UNIVERSITY OF CAPE COAST

DEVELOPING CULTIVATION PRACTICES TO COMBAT EARLY DROUGHT CHALLENGES: THE CASE OF SORGHUM IN MALI

BY

SIAKA DEMBELE

Thesis submitted to the Department of Crop Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy Degree in Crop Science

DECEMBER, 2016

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:…..…… ……..Date: 19 January, 2017

Name: Siaka Dembélé

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:

Name: Dr. Robert Zougmoré... ….Date: 10 January, 2017

Co-Supervisor's Signature:

Name: Prof. Jonathan. Padi Tetteh… …..Date: 19 January, 2017

Dr. Adama Coulibaly..…… ………….Date: 10 January, 2017

Dr. John Lamers…..… ..Date:10 January, 2017

ABSTRACT

Rainfall variability and early season drought are among the most severe consequences of climate change in the Sahelian zone of Mali in West Africa that affect the production of key staple crops such as Sorghum (*Sorghum bicolor* (L.) Moench). Therefore, a three-step research was conducted with trials in the laboratory, pots and field to improve seed germination and reduce crop establishment failure. The experiments were set up to evaluate the effects of heat and drought stress, priming of seeds and the z*aï* pits practice on the performance of nine sorghum varieties. During all steps, a wide series of recognized germination performance indicators were used to assess in promising varieties and pre-seed treatments (hydro or osmo-priming) in laboratory and pot trials for their impact on crop yield. The findings showed that the varieties Banidoka, CSM63E and Saba-tienda performed best under heat and drought stress conditions. Hydro-priming in tepid or hot water was an effective technique to improve seed germination and seedling growth parameters in general. Water derived from the river or well was most effective for hydro-priming whilst a hydro-priming duration of 8 hours at room temperature (25 ^{o}C) equaled the effect of 20 minutes priming in hot water (70 ^{o}C), but in both cases, treated seeds had to be immediately sown. Osmo-priming with 50 ppm of KH_2PO_4 or 100 ppm of K_2SiO_3 significantly improved seed germination and seedling growth in early drought conditions. A combination of priming and the *zaï* pits practice, which involves an application of organic matter, increased grain yield by 34% and straw yield by 42% over the control without priming and sown on the ridge.

KEYWORDS

Dought and heat stress,

Seed priming,

Seedling growth,

Sorghum,

West Africa Sahel,

Zaï pits practice

ACKNOWLEDGMENTS

I am sincerely indebted to the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), for the study fellowship. The financial, technical and moral support of WASCAL contributed immensely to achieve this degree. I am grateful to my supervisor Dr. Robert Zougmoré for his advice, encouragement and constructive corrections. Also my co-supervisors Prof. J.P Tetteh, Dr. Adama Coulibaly and Dr. John Lamers I owe gratitude for their invaluable contributions. I am grateful particularly to Dr. Guido Luetchers for all his help and explanations during the statistical analyses. I singularly acknowledge Dr. Aad van Ast for his tremendous corrections and contributions on proof reading of this thesis. I also wish to thank Prof. Dr. Amoro Coulibaly, and through him, all staff of the section of Climate Change and Agriculture for their support during this study. I am grateful also to all my colleagues and collaborators for their support and permanent encouragements. I have to thank Mr. Yaya Coulibaly, Jacob Coulibaly, Guillaume Kamate and all my student fellows, for their enthusiastic contribution during data collection. The list in fact is endless, but I am grateful to all those who have contributed towards this achievement. Yet, my sincerest gratitude goes to my family for their support, patience, prayers, and encouragements and understanding. I greatly thank my wife, Djenebou Kone and my sons Seydou, Kadiatou and Adama for their support and understanding during my periods of absences.

DEDICATION

Dedicated to my

Parents the late Seydou DEMBELE and Kadiatou KONE, my wife, Djenebou KONE and our sons Seydou, Kadiatou and Adama and the DEMBELE family.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AGRHYMET	Agriculture, hydrology, meteorology agro metrology and operational hydrology
ANOVA	Analysis of variance
AOSA	Association of official seed analysts
APFM	Associated programme on flood management
ATP	Adenosine triphosphate
CILSS	Comité permanent inter-etats de lutte contre la sécheresse dans le sahel
CC&CV	Climate change and climate variability
DAS	Days after sowing
DNA	Deoxyribonucleic acid
ECOWAS	Economic community of west african states
FAO	Food and agriculture organization of the united nations
GHG	Greenhouse gas
ICARDA	International center for agricultural research in the dry areas
ICRISAT	Internationl crop reseach institute for the semi-arid tropics
IER	Institut d’economie rurale
IPCC	Intergovernmental panel on climate change
OECD	Organisation for economic co-operation and development
PPM	Part per million

SWAC	Sahel and west africa club secretariat
UCC	University of cape coast
UNDP	United nations development programme
USDA	United states department of agriculture
WASCAL	West african science service center on climate change and adapted land use
WMO	World meteorological organization

CHAPTER ONE

INTRODUCTION

Climatological extremes including very high temperatures and droughts are predicted to have a general negative effect on plant growth and development, leading to catastrophic loss of crop productivity and resulting in wide spread famine. Future agricultural production and thus global food security will encounter additional challenges from human population growth (Bita & Gerats, 2013a). In most rainfed cropping systems of Mali, drought is the single most critical threat to agricultural production. Sorghum seedlings experience both soil and atmospheric water deficit (heat) as a consequence of growing unreliable rainfall, particularly at the beginning of the rainy season. The limited availability of soil water combined with increased temperatures cause moisture stress, which affects various metabolic processes of the plant. In addition, other factors such as low and declining soil fertility and reduced soil water-holding capacity and poor crop management (ex: delayed planting, lack of seed preparation techniques) can limit the productivity of sorghum, particularly in the context of climate change. The present study evaluates locally adaptable and socially and economically acceptable crop management options to meet drought challenges, in particular under early-season rainfall patterns, for sorghum production in Mali.

Background to the study

Sorghum (*Sorghum bicolor* (L.) Moench) ranks fifth worldwide among the most important cereals, after wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), rice (*Oryza sativa* L.) and barley (*Hordeum vulgare* L.). Furthermore, after maize it has the second highest production potential in Africa, which is particularly true in the semi-arid regions where it is therefore considered a "food security" crop. Sorghum reportedly is the dietary staple for more than 500 million people in over 90 countries, albeit primarily in the developing world (Reddy & Kumar, 2010). Sorghum grains are commonly used to satisfy human nutritional demands, but mainly in countries of Africa and Asia. The grains usually are ground to flour for producing bread in Africa, Central America, Southern Europe and Southern Asia, and also turned into porridges and side dishes (Dicko, Gruppen, Traore, Voragen, van Berkel, 2006; Malleshi & Desikachar, 1988). Sorghum has a wide range of uses, such as food, beer brewing and livestock feed and fodder (Thomson, 2006). In addition, the crop is used in the production of commercial alcohol, adhesives, waxes, construction materials and bio-ethanol from sweet sorghum varieties (Ng'uni, 2011). The starch content of sorghum grain ranges from 56 to 73 g/100g with an average of 69.5 g/100g (Ng'uni).

