This is a potential study area that should be explored to established why the relationship of Yg and eRDIst is weaker in fine texture soils and higher in medium texture soils.

Economic impact of drought in Gourma province has also been established and its reported that for a unity change in the eRDIst, between 676 and 760 $/Ha is lost by the pearl millet farmers. An economic model that gives the relationship between the drought and the money lost has also been established with a very high regression coefficient.

This study has also shown that the best combination of DMOs for the province of Gourma include exploitation of aquifers, reallocation of water supplies during drought, restriction of the irrigation of some crops and insurance schemes for farmers. But from the willingness to pay values collected from the fieldwork, the pearl millet only one out of eleven farmers are willing to pay around $12 for a group insurance scheme managed by them. This is thus a viable project that can be piloted in the province to help sensitize the farmers and empower them to be able to protect themselves from the impacts of drought in the province.

CHAPTER 6. CONCLUSIONS

The main objective of this research study achieved through four specific objectives which were accomplished one by one.

Firstly, drought events in Gourma province of eastern Burkina Faso between 1979 and 2013 were characterized by used of the eRDIst drought index in terms of their severity, intensity and duration. The severest drought was in 2002 while the event with the highest intensity and duration started in 1999 and ended in 2005.

Secondly, the implication of the occurrence of a drought event was also demonstrated in terms of high Yg (Kg/Ha) and economic losses ($/Ha). It has been established that Pear millet farmers lose an average of 775Kg/Ha due to drought and this results in economic losses of up to 676$/Ha incurred by the farmers.

Thirdly, drought mitigation options used world over were identified and a Multi criteria Decision Analysis process used to assess the options and show how they perform for the case of Gourma province. The best one under long term drought impact mitigation strategies being insurance.

Lastly, two recommendations for the mitigation of the drought impact in the area were proposed which included Le Guardien de l’espoir Insurance scheme and introduction of dry farming in Gourma province.

CHAPTER 7. RECOMMENDATIONS

From the results, it has been established that the relationship between drought and yield gaps is stronger in medium textured soils than in fine textured soils of Gourma province and thus more studies should be carried out determine the reasons behind this phenomenon.

Based on the nature of droughts in Gourma province and their impact on agriculture, I recommend two major DMOs namely:

1. Le Guardien de l'espoir Insurance scheme
2. Introduction of dry farming

Impact of drought on agriculture in Gourma is felt in the farmer's pockets and even though we have many technical options that can be used to improve the situation, the big question is who will fund these projects? Challenges resulting from drought in Gourma province are complex and cannot be solved by science and engineering only. Due to the nature of the challenges, these recommendations were made to cushion the farmer against the drought impacts.

The two recommendations are inspired by the ideas of one of the founders of the Organisation of African Unity (OAU), his excellency the former president of the United Republic of Tanzania, Julius Kambarage Nyerere who in one of his speeches of 1974 titled **Freedom and Development** said: "Development brings freedom provided it is development of people. But people cannot be developed; they can only develop themselves. For while it is possible for an outsider to build a man's house, an outsider cannot give the man pride and self-confidence in himself as a human being. Those things a man has to create in himself by his own actions" (Nyerere, 1974)

In the same spirit of His Excellency Julius Nyerere's speech, Le Guardien de l'espoire insurance scheme is an insurance scheme for the people, by the people and to cushion the people against the impacts of drought.

The adoption of dry farming techniques will be an initiative of the peole by the people to feed the people.

Le Guardien de l'espoir has two major components, the premiums collection component and the farmer's pay-outs component.

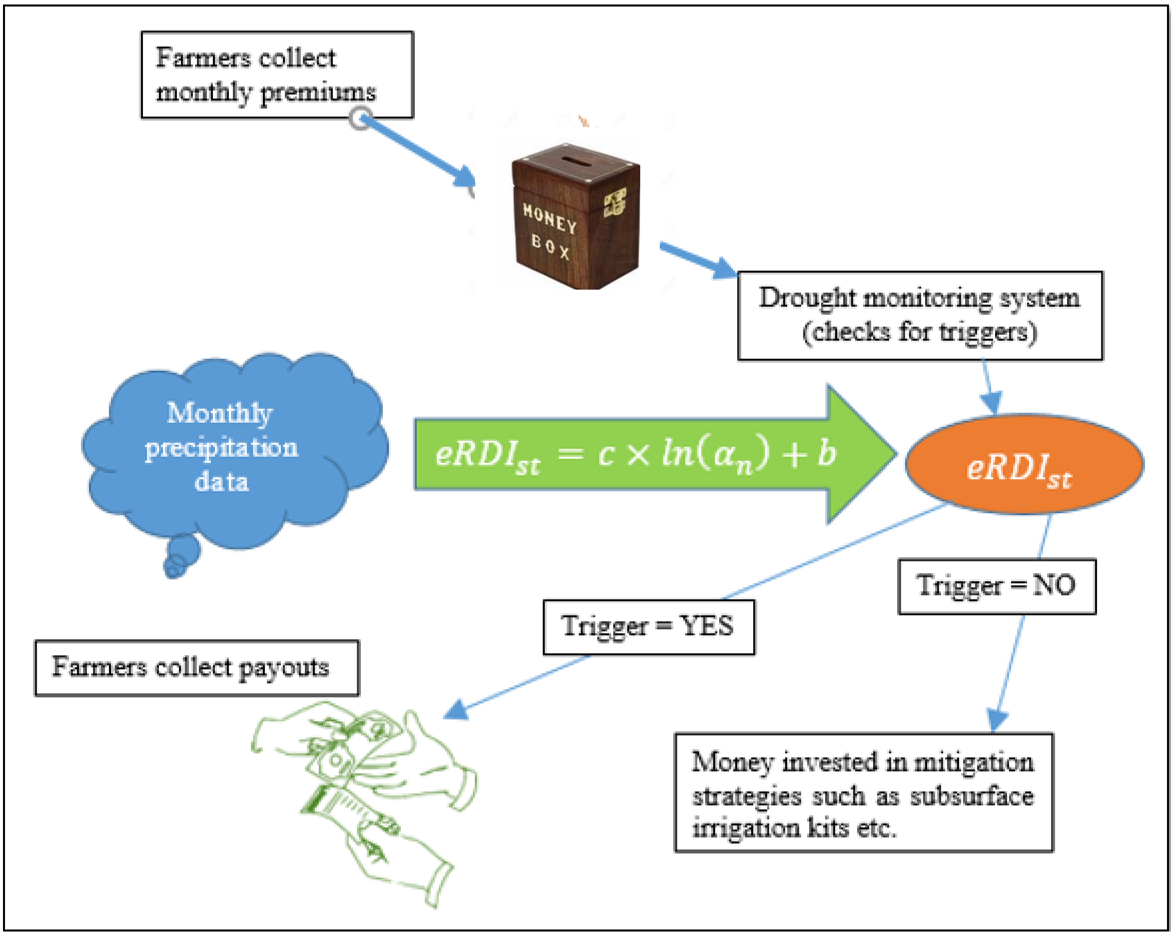


Figure 38: Le Guardien de l'espoir drought monitoring system

In a bid to make the province and region at large more food secure even in times of drought, the following dry farming crops are proposed:

Table 7.1: Food producing commercial crops

Cereals	**Legumes**	**Leafy Vegetables**	**Fruit vegetables**	**Oil plants**
Corn	Common beans	Cassava greens	Watermelons	Owala
Sorghum	Cowpeas	Comfrey	Okra	Sunflower seed
Millet	Pigeon peas	Leucaena	Dates	
			Papaya	
			Cashew	
			Olives	
			Tamarinds	

Table 7.2: Non-food producing commercial crops

Fiber-producing plants	**Timber plants**	**Feed legumes and grasses**
Sea Island Cotton	Umbrella thorn	Mesquite
sisal		Mother of Cacao
		Bermuda grass

CHAPTER 8. REFERENCES

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ANNEX 1:SAMPLE WEATHER DATA FILE

```
*-----------------------------------------------------*
*   Country: Burkina Faso
*   Station: Fada N'Gourma
*      Year: 1979
*    Source: Global Weather for SWAT.
*    Author: Julius Omondi
* Longitude: 0.37 E
*  Latitude: 12.03 N
* Elevation: 310 m.
*  Comments: Representative of Gourma Province.
*  Columns:
*  ========
*  station number
*  year
*  day
*  irradiation (kJ m-2 d-1)
*  minimum temperature (degrees Celsius)
*  maximum temperature (degrees Celsius)
*  vapour pressure (kPa)
*  mean wind speed (m s-1)
*  precipitation (mm d-1)
** WCCDESCRIPTION=Gourma, Burkina
** WCCFORMAT=2
** WCCYEARNR=2003
*-----------------------------------------------------*
   0.367  12.033    310.  -0.27 -0.49
   1 2003    1    21602.  14.2  32.8  2.899  3.4   0.0
   1 2003    2    21485.  13.7  33.5  2.913  3.2   0.0
   1 2003    3    21393.  14.0  34.4  3.018  3.2   0.0
   1 2003    4    21521.  14.5  34.7  3.085  3.0   0.0
   1 2003    5    21594.  13.5  36.2  3.135  2.5   0.0
   1 2003    6    21700.  13.7  37.4  3.274  2.2   0.0
   1 2003    7    21708.  14.4  38.8  3.488  2.3   0.0
   1 2003    8    21865.  14.6  40.0  3.624  2.1   0.0
   1 2003    9    21732.  14.7  42.0  3.852  1.9   0.0
   1 2003   10    21617.  14.5  40.4  3.663  1.7   0.0
   1 2003   11    21470.  15.9  41.3  3.921  1.8   0.0
   1 2003   12    20984.  16.7  42.4  4.143  1.9   0.0
   1 2003   13    18508.  20.2  36.3  3.836  2.8   0.0
   1 2003   14    21332.  19.4  37.6  3.888  3.5   0.0
   1 2003   15    21554.  19.4  37.7  3.903  3.4   0.0
   1 2003   16    21784.  18.6  38.9  3.950  2.8   0.0
```

ANNEX 2: SOIL DATA FILE

```
** file M01GAPj.AWC
** SOIL DATA FILE for yield gap simulations
** Moisture data set for texture class 2 (medium)
** Minimum data set on soil physics for use in subroutine WATFD, water
** balance for freely draining soils.
SOLNAM='texture 2-medium, AWC=75 mm per m for YGAP'
** PHYSICAL SOIL CHARACTERISTICS
** soil water retention
SMW      =   0.159  !  soil moisture content at wilting point [cm3/cm3]
SMFCF    =   0.264  !  soil moisture content at field capacity [cm3/cm3]
SM0      =   0.421  !  soil moisture content at saturation [cm3/cm3]
CRAIRC   =   0.157  ! critical soil air content for aeration [cm3/cm3]
** percolation parameters
K0       =  20.124  ! hydraulic conductivity of saturated soil [cm day-1]
SOPE     =  20.124   ! maximum percolation rate root zone[cm day-1]
KSUB     =  20.124   ! maximum percolation rate subsoil [cm day-1]
** soil workability parameters
SPADS    =   0.800  !  1st topsoil seepage parameter deep seedbed
SPODS    =   0.040  !  2nd topsoil seepage parameter deep seedbed
SPASS    =   0.900  !  1st topsoil seepage parameter shallow seedbed
SPOSS    =   0.070  !  2nd topsoil seepage parameter shallow seedbed
DEFLIM   =   0.000  !  required moisture deficit deep seedbed
```