The sorghum grain protein content is within the range of 7 to 15% (Dicko, et al., 2006). Using the solubility-based classification (Hamaker & Bugusu, 2003), sorghum proteins have been divided into albumins, globulins, kafirins, cross-linked kafirins and glutelins. The kafirins, which are aqueous alcohol-soluble prolins account for about 50-70% of the proteins vitamin B and more than 20 mineral elements (Gerrano, Labuschagne, & Biljon, 2016; Elzaki, 2015). It specifically is rich in phosphorus, potassium, and iron (Abdelghafor, 2015). Sorghum also is a better source of zinc, an important micronutrient for pregnant women, than corn and wheat (Dicko et al.).

Sorghum silage turns out to be rich in sugar and minerals such as calcium, phospohorus, and carotene. Furthermore, sorghum may be planted in intercropping or mixed cropping, indicating its compatibility with common practices of tropical subsistence farmers (Obayelu & Afolami, 2013). In West and Central Africa (WCA) the production potential is greatest in the moist savannah where annual rainfall and solar radiation are favourable, and incidence of pests and diseases are minimal (Badu-Apraku, Annor, Oyekunle, & Akinwale, 2015).

Sorghum is one of the most versatile and resilient staple crops in the world. Its ability to thrive in temperate and tropical zones has made it a key source of calories and nutrients also in developing regions (FAOSTAT, 2016). For millions of people in the semi-arid tropics of Asia and Africa (Table 1), sorghum has become one of the most important staple foods,which sustains the lives in particular of poor, rural people and that will continue to do so in the foreseeable future.

Table 1: *Global sorghum production statistics*

Region	Production (million metric tonnes)
Africa	23,314,557
Latin America & Caribbean	14,897,996
Asia & Oceania	11,741,527
NAFTA Region	6,272,360
Europe	0,775,888

Source: FAO, (2015)

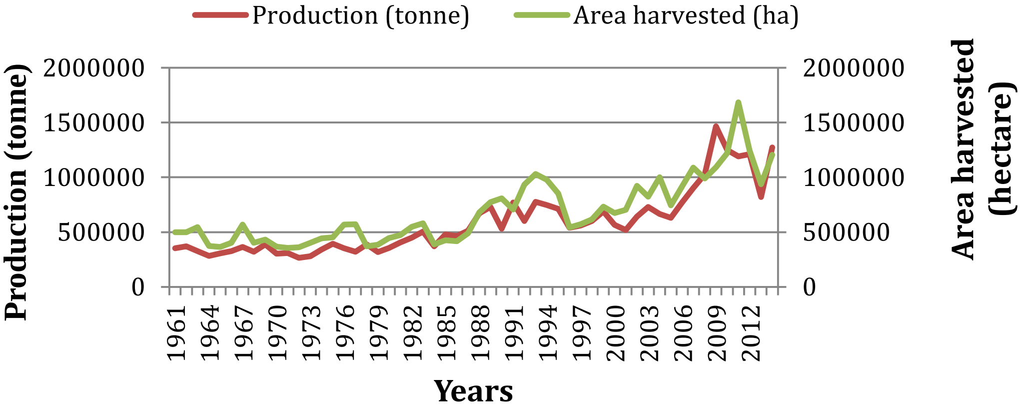
Statement of the Problem

The growing demand for sorghum in Africa is mirrored in the trend of the increasing area under sorghum production over the last fifty years. Unfortunately, per area production of sorghum, as of many other crops in Africa, has not kept pace with the increasing demand. This is due mainly to a lag in crop improvement practices on the one hand, but also owing to environmental conditions and the resource constrains, low-input farming systems in the zones where sorghum used to be grown. Furthermore, in these predominating dryland environments, climate variability and change as well as land degradation are not only acute, but the impacts are growing despite the efforts of the national institutions, such as developpement of early mature varieties and crop management practice i.e plant density, intercropping cereals/legumes (Dembele, 2015). Consequently, all efforts that aim for the development of innovations should be stepped up, be it technology-based (e.g. germplasm improvement, cultivation and management), or institutional-based (e.g. markets, extension, research) to counterbalance and when possible reverse the down-gowing trends in sorghum production in the dryland tropics of Africa (ICRISAT, & ICARDA, 2012).

Sorghum has a C_4-type of photosynthetic pathway, which allows sorghum to be more efficient in water, radiation, and nutrient use, which in turn helps sorghum to cope with harsh climatic conditions such as drought, high temperatures and nitrogen stress. The C_4 plants have a specialized leaf anatomy called Kranz anatomy (Prasad & Staggenborg, 2009).

Drought occurrence, which is highly unpredictable over time and space (Campos, Cooper, Habben, Edmeades, & Schussler, 2004), is difficult to control unless having access to irrigation facilities, which is not the case for the majority of the resource-poor farmers in West Africa. Moreover, the conventional varieties are not all tolerant to drought (Joshi-Saha & Reddy, 2015). The achievements remain modest according to breeders to ensure the development of drought-tolerant varieties, sorghum lines and hybrids in regard to this stress (Joshi-Saha & Reddy). To make things worse, drought is spreading rapidly on the African continent caused by climate change. Although the land area cultivated under sorghum increases annually in Mali (FAOSTAT, 2016), the negative correlation between land area cultivated and output could not be controlled (Figure 1).

Typical for the drought-prone regions in West Africa is that another drought event is likely to occur before a region fully recovers from the last drought occurance. Therefore, many believe the solution lies in early drought warning systems as a means to reduce the (future) impacts of drought and lessen the need for government interventions (Rahmat, Jayasuriya, & Bhuiyan, 2016).



Source: FAOSTAT, (2016)

Figure 1: Trend of sorghum production and area harvested in Mali from 1961-2014

Justification of the study

In Africa alone, nearly 500 million people rely on the crop but also in developed regions, sorghum is gradually becoming an increasingly important biofuel and feed crop (Food and Agricultural Organisation [FAO], 2015). Typical is the ability of sorghum to withstand harsh environments where other crops do not grow well. Hence, improvements in production, availability, storage, utilization and consumption of sorghum will significantly contribute to household food security and nutrition of many in West Africa.

The total world production of Sorghum in 2015/2016 was 62.32 million metric tonnes (United States Department of Agriculture [USDA], 2016). The largest producer worldwide was the United States of America (15,158,000 tonnes) followed by Mexico (7,150,000 tonnes) and Nigeria with 6,150,000 tonnes. The African continent produced 41% of the total output. In Africa, the top ten sorghum producing countries in 20015/2016 were Nigeria, Ethiopia, Sudan, Burkina, Mali, Niger, Cameroon, Chad, Tanzania and Egypt. The top five producing countries in West Africa are: Nigeria, Burkina Faso, Mali, Niger and Ghana. Of the 25.88 million tonnes produced in Africa in 2015/2016, 5% was cultivated in Mali.

The urge is growing for developing heat and drought-tolerant varieties that can withstand in particular early-season drought spells that frequently occurs over time in West Africa. Drought resistance can be induced by adopting various strategies: the exogenous use of various growth regulating and other chemicals that have proven to be worthwhile in producing drought resistance at various growth stages in a number of plants (Kaya, 2009). But, even though such means may be effective and efficient, they increase as well the dependency of the farming population on support from abroad and from outside their direct environment since such developments can hardly be achieved by farmers alone. Furthermore, the development of such means usually is time consuming and often prone to risks. Therefore, farmers will benefit in any case from means and practices that they may implement by themselves and without much support from abroad.

A short-term, pragmatic approach to overcome early-season drought stress is seed priming (Farooq, Aziz, Wahid, & Lee, 2009). Seed priming is a technique by which seeds are partially hydrated to a point where germination-related metabolic processes begin, but radicle emergence does not occur (Kadhimi, Alhasnawi, & Isahak, 2014). Primed seeds usually exhibit increased germination rate, greater germination uniformity, and often greater total germination percentage (Kaya, 2009). This approach has been tested to overcome drought stress in a range of crop species such as maize (Parera & Cantliffe, 1994), sunflower (Kaya), sorghum, rice cowpea (Harris, 2006). When these seed-based treatments are combined with typical water conservation measures such as *zaï* pits that have shown their advances during the growing season (Nyamadzawo, Wuta, Nyamangara, & Gumbo, 2013), the risks of crop failure could be substantially reduced by the farmers themselves. Although the development of management and cultivation methods that can be implemented by farmers to cope with drought and heat is direly needed, a screening of those practices that improve seed germination, in turn reduce crop establishment failure and improve final yields of sorghum. These options however should concurrently be locally suitable and socially and economically acceptable management options and be able to meet the challenges of Climate Change and Climate Variability (CC & CV) as predicted for the West African Sahel zone.

Resource-poor farmers in Mali depend on marginal, rain-fed land to grow sorghum. At the onset of the season, farmers often have to re-sow their crops because of irregular rainfall. Soils used to be low in nutrients and organic matter and over-exploided, which score situations with scarce rainfall. Under these conditions, it is a growing challenge to effectively germinate seeds and establish crops. At present, it is frequent to observe in farmers' fields the 'patchy' emergence of crop seedlings, and later even total crop failure. Revealing evidence indicates that the seeds used did not have the strength to germinate or to grow efficiently under the challenging circumstances of dry-land agriculture. Although sorghum and other corps can be re-sown, the extra expenses involved in this process, e.g. labour and new seeds, can lead farmers into crippling debt and there still is no guarantee of success (Harris, Breese, & Rao, 2005). In addition, it is well known that the first rainfall and high temperatures usually trigger as well the de/mineralization processes (Fritz et al., 2011).When germination and establishment fails major burst of highly needed minerals are lost to crops.

The impact of seed priming using water or chemical solutions, or the screening of drought and heat tolerant varieties, and the use of organic matter and *Zaï* pits planting technique could become a suitable coping strategy to drought. It can by hypothesized that an application of these single agronomic management practices, or a combination of these practices, will help to improve sorghum crop yields under changing environmental conditions in particular.

Purpose of the study

The purpose of this study is to develop agronomic practices that will prevent or reduce crop failure at early season in drought prone areas in the segou region of Mali.

Objectives of the study

The overarching objective of this study is to assess the effect of different seed priming methods on reducing the impact of drought and heat stress on germination and development of nine sorghum varieties and the effect of soil and water conservation methods in combination with priming techniques on the yields of various sorghum varieties. The main working objectives therefore were:

(i) to assess the effect of drought and heat stress on germination and seedling development from nine sorghum varieties;

(ii) to test if germination and seedling development can be enhanced through hydro- and osmo-priming; and

(iii) to assess the effects of a combination of priming and *zaï* pits practice on the field performance of sorghum varieties.

Research questions

It can by hypothesized the risk of crop establishment failure at early season in drought prone zones of Mali could increase under climate variability and change condition. Therefore developed agronomic practices such as heat/drought tolerant varieties, seed priming methods and water harvesting techniques could improve crop establishment and increased sorghum yields under changing environmental conditions in particular. In order to achieve the abovementioned objectives, the following questions were set in this research:

1. What are the response of sorghum varieties to heat and drought stress?
2. Is charcoal powder can generate heat for screening sorghum seedling at early growth stage?
3. What is the response of varieties to tepid hydro-priming?
4. What is the response of varieties to hot hydro-priming?
5. What is the response of varieties to osomo-priming?
6. What are the effects of differents water sources on sorghum seed germination and growth parameters?
7. What are the best chemicals and concentrations on sorghum seed germination and growth parameters?
8. What is the best hydro-priming duration in tepid water?
9. What is the best hydro-priming duration in hot water (70 ºC)?
10. Is priming combined with tolerante varieties and z*aï* pits practice with or without compost could reduce sorghum crop establisment failure and increase yield?

Significance of the study

This study is expected to contribute scientific knowledge to the development of sorghum adaptation options to meet the consequences of irregular rainfall patterns as a result of Climate Change in Mali. The Impact of seed priming using water or chemical solutions, screening of drought tolerant varieties, and the use of organic matter and z*aï* pits planting technique will be studied. The application of these single agronomic management practices, or a combination of these practices, will help to improve sorghum crop yields under changing environmental conditions in particular.

The research will contribute generating up-to-date climate-smart agricultural technologies for increased adaptive capacity to climate variability and change in rainfed cropping systems. The proposed study therefore, stands to contribute to sustainable increase of sorghum yields for attaining food security in Mali. Farming population in the study area and similar agro ecology zone in West Africa and beyong could benefit from the newly developed strategies to mitigate crop establishment failure at early season. The data collected will also be avaialable to the scientific community and others actors who need to invest or work in the sector.