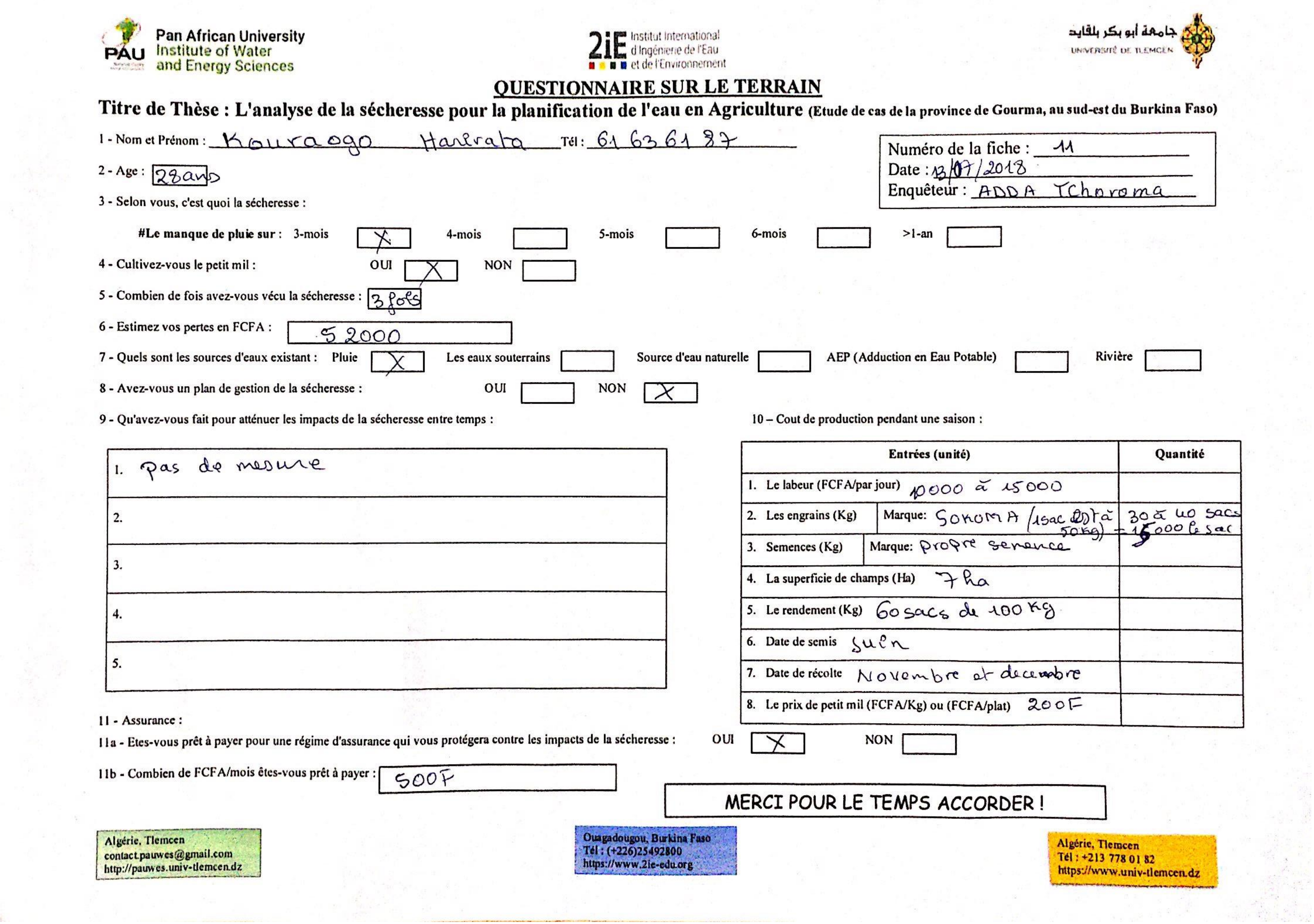
ANNEX 3: CROP DATA FILE

```
** File MILL-med-Burkina-GYGA.CAB
** CROP DATA FILE for use with WOFOST Version 7.1.7
** Reference: Heemst, H.van, 1988. Plant data values required for simple
** and universal simulation models: review and bibliography. Simulation
** reports CABO-TT.
** Some changes included for Millet (medium duration) for Burkina Faso for global yield gap atlas
CRPNAM='Pearl Millet, medium duration, Burkina Faso, Gourma'
** emergence
TBASEM   =  12.0    ! lower threshold temp. for emergence [cel]
TEFFMX   =  32.0    ! max. eff. temp. for emergence [cel]
TSUMEM   = 60.      ! temperature sum from sowing to emergence [cel d]
** phenology
IDSL     =   0      ! indicates whether pre-anthesis development depends
                    ! on temp. (=0), daylength (=1) , or both (=2)
DLO      =   1.0    ! optimum day length for development [hr]
DLC      =   0.0    ! critical daylength (lower threshold) [hr]
TSUM1    =1030.     ! temperature sum from emergence to anthesis [cel d]
TSUM2    = 650.     ! temperature sum from anthesis to maturity [cel d]
DTSMTB   =   0.00,    0.00,     ! daily increase in temp. sum
            10.00,    0.00,     ! as function of av. temp. [cel; cel d]
            27.00,   17.00,
            35.00,   17.00,
            45.00,    00.00
DVSI = 0.           ! initial DVS
```

```
DVSEND   =   2.00    ! development stage at harvest (= 2.0 at maturity [-])
** initial
TDWI     =  3.00    ! initial total crop dry weight [kg ha-1]
** ! Not used as input by WOF6_0 model
LAIEM    =   0.006912 ! leaf area index at emergence [ha ha-1]
RGRLAI   =   0.0500  ! maximum relative increase in LAI [ha ha-1 d-1]
** green area
SLATB    =   0.00,    0.0018,   ! specific leaf area
             0.40,    0.0027,   ! as a function of DVS [-; ha kg-1]
             0.85,    0.0019,
             2.00,    0.0019
SPA      =   0.000  ! specific pod area [ha kg-1]
SSATB =  0.0, 0.0,  ! specific stem area [ha kg-1]
         2.0, 0.0   ! as function of DVS
SPAN     =  42.     ! life span of leaves growing at 35 Celsius [d]
TBASE    =  10.0    ! lower threshold temp. for ageing of leaves [cel]
** assimilation
KDIFTB = 0.0, 0.50, ! extinction coefficient for diffuse visible light [-]
         2.0, 0.50  ! as function of DVS
EFFTB  = 0.0, 0.50, ! light-use effic. single leaf [kg ha-1 hr-1 j-1 m2 s]
        40.0, 0.50  ! as function of daily mean temp.
AMAXTB   =   0.00,   70.00,     ! max. leaf CO2 assim. rate
             1.30,   70.00,     ! function of DVS [-; kg ha-1 hr-1]
             2.00,    0.00
TMPFTB   =   0.00,    0.00,     ! reduction factor of AMAX
             8.00,    0.00,     ! as function of av. temp. [cel; -]
            20.00,    1.00,
            35.00,    1.00,
            45.00,    0.00
TMNFTB   =   5.00,    0.00,     ! red. factor of gross assim. rate
            12.00,    1.00      ! as function of low min. temp. [cel; -]
** conversion of assimilates into biomass
CVL      =   0.720  ! efficiency of conversion into leaves [kg kg-1]
CVO      =   0.730  ! efficiency of conversion into storage org. [kg kg-1]
CVR      =   0.720  ! efficiency of conversion into roots [kg kg-1]
CVS      =   0.690  ! efficiency of conversion into stems [kg kg-1]
** maintenance respiration
Q10      =   2.0    ! rel. incr. in resp. rate per 10 Cel temp. incr. [-]
RML      =   0.0300 ! rel. maint. resp. rate leaves [kg CH2O kg-1 d-1]
RMO      =   0.0100 ! rel. maint. resp. rate stor.org. [kg CH2O kg-1 d-1]
RMR      =   0.0100 ! rel. maint. resp. rate roots [kg CH2O kg-1 d-1]
RMS      =   0.0150 ! rel. maint. resp. rate stems [kg CH2O kg-1 d-1]
RFSETB   =   0.00,    1.00,     ! red. factor for senescence
             2.00,    1.00      ! as function of DVS [-; -]
** partitioning
FRTB     =   0.00,    0.50,     ! fraction of total dry matter to roots
             0.10,    0.50,     ! as a function of DVS [-; kg kg-1]
             0.25,    0.30,
             0.40,    0.17,
             1.00,    0.00
             2.00,    0.00
FLTB     =   0.00,    1.00,     ! fraction of above-gr. DM to leaves
             0.10,    1.00,     ! as a function of DVS [-; kg kg-1]
             1.00,    0.00,
```

```
          2.00,   0.00
FSTB    =  0.00,   0.00,    ! fraction of above-gr. DM to stems
          0.10,   0.00,    ! as a function of DVS [-; kg kg-1]
          1.00,   1.00,
          1.60,   0.00,
          2.00,   0.00
FOTB    =  0.00,   0.00,    ! fraction of above-gr. DM to stor. org.
          1.00,   0.00,    ! as a function of DVS [-; kg kg-1]
          1.60,   1.00,
          2.00,   1.00
** death rates
PERDL   =  0.030  ! max. rel. death rate of leaves due to water stress
RDRRTB  =  0.00,   0.000,   ! rel. death rate of roots
          1.50,   0.000,   ! as a function of DVS [-; kg kg-1 d-1]
          1.5001,  0.020,
          2.00,   0.020
RDRSTB  =  0.00,   0.000,   ! rel. death rate of stems
          1.50,   0.000,   ! as a function of DVS [-; kg kg-1 d-1]
          1.5001,  0.020,
          2.00,   0.020
** water use
CFET    =  1.00   ! correction factor transpiration rate [-]
DEPNR   =  4.5    ! crop group number for soil water depletion [-]
IAIRDU  =  0      ! air ducts in roots present (=1) or not (=0)
** rooting
RDI     =  10.    ! initial rooting depth [cm]
RRI     =  4.0    ! maximum daily increase in rooting depth [cm d-1]
RDMCR   = 150.    ! maximum rooting depth [cm]
** nutrients
** maximum and minimum concentrations of N, P, and K
** in storage organs        in vegetative organs [kg kg-1]
NMINSO  =  0.0100 ;     NMINVE  =  0.0032
NMAXSO  =  0.0300 ;     NMAXVE  =  0.0105
PMINSO  =  0.0014 ;     PMINVE  =  0.0005
PMAXSO  =  0.0080 ;     PMAXVE  =  0.0025
KMINSO  =  0.0030 ;     KMINVE  =  0.0070
KMAXSO  =  0.0080 ;     KMAXVE  =  0.0280
YZERO   = 200.    ! max. amount veg. organs at zero yield [kg ha-1]
NFIX    =  0.00   ! fraction of N-uptake from biol. fixation [kg kg-1]
```

ANNEX 4: COST OF PRODUCTION QUESTIONNAIRES



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QUESTIONNAIRE SUR LE TERRAIN

Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 11
Date : 13/07/2018
Enquêteur : ADDA TChoroma

1 - Nom et Prénom : Kouraogo Harirata Tél : 61 63 61 87

2 - Age : 28ans

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☒ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☒ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3 fois

6 - Estimez vos pertes en FCFA : 52000

7 - Quels sont les sources d'eaux existant : Pluie ☒ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☒

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1. pas de mesure
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour) 10000 à 15000		
2. Les engrains (Kg)	Marque: SOKOMA (1sac est à 50Kg)	30 à 40 sacs = 15000 le sac
3. Semences (Kg)	Marque: propre semence	
4. La superficie de champs (Ha) 7 ha		
5. Le rendement (Kg) 60 sacs de 100 Kg		
6. Date de semis Juin		
7. Date de récolte Novembre et decembre		
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 200F		