Delimitations

The study was conducted at the Agricultural Research Station of Cinzana (Longitude: 5° 57’ W, Latitude: 13° 15’ N, and Altitude: 280 m), in the segou region, Mali. This zone belongs to the Sahel zone agro-ecological zone of West Africa. The study was conducted in laboratory, pot and field. The effects of priming methods, duration and varieties response in laboratory were evaluated while in pot was examined the effects of heat and drought stress on differents varieties and different levels of heat and drought stress. Finally the combined effects of priming, cultural practices and varieties effects were assessed in the field. The laboratory experiments were under room temperature while pots experiments were conducted in an open area. The field was carried at farmer’s field.

Limitations

In laboratory experiments seeds were sown in petri dish in varying room temperature. No enzymes analysis was done which could probably explain the inhibition effect of rain water on all seed germination and seedling growth parameters compared to others water sources. In pots experiment charcoal layer was used to generate heat, the specific charcoal heat capacity was not measured. They were variation on sowing depth according to charcoal layer.

Definitions of terms

Heat stress

Heat stress often is defined as where temperatures are hot enough for sufficient time that they cause irreversible damage to plant function or development. In addition, high temperatures can increase the rate of reproductive development, which shortens the time for photosynthesis to contribute to fruit or seed production. I also will consider this as a heat-stress effect even though it may not cause permanent (irreversible) damage to development because the acceleration does substantially reduce total fruit or grain yield (Brown, 2008).

Drought stress

Drought stress can be defined as the absence of rainfall or irrigation for a period of time sufficient to deplete soil moisture and injure plants (Loon, Lanen, & Hisdal, 2010). Drought stress results when water loss from the plant exceeds the ability of the plant's roots to absorb water and when the plant's water content is reduced enough to interfere with normal plant processes. Some species have an inherent tolerance of drought because they have evolved in arid areas, regions with frequent drought, or regions with soils of low water holding capacity. Some species have anatomical or physiological characteristics that allow them to withstand drought or to acclimate to drought. All plants have a waxy coating on their leaves called "cuticle," but some species have developed exceptionally thick cuticles that reduce the amount of water lost by evaporation from the leaf surface (Prasad et al., 2008).

Seed priming

Seed priming is defined as a simple and low cost hydration technique in which seeds are partially hydrated to a point where pre-germination metabolic activities start without actual germination, and then re-dried until close to the original dry weight. Seed priming is an effective technology to enhance rapid and uniform emergence and to achieve high vigour, leading to better stand establishment and yield (Harris et al., 2001). Well-known priming techniques include (a) hydro-priming where seeds are soaked in a fluid such as water, (b) osmo-priming where seeds are soaked into an osmotic solution such as polyethylene glycol 6000 (PEG-6000), (c) halo-priming where seeds are soaked in salt solutions, and (d) priming with growth-stimulating hormones. Previous findings underscored that the success of seed priming was determined by the complex interactions of plant species, the water potentiality (i.e. water chemical composition) of the priming agent, the duration of priming, temperature, seed vigour and storage conditions of the primed seeds (Parera, & Cantliffe, 1994).

Tolerance

Tolerance is defined as a relative term and it is also man made to some extent. In agriculture, tolerance means the plant can be under stress (abiotic/biotic) or physiologically challenged but the extent of loss does not exceed the economic threshold level (an extent of loss which do not hamper the economic potential of the produce). Examples of tolerance can be found in case of high tolerance to heat and drought stress.

Zaï pits practice

The *zaï* pits practice is a technique used in dry parts of West and East Africa to harvest water and to help concentrate nutrients where the crops will grow. A typical z*aï* pits have a diameter of 15 to 30 cm and a depth of 10 to 20 cm to collect rainfall and runoff (Roose, Kabore, & Guenat, 2010). *Zaï* pits concept captures rainfall and runoffs, promotes the efficient use of limited quantities of organic matter and ensures the concentration of water and soil fertility at the beginning of the rainy season. The use of the *zaï* method increases the amount of water stored in the soil profile by trapping rain water. It retains moisture in-situ and holds water long enough to allow it to infiltrate. This means that more water infiltrates so that water will be available to plant roots (Roose et al).

Organization of the study

This thesis is organized into eight chapters. Following this chapter one, which presents an introduction to the topic, present the background to the study, the statement of the problem, the purpose of the study, the objectives, the research question, the significance of the study, the delimitation, the limitations and the definition of terms and organization of the study. The second chapter presents the literature review focusing on early drought, heat stress, sorghum response to stress and agronomic practices to reduce crop establishment failure. The third chapter presents an extended description of the materials and methods used for the different studies and the study area. This chapter also presents the materials and methods used for study design, data collection and data analysis. The findings of the various studies are presented and discussed in subsequent chapters such as on the effects of drought and heat stress screening on seed germination and seedling development (chapter 4), the effect of hydro-priming (chapter 5) and osmo-priming (chapter 6) on seed germination and seedling development under laboratory conditions. Chapter 7 reports on the effects of a combination of the most promising priming technologies and z*aï* pits practice on the field performance of sorghum. Finally, chapter 8 summarizes the main conclusions and recommendations for future work on seed priming as well as on options to face early drought and heat stress nutrient management in the Sahel.

Chapter summary

The problem statement is presented in chapter one, increasing of crop establishment failure at early season under climate variability and change. Simple but effective agronomic practices are needed by the farming population of the drought prone zones. Chapter one points out the existing knowledge gaps, to be resolved and what previous researchers have not been able to resolve. This chapter presents also the purpose of the study; the research objectives, questions and significance. Finally, chapter on presents the delimitations, limitations, the definitions of terms as used within the context of the study and the organization of the thesis.

CHAPTER TWO

LITERATURE REVIEW

Climate change prediction and agriculture

Agriculture is an economic activity highly dependent upon weather and climate to produce the food, feed, fuel and fibre necessary to sustain human life. Not surprisingly, agriculture is thus vulnerable to climate variability and change, which has thus become of major importance to the national and international scientific community.

On a global basis, climate variability and change may have an overall negligible effect on total food production (Parry & Rosenzweig, 2005); however, the regional impacts are likely to be substantial and variable, with some regions benefiting from an altered climate and other regions adversely affected. Generally, food production is likely to decline in most critical countries but may actually benefit where technology is more available and if appropriate adaptive adjustments are employed (Smit & Pilifosova, 2003).

The predicted changes in temperature and other weather parameters will impact agro-ecological conditions and hence the production of commodities. As a result, farmers will need to adjust their technologies and practices to continue meeting their commodity requirements such as for food. However, adjustments to new, unknown climate scenarios may become more and more impracticable in all situations since the adaptive capacity depends also on resources such as access to weather forecasts, better seeds and varieties or even to management practices as to further reduce food insecurity. To better prepare vulnerable regions, climate scientists and economists are using integrated assessment models to help identify those regions and crops that may be at high risk due to climate change and its resulting socio-economic impact (Bein et al., 1999; Smit & Pilifosova, 2003)

Agriculture is contributing a significant share of the greenhouse gas (GHG) emissions that is causing climate change: about 17% of the emissions are directly through agricultural activities and an additional 7% to 14% through changes in land use (Reay, Davidson, Smith, & Smith, 2012; Tubiello et al., 1990). The main direct agricultural GHGs emissions are nitrous oxide emissions from soils, applications of fertilisers, waste from grazing animals, and methane production by ruminant animals (enteric fermentation) and paddy rice cultivation. Currently accounting for 58% of the total anthropogenic nitrous oxide emissions and 47% of the total anthropogenic methane emissions, agriculture is expected to remain the main source of these non-CO_2 gases in the coming decades. This trend is particularly disturbing given the significantly higher global warming potential of nitrous oxide and methane relative to CO_2. In addition, the sector generates emissions indirectly due to changes in land use, including land clearing and deforestation (Schmitz, Meijl, van Kyle & Nelson, 2014).

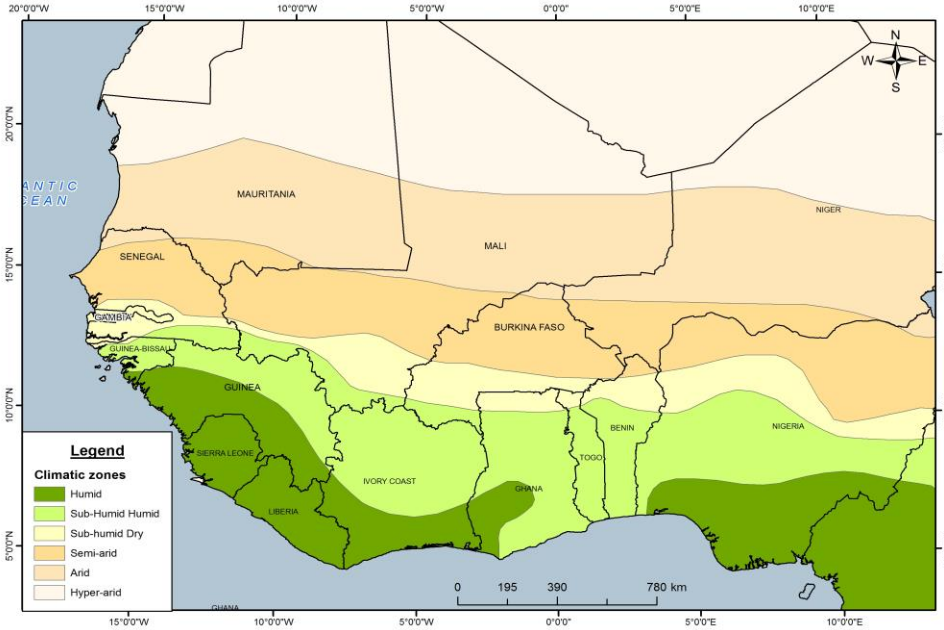
Productivity growth has been maintained in the agricultural sector because farmers have been taking measures to adapt to climate change. They have begun to adapt farming practices based on their own private cost-benefit calculations, taking into account the additional production risks created by climate variability as well as the need to achieve higher productivity to improve resource-use efficiency (Reay et al., 2012) Many climate adaptation options that have been adopted to date reflect current “best practices” and “sustainable resource management”. Practices such as adopting climate-smart inputs and shifting to more efficient irrigation methods have helped many farmers to maintain productivity levels and concurrently reduce GHG emission intensity. However, there is still room for further adoption of climate-friendly and climate-proof practices (Schmitz et al., 2014).

Seasonal changes in rainfall and temperature could impact agro-climatic conditions, altering growing seasons, planting and harvesting calendars, water availability, pest, weed and disease populations, etc (Ignaciuk, 2015). Not only evapotranspiration, photosynthesis and biomass production are altered, but also land suitability.

Global climate models consistently highlight risk disparities between developed and developing countries (Rosegrant, Yohe, & Ewing, 2010). For instance, for temperature increases of only 1-2 °C, developing countries without adaptation will likely face a depression in major crop yields. In mid to high latitudes, increases in temperature of 1-3 °C can improve yields slightly, with negative yield effects if temperature increases beyond this range. Stronger yield-depressing effects will occur in tropical and sub-tropical regions for all crops, which reflect a lower growing temperature threshold capacity in these areas. Estimations predict that cereal imports will increase in developing countries by 10 to 40 percent by 2080. Africa will become the region with the highest share of food-insecure population, accounting for up to 75 percent of the world total by 2080 (Rosegrant et al.). In terms of diversity, extent and density this is however closely related to annual rainfall amounts, which are predicted to decline moving north from the southern coast to the Sahara Desert (Parry & Rosenzweig, 2005) (Figure 2). But experience shows that annual rainfall amounts in West Africa as well as the timing of the seasons vary significantly from year to year (Parry & Rosenzweig). More recently, however, scientists disclosed that climate variability has also exhibited a strong decadal component related to variations in global sea surface temperatures, with a wetter period in the 1950s to 1960s and a drier period in the 1970s to early 2000s.

More than 70% of the total population in West Africa lives in rural areas with agriculture as the main source of their livelihood (Africa Committee on Sustainable Development [ACSD], 2007). Hence, the majority of the people will suffer from a continuous food insecurity and water scarcity due to climate change and climate variability (CC & CV).

This in particular is alarming since agriculture in this region is dominated by a combination of semi-subsistence, rainfed cereal cropping and livestock practices, which are severely threatened by CC&CV.



Source: WMO, (2011)

Figure 2: Agro-ecological zone s of West Africa

Predictions suggest that the impact of CC&CV in this region will include among others reduced crop yields. Predictions include furthermore a drastic decline in net farm revenues ranging from -$25 to -$49 for every +2 °C rise in temperature, or a -7% fall in precipitation as well as annual Gross Domestic Product (GDP) losses of about 3-5% stemming from CC&CV alone (Parry & Rosenzweig, 2005). Due to a low level of technology use by the farming population in this region, the scope for developing effective adaptation strategies to CC&CV are much higher than in agricultural areas relying already on technology inputs for the production of food, feed, fibre and fuel (Hertel, 2011). Yet, adapting the cultivation strategies to the anticipated CC&CV vagaries is eminent especially for the dominating staple crops such as sorghum.