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☒ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 500F

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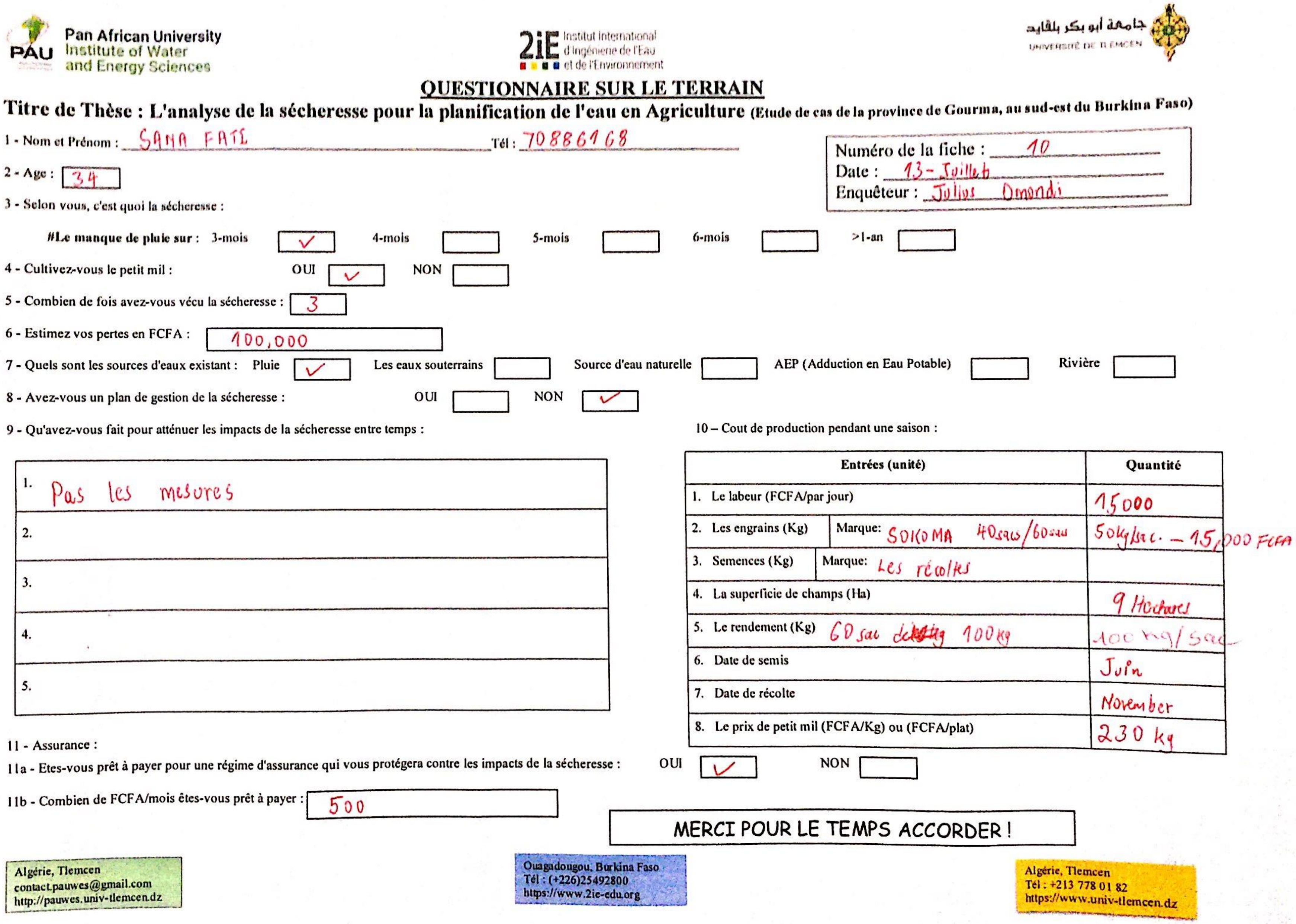

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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 10
Date : 13- Juillet
Enquêteur : Julius Omondi

1 - Nom et Prénom : SANA FATI Tél : 70886168

2 - Age : 34

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☑ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☑ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3

6 - Estimez vos pertes en FCFA : 100,000

7 - Quels sont les sources d'eaux existant : Pluie ☑ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☑

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1. Pas les mesures
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour)		15000
2. Les engrains (Kg)	Marque: SOKOMA 40sacs/60sacs	50kg/sac. – 15,000 FCFA
3. Semences (Kg)	Marque: Les récoltes	
4. La superficie de champs (Ha)		9 Hectares
5. Le rendement (Kg)	60 sac de 100kg	100 kg/sac
6. Date de semis		Juin
7. Date de récolte		November
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat)		230 kg

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☑ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 500

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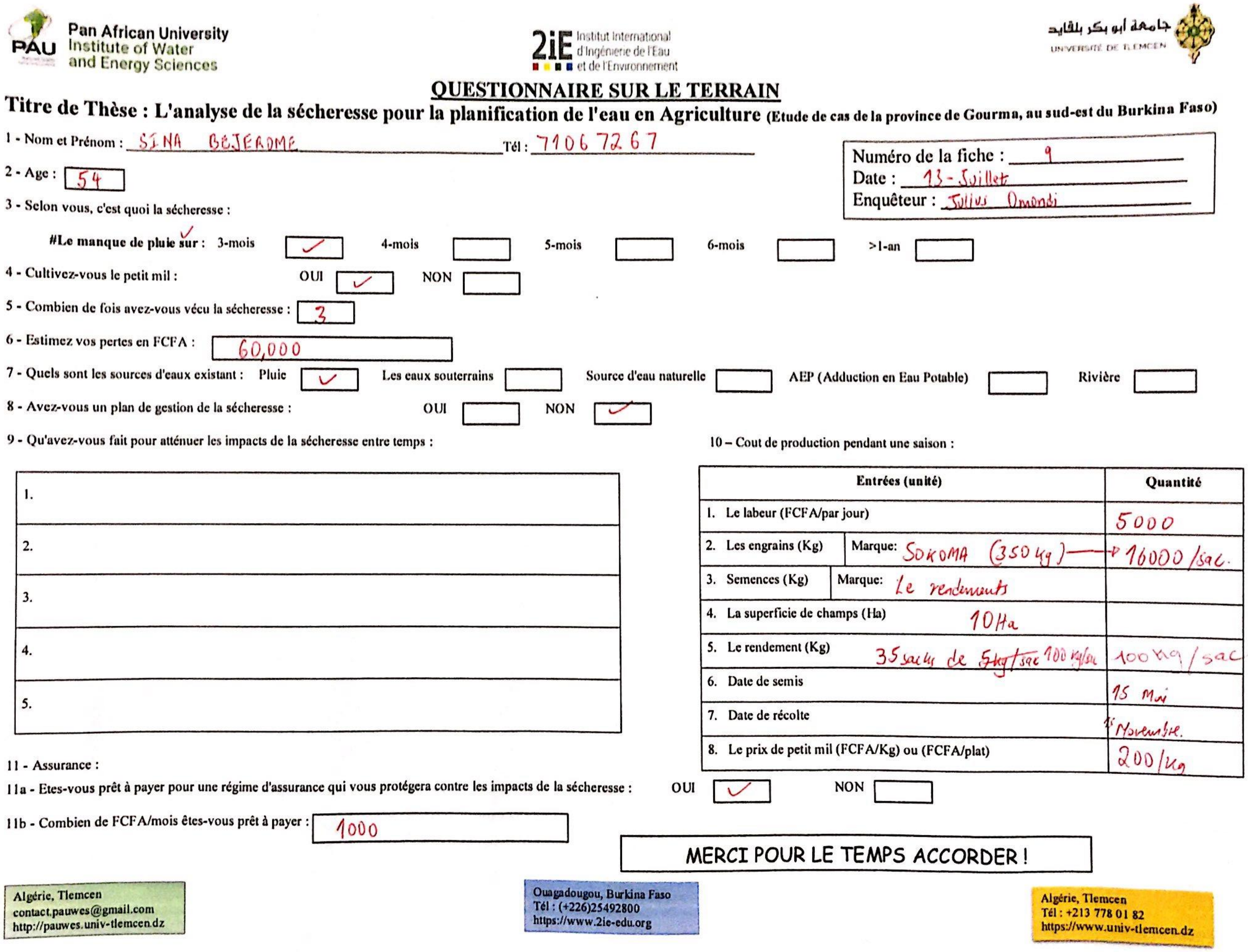

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QUESTIONNAIRE SUR LE TERRAIN

Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 9
Date : 13 - Juillet
Enquêteur : Julius Omondi

1 - Nom et Prénom : SINA BEJEROME Tél : 71067267

2 - Age : 54

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☑ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☑ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3

6 - Estimez vos pertes en FCFA : 60,000

7 - Quels sont les sources d'eaux existant : Pluie ☑ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☑

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1.
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour)		5000
2. Les engrains (Kg)	Marque: SOKOMA (350 kg) →	16000 /sac.
3. Semences (Kg)	Marque: Le rendements	
4. La superficie de champs (Ha)	10Ha	
5. Le rendement (Kg)	35 sacks de ~~5kg~~/sac 100 kg/sac	100 kg / sac
6. Date de semis		15 Mai
7. Date de récolte		15 Novembre.
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat)		200/kg

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☑ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 1000

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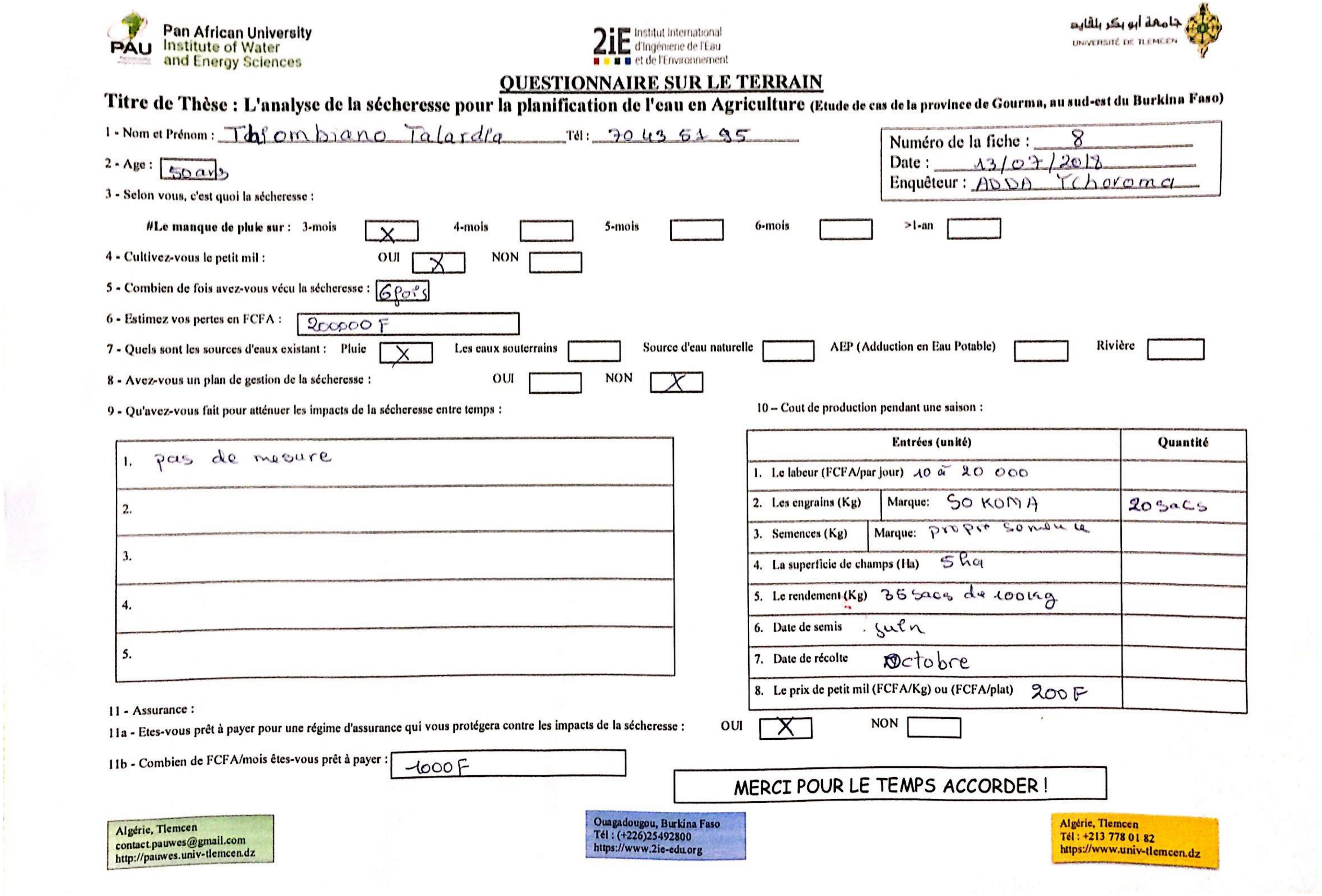