In the Sahel, changes in total rainfall amounts are related to fewer rainy days and longer dry spells within the season and not to reduced rainfall amounts per event per se or significant long-term changes in the overall duration of the season (Carnemark, 2013). This decadal variability, unrelated to the overall anthropogenic climate change and significant amplitude, is unique to the region and makes detection and projection of climate trends related to anthropogenic climate change even more difficult. Predictability and interactions between the decadal component and longer-term climate change remain unclear. Models agree on a long-term increase in temperature in the order of 2.5-3.5°C by the end of the twenty-first century, but the findings strongly disagree on future precipitation (Carnemark). Other characteristics of the climate, such as the onset and length of the rainy season and the distribution of dry spells within the season, which are critical for climate-sensitive sectors such as agriculture, are even more difficult to project with confidence. There is some indication that the rainy season in the Sahelian region might be delayed in the future and that extreme rainfall events, such as droughts and floods, might become more frequent (Carnemark).

Historical background of drought

Drought is at the core of serious challenge and treats facing sustainable development in Africa. Although drought has several definitions, the central element in these definitions is water deficit. In general, drought is defined as an extended period (e.g. a season, a year, or several years) of deficient rainfall relative to the statistical, multi-year average for a region. This deficiency results in a water shortage for some activity, group, or environmental sector. A more in-depth definition of drought includes four sub definitions including meteorological, hydrological, agricultural and socio-economic drought as visualised in Figure 3 (Mishra & Singh, 2010).

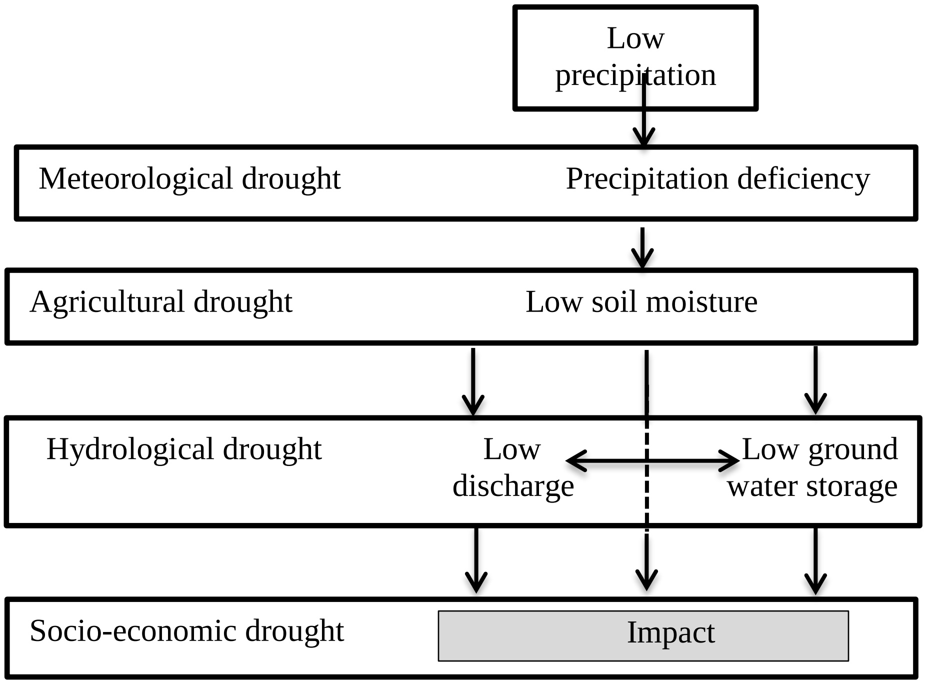


Figure 3: Categories of drought and their development adapted from Loon (2015)

Definitions of drought

Meteorological drought refers to a precipitation deficiency, possibly combined with increased potential evapotranspiration, extending over a large area and spanning an extensive period of time (Mishra & Singh, 2010).

Agricultural drought or soil moisture drought is a deficit of (mostly root zone) soil moisture, reducing the supply of moisture to vegetation. Soil moisture drought is also called agricultural drought, because it is strongly linked to crop failure. Soil moisture deficits have additional impacts on living organisms, for example, in natural ecosystems but also on infrastructure (Loon, 2015; Seneviratne, 2012).

Hydrological drought is a broad term related to negative anomalies in surface and subsurface water. Examples are below-normal groundwater levels or water levels in lakes, declining wetland area, and decreased river discharge. Groundwater drought and stream flow drought are sometimes defined separately as below-normal groundwater levels (Mishra & Singh, 2010) and below-normal river discharge (Feyen & Dankers, 2009; Loon & Lanen, 2012) respectively.

Socio-economic drought is associated with the impacts of the three above-mentioned types. It can refer to a failure of water resources systems to meet water demands and to ecological or health-related impacts of drought.

The underlying cause of most droughts can be related to changing weather patterns manifested through the excessive buildup of heat on the earth's surface, meteorological changes which result in a reduction of rainfall, and reduced cloud cover, all of which results in greater evaporation rates. The resultant effects of drought are exacerbated by human activities such as deforestation, overgrazing and poor cropping methods, which reduce water retention of the soil, and improper soil conservation techniques, which lead to soil degradation.

Many scientists report that during 1900–2013, 642 drought events occurred across the world resulting in a huge toll to humanity, killing about 12 million people and affecting over 2 billion (EM-DAT, 2016). The total economic damages are estimated at USD135 billion (Table 2).

Table 2: *Overview of droughts and their impact across the World during 1900-2013*

Continent	events	# people killed	# people affected	# of Damage (×10 USD)
Africa	291	847 143	362 225 799	2 920 593
Americas	134	77	69 505 391	50 471 139
Asia	153	9 663 389	1707 836 029	44 251 865
Europe	42	1 200 002	15 488 769	25 481 309
Oceania	22	660	8 034 019	12 303 000
Total	642	11 711 271	2163 090 007	135 427 906

Source: (EM-DAT, 2016)

Most of the studies based on instrumental records indicate that droughts have become more frequent, intense and widespread during the last 50 years. The extreme droughts of 1972-1973, 1983-1984 and 1991-1992 were continental in nature and stand unique in the available records. Additionally, many severe and prolonged droughts were recorded in the recent past such as the 1999-2002 drought in northwest Africa, the 1970s and 1980s droughts in western Africa (Sahel), the 2010-2011 drought in eastern Africa (Horn of Africa) and the 2001-2003 drought in southern and southeastern Africa, to name a few (Masih, Maskey, Mussa, & Trambauer, 2014). The available (though limited) evidence before the 20th century confirms the occurrence of several extremes. Multi-year droughts during each century are commonly occurring in the Sahel and equatorial eastern Africa. The complex and highly variant nature of many physical mechanisms such as El Niño-Southern Oscillation (ENSO), sea surface temperature (SST) and land atmosphere feedback adds to the daunting challenge of drought monitoring and forecasting (Masih et al., 2014).

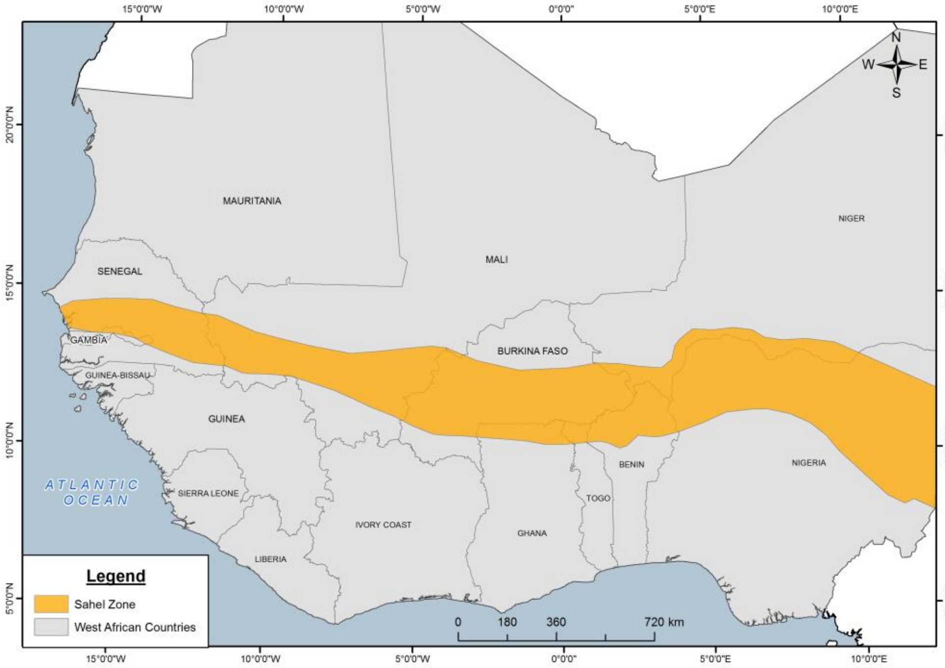
The future predictions of droughts based on global climate models indicate increased droughts and aridity at the continental scale, but large differences exist due to model limitation and complexity of the processes especially for the Sahel and northern Africa. However, the available evidence from the past clearly shows that the African continent is likely to face extreme and widespread droughts in future. This obvious challenge is likely to aggravate due to slow progress in drought risk management, increased population and in turn the increase in demand for water and and land and consequent degradation of land and environment. Thus, there is a clear need for increased and integrated efforts in drought mitigation to reduce the negative impacts of droughts anticipated in the future (Masih et al., 2014). The droughts of the Sahel, which have started since the 1970s to gain worldwide attention, have caused rainfall deficits of about 30% and a "descent" of the isohyets by about 200 km towards the south (Masih et al). At the same time, the river flows have diminished even more than rainfall. The droughts have further impacted on the groundwater tables in this zone (Dameris et al., 2014).

Drought as recurrent event in the Sahel

The Sahel is a semi-arid strip (Figure 4) of land South of the Sahara desert that stretches from Senegal to Chad, and is nominally located between latitudes 11^{o} and 15^{o} (Sivakumar, 1992) (Sivakumar & Sivakumar, 1992). The Sahel is characterized by recurrent droughts and one of the driest inhabited parts on Earth. This is substantiated by rainfall and run-off that are much lower compared with other zones (Moussa, Maiga, Ambouta, & Sarr, 2009). Temperatures in West Africa in general, but particularly in the Sahel, have changed faster than the global trend, with increases ranging from 0.2 ºC to 0.8 ºC per decade since the late 1970s (Agriculture, hydrology, meteorology agro metrology [AGRHYMET], 2009).

and operational hydrology Obvious increase in minimum temperatures (up to +1ºC) than for the maximum ones (up to 0.5 ºC) was observed (AGRHYMET, 2009). In addition it is predicted that by 2100 the warming in this region could be as high as 3 to 6 ºC depending on the emission scenarios (Moussa et al., 2009).

Although the region hardly contributes to greenhouse gas (GHG) emissions, the surface area affected by drought and heat in the region has gradually increased since the 1970s (Moussa et al., 2009).



Source: WMO, (2011).

Figure 4: Sahel zone of West Africa

More than 80 to 90% of the natural disasters are due to hydro-climatic events such as droughts, heavy downpours, and floods (WMO, 2006). But most alarming, according to Smith, Martino, Cai, Gwary, & Janzen, 2007) are very likely (probability >90) heavy precipitation events, devastating floods and heat waves that will become more frequent worldwide. These events will become more intense and particularly more variable from one year to another. The extreme rainfall is associated partly with the increase in atmospheric water vapor that will increase with climate change, thus enhancing the condensation-rainfall-runoff cycle. Over the coming years, contrasting situations can be expected in which periods of drought alternate with periods of excessive rainfall.

In the Sahel, rainfall is considered by many as being by far the most decisive climate variable affecting the lives of people (Moussa et al., 2009). Some authors

(Moussa et al.) consider that rainfall alone can determine the evolution of the environment in this region and rainfall is therefore regarded as the most appropriate indicator to characterize or analyze climate change in the Sahel. Historically, changing rainfall in the Sahel is characterized by two distinct periods, namely: the period 1950-1969, which was marked by a succession of wet years and the period 1970-1993 by the persistence of consecutive dry years. Current debates include as well if droughts in the Sahel will soon be history, or if such phenomena even will continue to occur and if yes, with what vigour (Moussa et al.). Subject of debate are also other observations such as inter-annual variability in rainfall, characterized by sudden alternations between very wet and very dry years. Present observations indicate an increasing inter-annual variability in rainfall, which makes it again more difficult to predict rainfall in the Sahel (Moussa et al.). This however is crucial to the farming population that depends heavily on rainfall for its survival and which is thus in need for improved practices that enable plant and food production despite sad predictions.