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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 8
Date : 13/07/2018
Enquêteur : ADDA Tchoroma

1 - Nom et Prénom : Thiombiano Talardia Tél : 70 43 61 95

2 - Age : 50 ans

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☒ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☒ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 6 fois

6 - Estimez vos pertes en FCFA : 200000 F

7 - Quels sont les sources d'eaux existant : Pluie ☒ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☒

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1.	pas de mesure
2.	
3.	
4.	
5.	

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour) 10 à 20 000		
2. Les engrains (Kg)	Marque: SO KOMA	20 sacs
3. Semences (Kg)	Marque: propre semence	
4. La superficie de champs (Ha) 5 ha		
5. Le rendement (Kg) 35 sacs de 100kg		
6. Date de semis juin		
7. Date de récolte Octobre		
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 200 F		

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☒ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 1000 F

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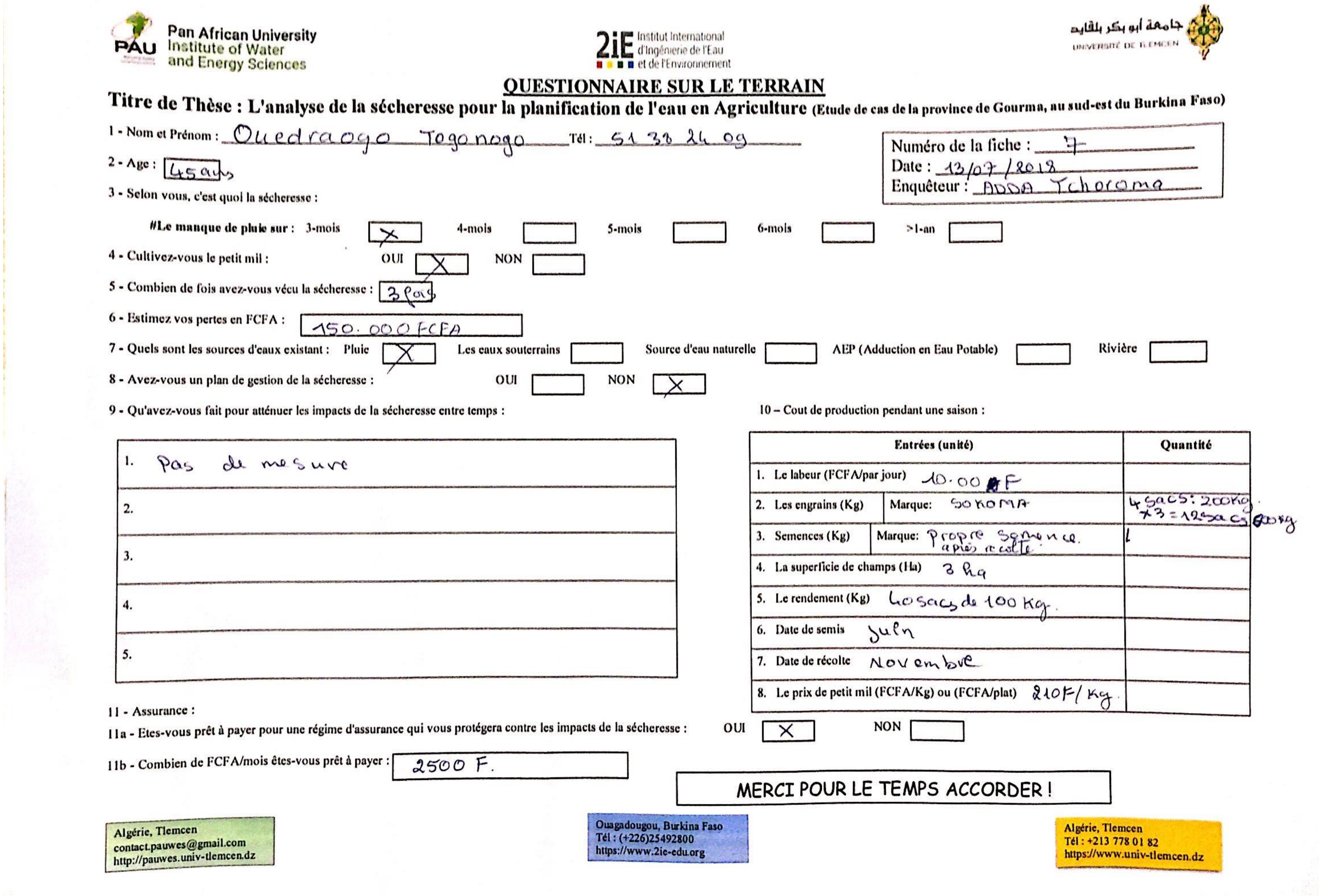

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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 7
Date : 13/07/2018
Enquêteur : ADDA Tchoroma

1 - Nom et Prénom : Ouedraogo Togonogo Tél : 51 38 24 09

2 - Age : 45 ans

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☒ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☒ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3 fois

6 - Estimez vos pertes en FCFA : 150.000 FCFA

7 - Quels sont les sources d'eaux existant : Pluie ☒ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☒

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1. Pas de mesure
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour) 10.00 F		
2. Les engrains (Kg)	Marque: SOKOMA	4 sacs : 200Kg. ×3 = 12 sacs 600Kg
3. Semences (Kg)	Marque: Propre semence. après récolte	
4. La superficie de champs (Ha) 3 ha		
5. Le rendement (Kg) 40 sacs de 100 Kg.		
6. Date de semis Juin		
7. Date de récolte Novembre		
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 210F/Kg.		

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☒ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 2500 F.

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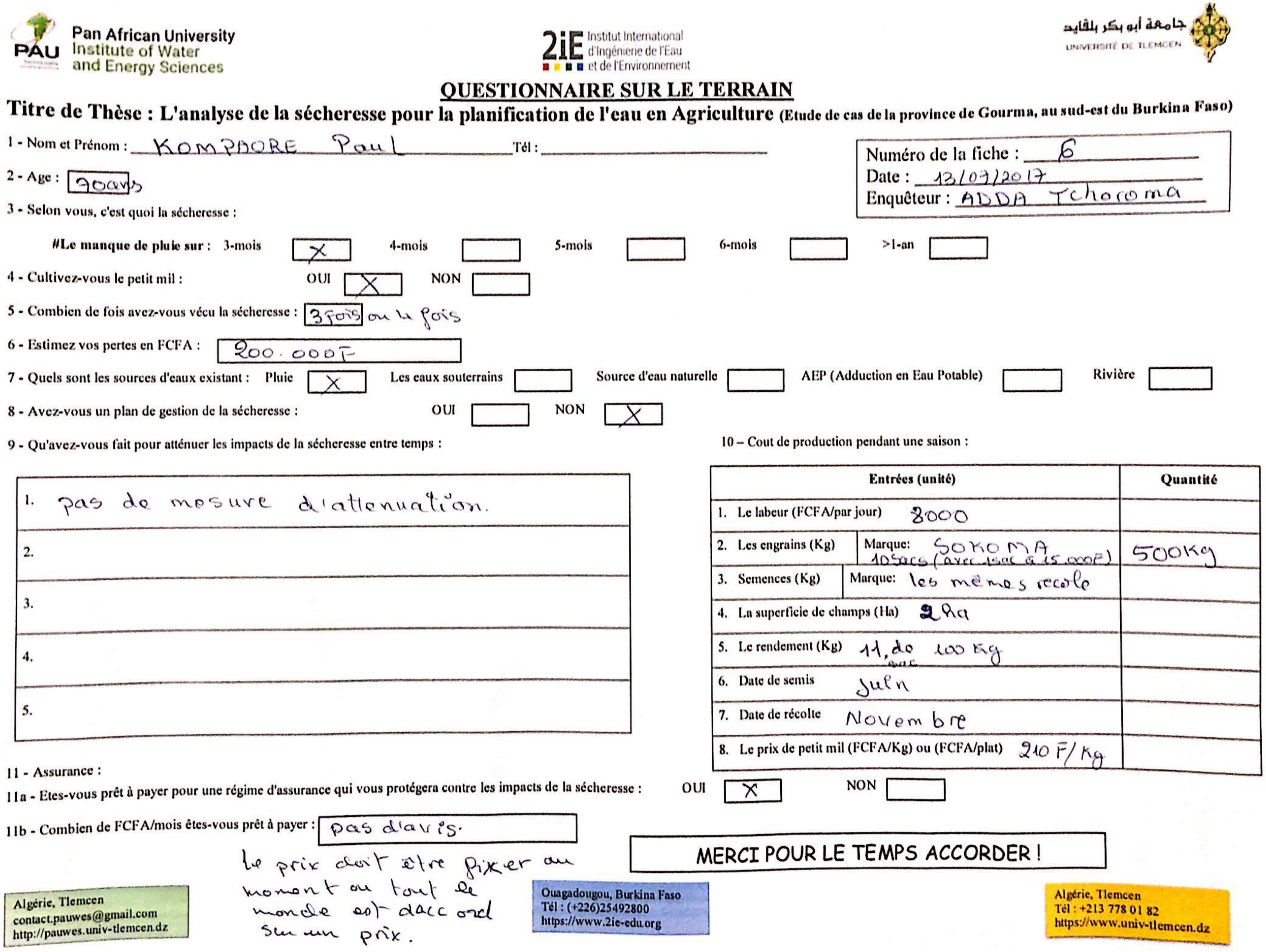

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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 6
Date : 13/07/2017
Enquêteur : ADDA Tchoroma

1 - Nom et Prénom : KOMPAORE Paul Tél :

2 - Age : 70ans

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☒ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☒ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3fois ou 4 fois

6 - Estimez vos pertes en FCFA : 200.000F

7 - Quels sont les sources d'eaux existant : Pluie ☒ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☒

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1. pas de mesure d'attenuation.
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour) 8000		
2. Les engrains (Kg)	Marque: SOKOMA 10Sacs (avec 1sac à 15.000F)	500Kg
3. Semences (Kg)	Marque: les mêmes recolte	
4. La superficie de champs (Ha) 2ha		
5. Le rendement (Kg) 11, de 100 Kg sac		
6. Date de semis Juin		
7. Date de récolte Novembre		
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 210 F/Kg		

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☒ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : pas d'avis.

le prix doit être fixer au moment ou tout le monde est d'accord sur un prix.

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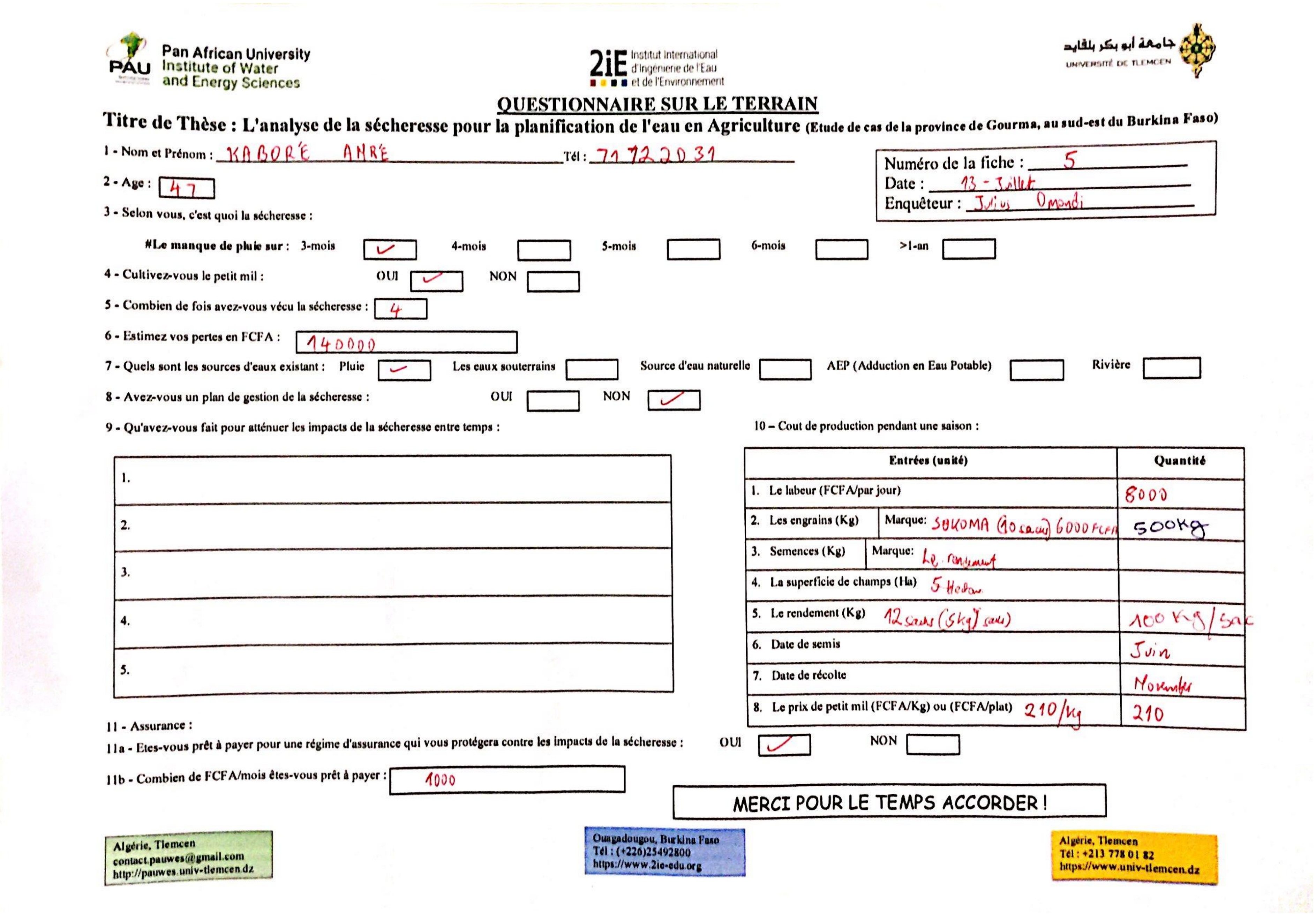

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QUESTIONNAIRE SUR LE TERRAIN

Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 5
Date : 13 - Juillet
Enquêteur : Julius Omondi

1 - Nom et Prénom : KABORÉ ANRÉ Tél : 71 72 20 31

2 - Age : 47

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☑ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☑ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 4

6 - Estimez vos pertes en FCFA : 140000

7 - Quels sont les sources d'eaux existant : Pluie ☑ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☑

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1.
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour)		8000
2. Les engrains (Kg)	Marque: SUKOMA (10 sacs) 6000 FCFA	500kg
3. Semences (Kg)	Marque: Le rendement	
4. La superficie de champs (Ha) 5 Hectare		
5. Le rendement (Kg) 12 sacs (5kg/sacs)		100 Kg/Sac
6. Date de semis		Juin
7. Date de récolte		Novembre
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 210/kg		210

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☑ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 1000

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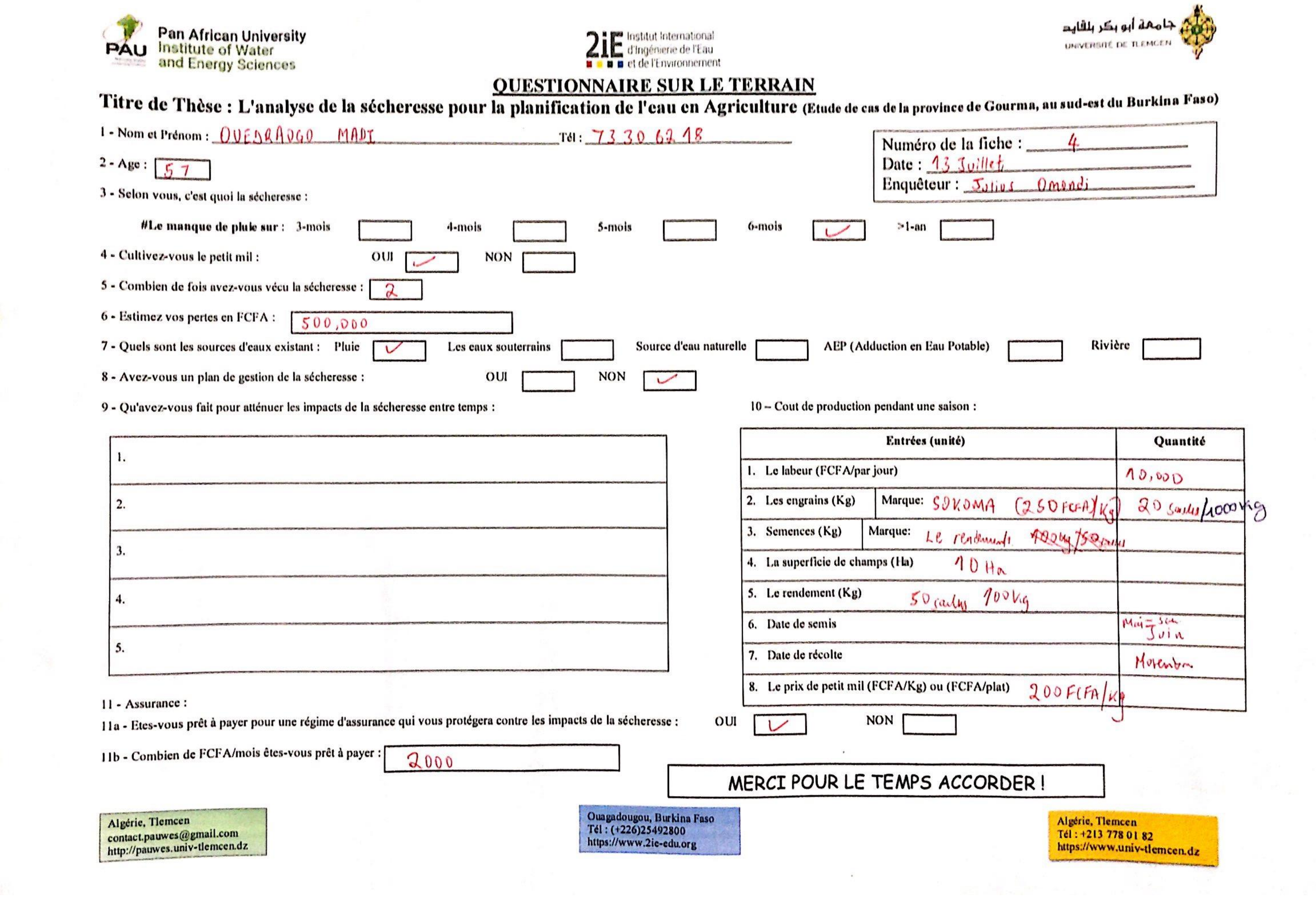

QUESTIONNAIRE SUR LE TERRAIN

Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 4
Date : 13 Juillet
Enquêteur : Julius Omondi

1 - Nom et Prénom : OUEDRAOGO MADI Tél : 73 30 62 18

2 - Age : 57

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☐ 4-mois ☐ 5-mois ☐ 6-mois ☑ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☑ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 2

6 - Estimez vos pertes en FCFA : 500,000

7 - Quels sont les sources d'eaux existant : Pluie ☑ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☑

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1.
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)	Quantité
1. Le labeur (FCFA/par jour)	10,000
2. Les engrains (Kg) Marque: SOKOMA (250 FCFA/Kg)	20 sacs/1000 Kg
3. Semences (Kg) Marque: Le rendement 100kg/50 sacs	
4. La superficie de champs (Ha) 10 Ha	
5. Le rendement (Kg) 50 sacs 100 Kg	
6. Date de semis	Mai – Juin
7. Date de récolte	Novembre
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 200 FCFA/Kg	

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☑ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 2000

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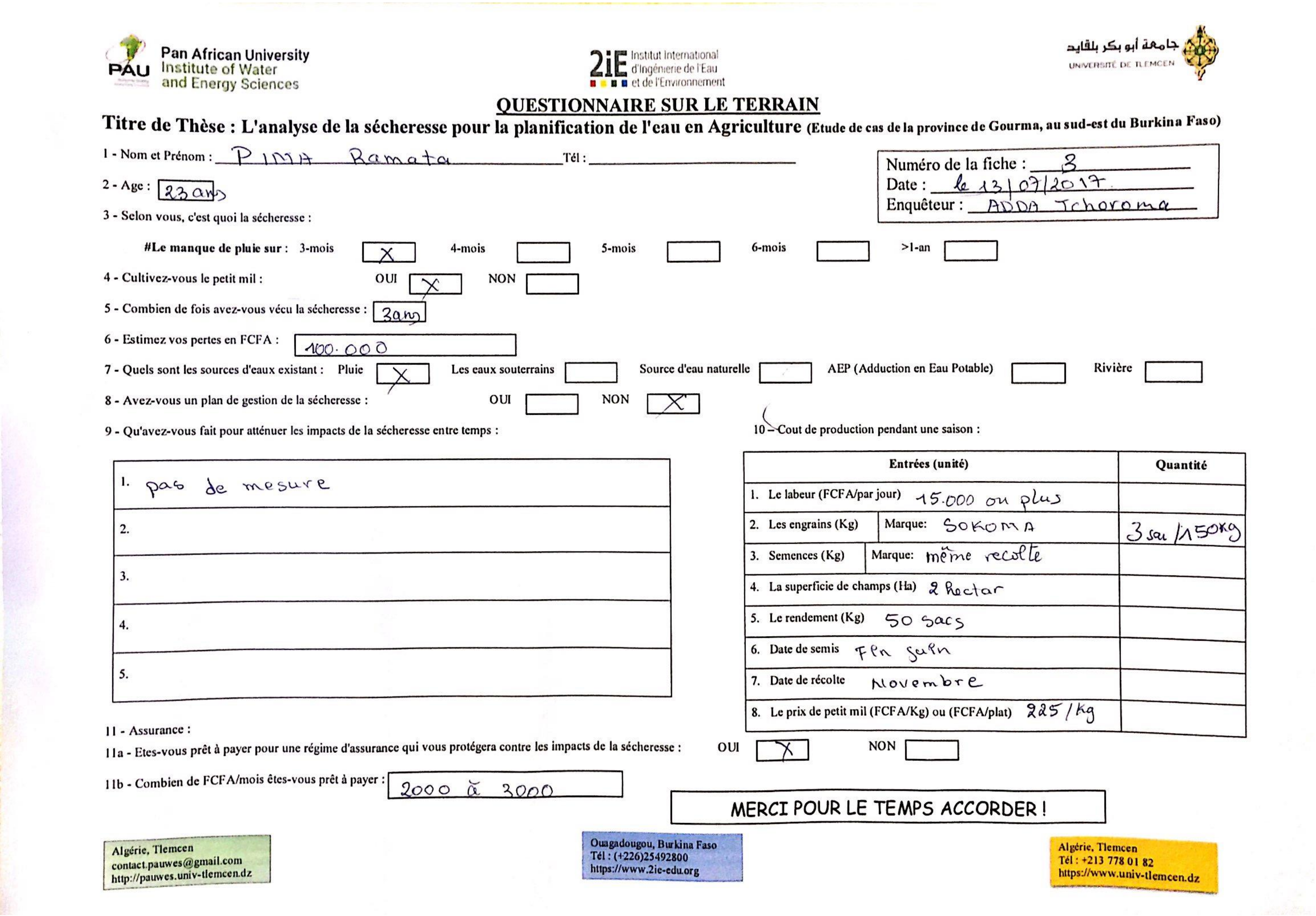

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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 3
Date : le 13/07/2017
Enquêteur : ADDA Tchoroma

1 - Nom et Prénom : PIMA Ramata Tél :

2 - Age : 23 ans

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☒ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☒ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3ans

6 - Estimez vos pertes en FCFA : 100.000

7 - Quels sont les sources d'eaux existant : Pluie ☒ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☒

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1.	pas de mesure
2.	
3.	
4.	
5.	

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour) 15.000 ou plus		
2. Les engrains (Kg)	Marque: SOKOMA	3 sac/150kg
3. Semences (Kg)	Marque: même recolte	
4. La superficie de champs (Ha) 2 hectar		
5. Le rendement (Kg) 50 sacs		
6. Date de semis Fin juin		
7. Date de récolte Novembre		
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 225/Kg		

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☒ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 2000 à 3000

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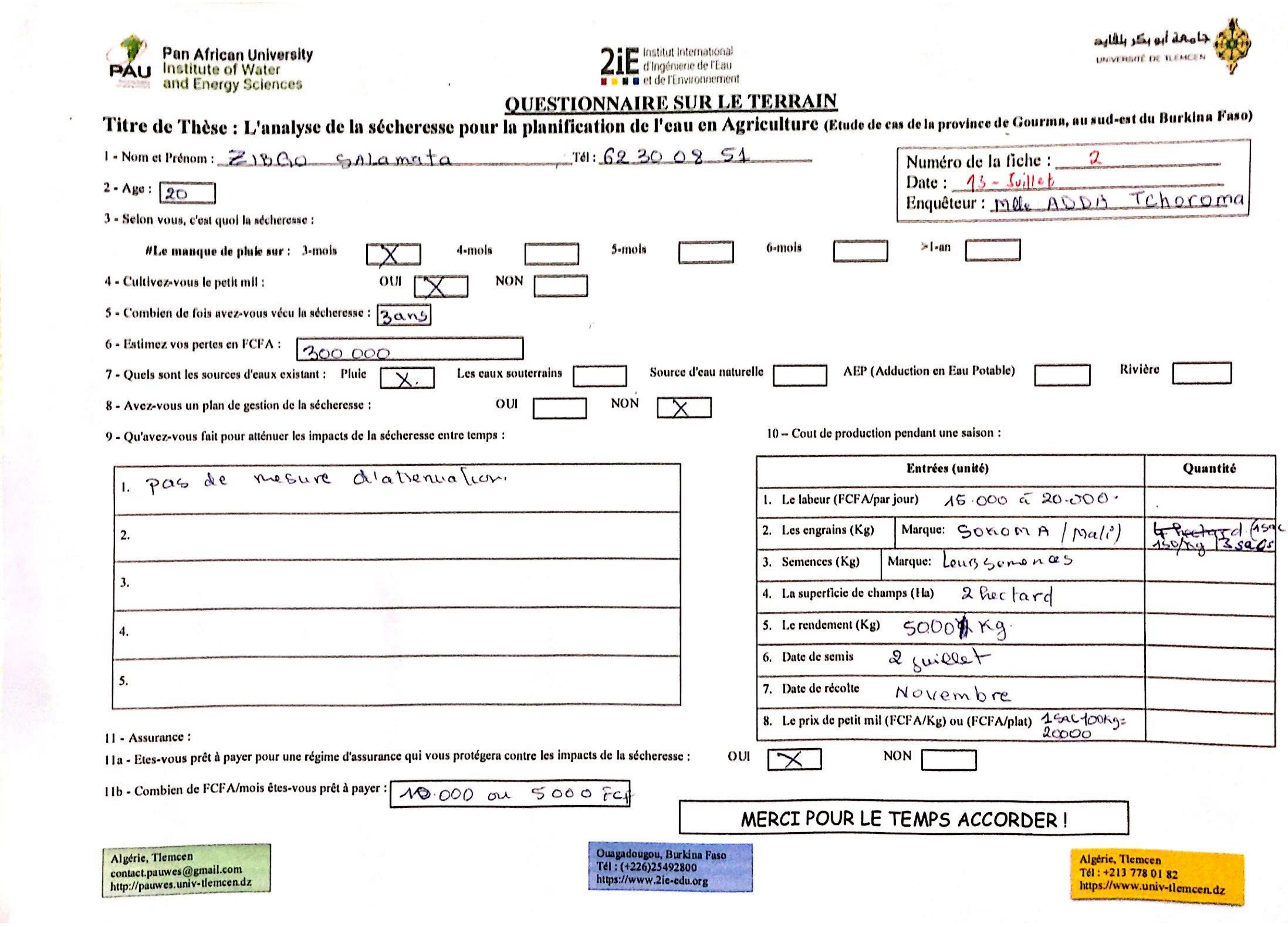

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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 2
Date : 13 - Juillet
Enquêteur : Mlle ADDA Tchoroma

1 - Nom et Prénom : ZIBGO SALamata Tél : 62 30 08 51

2 - Age : 20

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☒ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☒ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3ans

6 - Estimez vos pertes en FCFA : 300 000

7 - Quels sont les sources d'eaux existant : Pluie ☒ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☒

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1. pas de mesure d'attenuation.
2.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		Quantité
1. Le labeur (FCFA/par jour) 15.000 à 20.000.		
2. Les engrains (Kg)	Marque: SOKOMA / Mali)	~~4 hectard~~ (1sac à 16.000) 150/kg | 3 sacs
3. Semences (Kg)	Marque: Lours semences	
4. La superficie de champs (Ha) 2 hectard		
5. Le rendement (Kg) 5000 kg.		
6. Date de semis 2 juillet		
7. Date de récolte Novembre		
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat) 1sac 100kg= 20000		

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☒ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 10.000 ou 5000 Fcf

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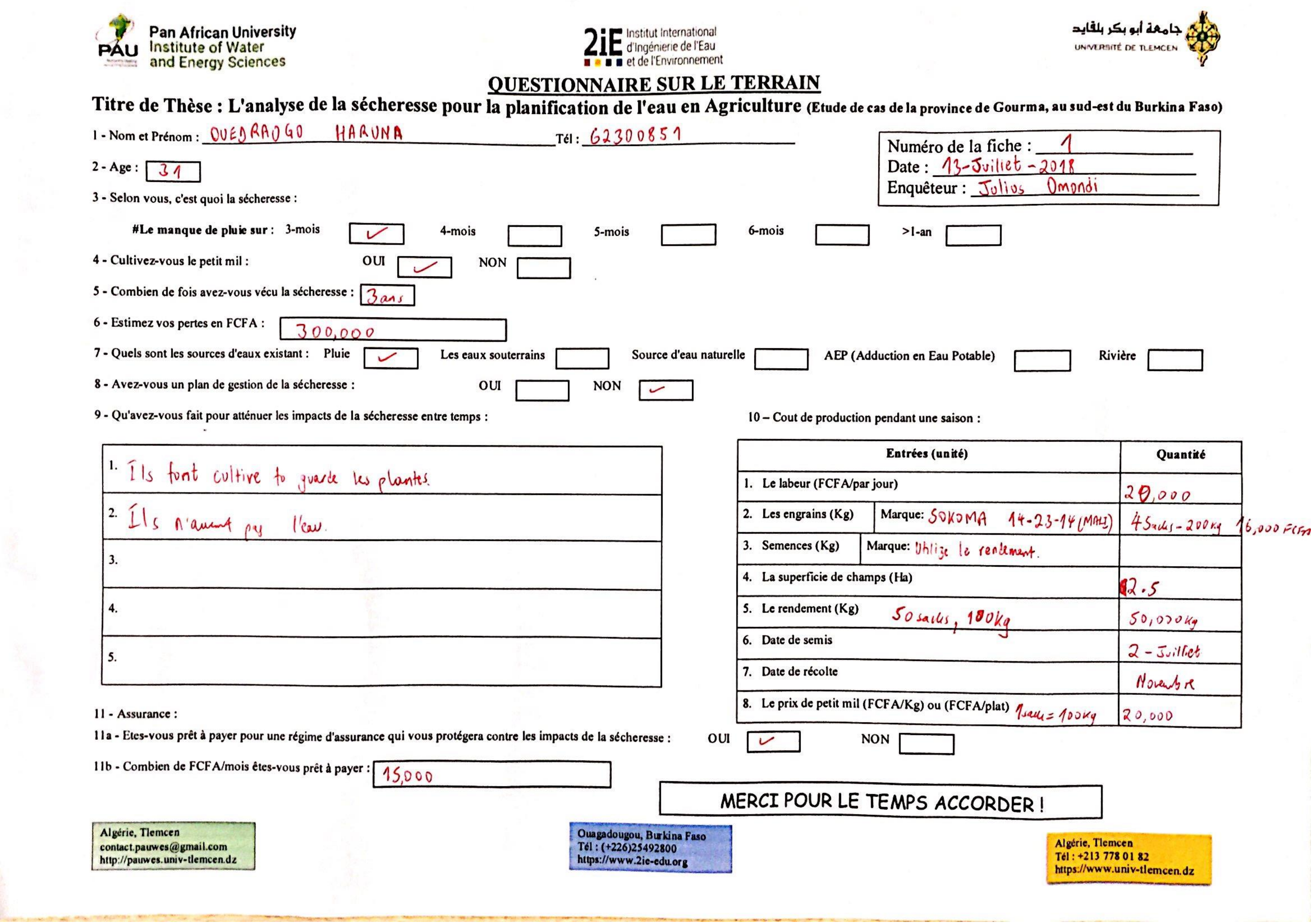

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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture **(Etude de cas de la province de Gourma, au sud-est du Burkina Faso)**

Numéro de la fiche : 1
Date : 13-Juillet-2018
Enquêteur : Julius Omondi

1 - Nom et Prénom : OUEDRAOGO HARUNA Tél : 62300851

2 - Age : 31

3 - Selon vous, c'est quoi la sécheresse :

#Le manque de pluie sur : 3-mois ☑ 4-mois ☐ 5-mois ☐ 6-mois ☐ >1-an ☐

4 - Cultivez-vous le petit mil : OUI ☑ NON ☐

5 - Combien de fois avez-vous vécu la sécheresse : 3ans

6 - Estimez vos pertes en FCFA : 300,000

7 - Quels sont les sources d'eaux existant : Pluie ☑ Les eaux souterrains ☐ Source d'eau naturelle ☐ AEP (Adduction en Eau Potable) ☐ Rivière ☐

8 - Avez-vous un plan de gestion de la sécheresse : OUI ☐ NON ☑

9 - Qu'avez-vous fait pour atténuer les impacts de la sécheresse entre temps :

1. Ils font cultive to guarde les plantes.
2. Ils n'aurent pas l'eau.
3.
4.
5.

10 – Cout de production pendant une saison :

Entrées (unité)		**Quantité**
1. Le labeur (FCFA/par jour)		20,000
2. Les engrains (Kg)	Marque: SOKOMA 14-23-14 (MALI)	4Sacks - 200kg 16,000 FCFA
3. Semences (Kg)	Marque: Uhlize le rendement.	
4. La superficie de champs (Ha)		2.5
5. Le rendement (Kg)	50 sacks, 100kg	50,000kg
6. Date de semis		2 - Juillet
7. Date de récolte		Novembre
8. Le prix de petit mil (FCFA/Kg) ou (FCFA/plat)	1sack = 100kg	20,000

11 - Assurance :

11a - Etes-vous prêt à payer pour une régime d'assurance qui vous protégera contre les impacts de la sécheresse : OUI ☑ NON ☐

11b - Combien de FCFA/mois êtes-vous prêt à payer : 15,000

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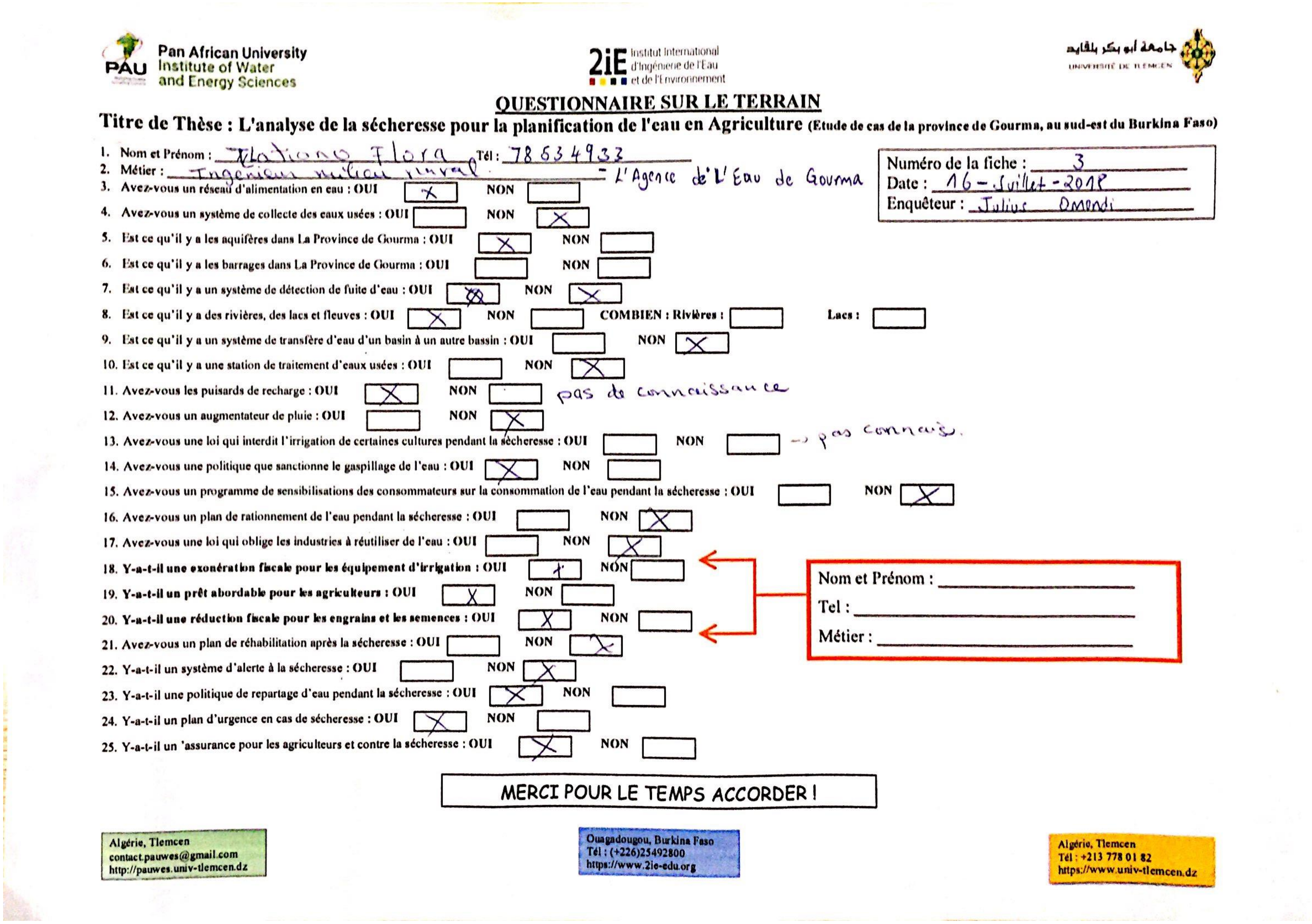
ANNEX 5: WATER RESOURCES INVENTORY QUESTIONNAIRES



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Titre de Thèse : L'analyse de la sécheresse pour la planification de l'eau en Agriculture (Etude de cas de la province de Gourma, au sud-est du Burkina Faso)

Numéro de la fiche : 3
Date : 16-Juillet-2018
Enquêteur : Julius Omondi

1. Nom et Prénom : Tlatiano Flora Tél : 78 53 49 33
2. Métier : Ingenieur milieu rural = L'Agence de L'Eau de Gourma
3. Avez-vous un réseau d'alimentation en eau : OUI ☒ NON ☐
4. Avez-vous un système de collecte des eaux usées : OUI ☐ NON ☒
5. Est ce qu'il y a les aquifères dans La Province de Gourma : OUI ☒ NON ☐
6. Est ce qu'il y a les barrages dans La Province de Gourma : OUI ☐ NON ☐
7. Est ce qu'il y a un système de détection de fuite d'eau : OUI ☒ NON ☒
8. Est ce qu'il y a des rivières, des lacs et fleuves : OUI ☒ NON ☐ COMBIEN : Rivières : ☐ Lacs : ☐
9. Est ce qu'il y a un système de transfère d'eau d'un basin à un autre bassin : OUI ☐ NON ☒
10. Est ce qu'il y a une station de traitement d'eaux usées : OUI ☐ NON ☒
11. Avez-vous les puisards de recharge : OUI ☒ NON ☐ pas de connaissance
12. Avez-vous un augmentateur de pluie : OUI ☐ NON ☒
13. Avez-vous une loi qui interdit l'irrigation de certaines cultures pendant la sècheresse : OUI ☐ NON ☐ → pas connais.
14. Avez-vous une politique que sanctionne le gaspillage de l'eau : OUI ☒ NON ☐
15. Avez-vous un programme de sensibilisations des consommateurs sur la consommation de l'eau pendant la sécheresse : OUI ☐ NON ☒
16. Avez-vous un plan de rationnement de l'eau pendant la sécheresse : OUI ☐ NON ☒
17. Avez-vous une loi qui oblige les industries à réutiliser de l'eau : OUI ☐ NON ☒
18. Y-a-t-il une exonération fiscale pour les équipement d'irrigation : OUI ☒ NON ☐
19. Y-a-t-il un prêt abordable pour les agriculteurs : OUI ☒ NON ☐
20. Y-a-t-il une réduction fiscale pour les engrains et les semences : OUI ☒ NON ☐
21. Avez-vous un plan de réhabilitation après la sécheresse : OUI ☐ NON ☒
22. Y-a-t-il un système d'alerte à la sécheresse : OUI ☐ NON ☒
23. Y-a-t-il une politique de repartage d'eau pendant la sécheresse : OUI ☒ NON ☐
24. Y-a-t-il un plan d'urgence en cas de sécheresse : OUI ☒ NON ☐
25. Y-a-t-il un 'assurance pour les agriculteurs et contre la sécheresse : OUI ☒ NON ☐

Nom et Prénom : ____
Tel : ____
Métier : ____

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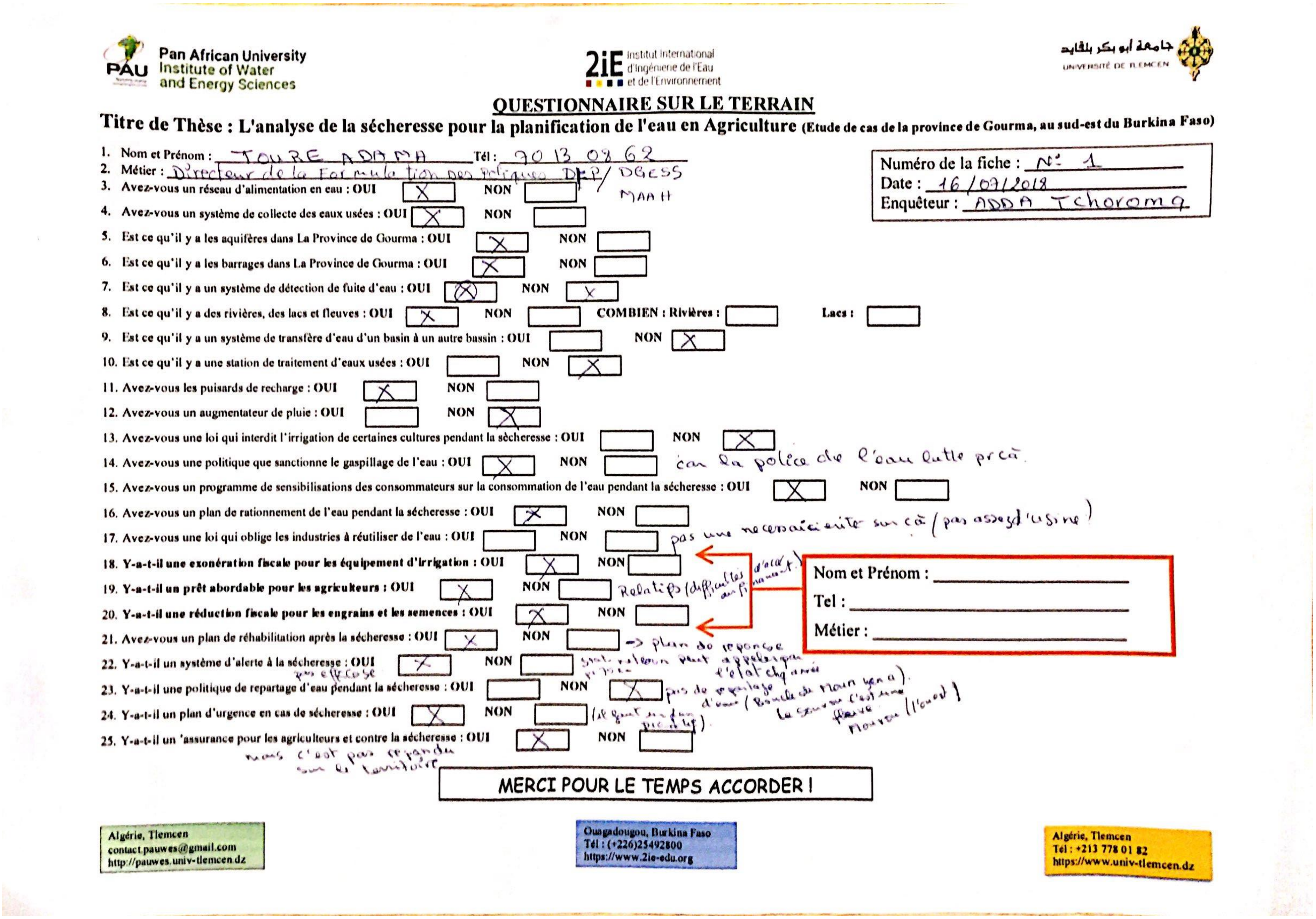

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Numéro de la fiche : N° 1
Date : 16/07/2018
Enquêteur : ADDA Tchoroma

1. Nom et Prénom : TOURE ADAMA Tél : 70 13 08 62
2. Métier : Directeur de la Formulation des Politiques DFP/ DGESS MAAH
3. Avez-vous un réseau d'alimentation en eau : OUI ☒ NON ☐
4. Avez-vous un système de collecte des eaux usées : OUI ☒ NON ☐
5. Est ce qu'il y a les aquifères dans La Province de Gourma : OUI ☒ NON ☐
6. Est ce qu'il y a les barrages dans La Province de Gourma : OUI ☒ NON ☐
7. Est ce qu'il y a un système de détection de fuite d'eau : OUI ☒ NON ☒
8. Est ce qu'il y a des rivières, des lacs et fleuves : OUI ☒ NON ☐ COMBIEN : Rivières : ☐ Lacs : ☐
9. Est ce qu'il y a un système de transfère d'eau d'un basin à un autre bassin : OUI ☐ NON ☒
10. Est ce qu'il y a une station de traitement d'eaux usées : OUI ☐ NON ☒
11. Avez-vous les puisards de recharge : OUI ☒ NON ☐
12. Avez-vous un augmentateur de pluie : OUI ☐ NON ☒
13. Avez-vous une loi qui interdit l'irrigation de certaines cultures pendant la sècheresse : OUI ☐ NON ☒
14. Avez-vous une politique que sanctionne le gaspillage de l'eau : OUI ☒ NON ☐ car la police de l'eau lutte pr cā.
15. Avez-vous un programme de sensibilisations des consommateurs sur la consommation de l'eau pendant la sécheresse : OUI ☒ NON ☐
16. Avez-vous un plan de rationnement de l'eau pendant la sécheresse : OUI ☒ NON ☐
17. Avez-vous une loi qui oblige les industries à réutiliser de l'eau : OUI ☐ NON ☐ pas une necessaicieuite sur cā (pas assez d'usine)
18. **Y-a-t-il une exonération fiscale pour les équipement d'irrigation : OUI** ☒ **NON** ☐
19. **Y-a-t-il un prêt abordable pour les agriculteurs : OUI** ☒ **NON** ☐ Relatifs (difficultés d'accès au financement).
20. **Y-a-t-il une réduction fiscale pour les engrains et les semences : OUI** ☒ **NON** ☐
21. Avez-vous un plan de réhabilitation après la sécheresse : OUI ☒ NON ☐ -> plan de reponse
22. Y-a-t-il un système d'alerte à la sécheresse : OUI ☒ NON ☐ pas efficace [illegible] peut appeler par l'état chq année
23. Y-a-t-il une politique de repartage d'eau pendant la sécheresse : OUI ☐ NON ☒ pas de partage d'eau (Boucle du Mouhoun yen a). La source c'est une fleuve Mouhoun (l'ouest)
24. Y-a-t-il un plan d'urgence en cas de sécheresse : OUI ☒ NON ☐ (il faut un plan proactif).
25. Y-a-t-il un 'assurance pour les agriculteurs et contre la sécheresse : OUI ☒ NON ☐ mais c'est pas répandu sur le territoire

Nom et Prénom : ____
Tel : ____
Métier : ____

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ANNEX 6: CROP YIELDS RESULTS SAMPLE

YEAR	RUNNAM	SET	SOW	EM	DUR	TWLV	TWST	TWSO	TAGP	LAIM	HINDEX	TRC	RAINT	DELWAT	TRAT	EVSOL	LOSST	TSR	RYLD	RAGP
1979	WCC1	1	182	186	90	1289	6070	3413	10772	2.89	0.32	113	160.5	-1.3	12.2	36.2	99.9	13.5	100	100
1980	WCC1	1	182	187	90	1337	7053	3501	11891	2.94	0.29	126	81.8	-3.2	15	33.3	29.6	7.1	84.7	78.1
1981	WCC1	1	182	186	89	1233	6103	3271	10607	2.73	0.31	126	73.7	-1.9	13.4	25.4	33.3	3.5	92.3	90.5
1982	WCC1	1	182	186	89	715	4485	2174	7374	1.57	0.29	130	63.6	-3.7	9.6	23.9	31.7	2.1	68.2	64.4
1983	WCC1	1	182	186	86	1074	5095	1395	7564	2.34	0.18	147	18.8	-6.8	11.1	13.4	0.6	0.6	47.7	57.3
1984	WCC1	1	182	186	86	726	4471	1762	6959	1.57	0.25	148	34	-6.5	10.3	19.3	4.6	6.2	63.2	57.7
1985	WCC1	1	182	186	88	891	5549	2315	8755	1.93	0.26	134	56.8	-2.8	11.8	24.7	21.3	1.9	73.4	68.1
1986	WCC1	1	182	186	88	962	5072	2694	8727	2.1	0.31	130	28.2	-3.4	11.4	17	2.3	0.9	72.4	64.9
1987	WCC1	1	182	185	87	809	4722	2435	7966	1.78	0.31	133	80.1	0.5	10.6	22	38.5	8.5	72.2	68.3
1988	WCC1	1	182	186	90	341	2129	1233	3703	0.75	0.33	112	92.2	-1.8	4.2	27.4	59.5	3	44.7	42.7
1989	WCC1	1	183	187	90	898	5237	2452	8587	1.97	0.29	126	58.9	-1.3	10.8	21.9	25.5	1.9	75.8	71.3
1990	WCC1	1	182	186	87	920	5243	1361	7524	1.99	0.18	127	26.3	-9.2	9.6	17.2	7.8	0.9	40.2	53.5
1991	WCC1	1	182	186	88	1095	5732	2726	9554	2.4	0.29	138	60.9	-7	13.2	24	20.3	10.4	77.8	67.4
1992	WCC1	1	182	186	89	944	5052	2490	8486	2.05	0.29	130	38.8	-4.7	11	19.2	7.8	5.5	72	64
1993	WCC1	1	182	186	87	726	4528	2128	7382	1.58	0.29	139	27.3	-6	10.3	14.1	8	0.9	61.8	55.3
1994	WCC1	1	182	186	90	1098	5821	2836	9755	2.42	0.29	123	65	-1	12	16.9	34.9	2.1	81.3	76.4
1995	WCC1	1	182	186	88	1162	6529	2954	10645	2.56	0.28	126	44.9	-0.4	13.4	20.5	9.9	1.5	80.6	74.4
1996	WCC1	1	182	186	88	790	4811	2210	7812	1.72	0.28	131	43.2	-2.6	10.3	25.6	8.2	1.8	66.3	60.2
1997	WCC1	1	182	186	87	725	4548	2024	7297	1.58	0.28	146	48.2	-6.2	10.7	20.2	22	1.6	62.5	55.7
1998	WCC1	1	182	185	87	864	5160	2458	8482	1.88	0.29	133	26.1	-3.9	11.3	15.5	2.4	0.9	68.6	62.3
1999	WCC1	1	182	186	86	1076	6147	2320	9543	2.36	0.24	123	10.9	-9	11.7	7.3	0.6	0.4	62.9	63.9
2000	WCC1	1	182	185	86	912	3049	34	3995	1.92	0.01	150	1.9	-9.9	6	5.2	0.6	0.1	1.3	29.9
2001	WCC1	1	182	185	86	792	3801	298	4891	1.72	0.06	139	6.3	-9.7	6.8	8.5	0.6	0.2	10.3	39.7
2002	WCC1	1	182	186	86	771	3616	285	4672	1.68	0.06	152	6.6	-9.7	7.1	8.4	0.6	0.2	10.5	39.7
2003	WCC1	1	182	186	86	710	4438	1686	6835	1.54	0.25	129	11.2	-8.7	8.8	10.2	0.6	0.4	52.8	55.6
2004	WCC1	1	182	186	86	977	4231	322	5529	2.07	0.06	138	4.7	-9.7	7.6	6.1	0.6	0.2	11.8	41.6
2005	WCC1	1	182	186	86	904	4521	1127	6552	1.97	0.17	134	9.7	-9.4	8.8	9.4	0.6	0.3	40.2	52
2006	WCC1	1	182	186	87	911	5314	2530	8754	1.98	0.29	131	30.6	-3.1	11.5	16.4	4.7	1	69.2	61.3
2007	WCC1	1	182	186	88	691	4242	1959	6893	1.49	0.28	134	24.8	-5	9.3	14.3	5.4	0.8	60.2	53.5
2008	WCC1	1	182	186	87	1276	6221	1011	8508	2.81	0.12	134	32.6	-8	11.4	14.4	2.5	12.2	28.9	60.9
2009	WCC1	1	182	185	86	925	5142	2519	8587	2.03	0.29	143	30.5	-4.1	12.3	9.9	11.4	1	72.1	66
2010	WCC1	1	182	186	88	824	5221	2112	8158	1.78	0.26	133	41.7	-0.8	10.9	18.8	11.4	1.4	67.9	61.2
2011	WCC1	1	182	186	87	1375	7560	2712	11647	3.02	0.23	129	33.5	-8.8	15	16.4	9.8	1.1	80.5	75.4
2012	WCC1	1	182	186	87	890	5407	2636	8934	1.94	0.3	134	44.5	-4.4	12	17.8	17.7	1.5	71.9	66.6
2013	WCC1	1	182	186	86	1406	7301	3278	11985	3.09	0.27	134	40	-5.5	16	14.6	13.5	1.3	86.6	77.8
2014	WCC1	1	182	186	90	120	77	0	197	0.3	0	104	8.5	-2.5	0.2	10	0.6	0.3	0	22.3

Drought analysis for water planning in Agriculture

(A case-study of Gourma Province, Eastern Burkina Faso)

By Julius Omondi

Research grant expenditure report

	Expenditure	Currency of expenditure	Value of expenditure	Expenditure in USD
1	Air Ticket	FCFA	101,100	193
2	Air Ticket	FCFA	83,000	158
3	Air Ticket	DZD	62,103	554
4	Fada Transport	FCFA	18,000	34
5	Printing (color)_A4	FCFA	63,000	120
6	Passport Photo	USD	50	50
7	Air Time	FCFA	6,250	12
8	Internet connection_1	FCFA	66,600	127
9	Internet connection_2	FCFA	284,000	542
10	Scanning_A3	FCFA	22,000	42
11	Photocopying_A3	FCFA	26,780	51
12	Printing (color) A3	FCFA	46,750	89
13	Taxi Fada	USD	561	561
14	Farmers	FCFA	22,000	42
15	Interviewers	FCFA	20,000	38
16	Data Analysis	FCFA	50,000	95
17	Computer repair	FCFA	100,000	191
18	Flip chart	FCFA	8,000	15
19	Marker pens	FCFA	5,000	10
20	Notebook	FCFA	9,000	17
21	Document Translation	FCFA	30,000	57
			Total	**3,000**