Water/rain is a key and limiting factor in the semi-arid Sahelian region, where populations have experienced a series of widespread droughts, most notably in the mid-1970s and mid-1980s, that resulted in humanitarian crises associated with periodic famines, region-wide food insecurity, population displacement, and migration (Moussa et al., 2009). The rainy season (July-September) generally starts abruptly, signaling the beginning of the farming season. Delayed rainfall onset, or early retreat, shortens the growing season, thereby reducing productivity. Rainy seasons that last too long will often lead to floods and crop losses due to high humidity during the harvest and postharvest processing periods (Masih et al., 2014).

Models project temperatures in the Sahel to increase more than in the coastal region, and agricultural modeling studies suggest that these will result in declines in the yields of a range of staple crops (Moussa et al). As stated earlier, however, precipitation is difficult to model for West Africa, and existing models disagree on the projected long-term evolution of annual rainfall amounts even though most project a slight increase in the central Sahel and decrease in the western Sahel.

A number of models appear to agree that future climate variations could bring possible delays in the onset of the rainy season as well as higher frequency of extreme events such as droughts and floods. However, it is the influence of temperature increases that will likely result in higher levels of evapotranspiration (a combination of evaporation from land and water surfaces and transpiration from vegetation). Coupled with precipitation changes, this will ultimately have the greatest impact on traditional livelihoods because the combined effects will tend to reduce the overall availability of water in those areas where rainfall does not increase (Masih et al., 2014).

Drought remains a major challenge causing potentially huge damages to humanity, the environment and the economy, despite making considerable progress on monitoring, forecasting and mitigation of droughts across the world. The lack of desired levels of success could be attributed to many reasons. Drought is a complex phenomenon, which varies every time in terms of its onset, intensity, duration and geographical coverage. The capacity of people facing this hazard may be limited to avoid adverse impacts compounded by shortcomings in government capacity (e.g.

financial, institutional and political) to provide short-term relieve and install long-term drought mitigation measures.

There is an urgent and dire need to progress on various fronts of drought mitigation such as early warning and forecasting, building the resilience of the societies, short term relief efforts, long-term planning and capacity building (e.g. (Masih et al., 2014; Mishra & Singh, 2010; Tøttrup et al., 2012; Vogel et al., 2010). A summary of the drought events recorded in the EM-DAT database along with the number of people killed and affected and estimated economic damage in West Africa (Table 3).

Drought and heat stress

Drought stress, a major constrain to crop productivity, is affecting 1/3 of the arable land world-wide and this will probably increase given the ongoing climate changes. Therefore, sustaining the future productivity of land will be, at least partially, dependent on the production of crops for instance with increased drought tolerance.

Much research has been directed to research into drought resistance/tolerance; however the output of these efforts has not met the demand for crop production.

Table 3: *Drought events and their effects in West Africa: 1900-2013*

Country	No. of drought events	No. of people killed	No. of people affected	Damage (USD×10)
Benin	2	0	2 215 000	651
Burkina Faso	12	0	8 413 290	0
Cape Verde Is	10	85 000	40 000	0
Cote d'Ivoire	1	0	0	0
The Gambia	8	0	1 258 000	700
Ghana	3	0	12 512 000	100
Guinea	2	12	0	0
Guinea Bissau	6	0	132 000	0
Liberia	1	0	0	0
Mali	11	0	6 927 000	0
Mauritania	12	0	7 398 907	59 500
Niger	13	85 000	23 655 058	0
Nigeria	1	0	3 000 000	71 103
Senegal	9	0	8 399 000	374 800
Togo	3	0	550 000	500
West Africa	94	170 012	74 500 255	507 354

Source: (EM-DAT, 2016).

This could be explained with the extreme variability and complexity of drought stress effects: firstly, drought can affect plants at different stages of their growth; either early during plant establishment, in the developmental vegetative stage (intermittent drought) or at the end of the growing season in the reproductive stage (terminal drought). Out of these, terminal drought is shown to contribute to the most severe yield losses as it affects spikelet establishment and its fertility reduction (Bernier, Kumar, Ramaiah, Spaner, & Atlin, 2007).

Secondly, drought has different intensities and effects and plants have developed several strategies to deal with them on different levels of their phenological, morphological and anatomical structures as well as on the levels of various physiological and biochemical processes. Since there exist diverse drought patterns and various plant adjustments to counteract the drought effects, it is very important to define which type of drought stress is targeted by a management practice programme. There are basically several levels of plant drought tolerance/resistance.

Levels of plant drought tolerance/resistance

Drought escape

The success of plant in water deficient environment can be dependent only on its phenology; e.g. plant will complete its reproduction during the wet season before drought occurs (early flowering).

Drought avoidance and drought adaptation

Both strategies relate to the morphological, anatomical and/or biochemical plant’s adjustment to avoid water deficit in plants tissues (e.g. development of succulence of leaves and roots, reducing of transpiring surfaces, sunken stomata, presence of specialized photosynthetic pathways, thick cuticle, extensive root growth, and efficient water use). These mechanisms can be either induced by drought (avoidance) or could have constitutive character i.e. are also present in non-stressed conditions (adaptation).

Drought acclimatization (sometimes referred as drought tolerance)

Is commonly understood as series of biochemical adjustments induced by water deficit (e.g. osmoprotection, anti-oxidative enzymes induction, chlorophyll degradation).

Drought and high temperature (heat) stress are considered to be the two major environmental factors limiting crop growth and yield. These two stresses induce many biochemical, molecular, and physiological changes and responses that influence various cellular and whole-plant processes that consequently affect crop yield and quality. The impacts of environmental stress, particularly those of drought and heat, have been studied independently. However, under field conditions, both of these stresses often occur in combination (Prasad, Staggenborg, & Ristic, 2008) .

Drought stress induces several changes in various physiological, biochemical, and molecular components of photosynthesis. Drought can influence photosynthesis either through pathway regulation by stomatal closure and decreasing flow of CO_2 into mesophyll tissue (Chaves, Flexas, & Pinheiro, 2009) or by directly impairing metabolic activities (Farquhar, Ehleringer, & Hubick, 2003). Sorghum biological structures (e.g C_4 metabolism and extensive root system) enable it to adapt to a wide range of environmental conditions.

The processes involved in photosynthesis are much more tolerant to heat stress and are mostly stable in the temperature range of 30 to 35°C, depending on crop species. However, very high temperatures (>40°C) can negatively affect photosynthesis (Prasad, Pisipati, Momčilović, & Ristic, 2011). The response of photosynthesis to heat stress is related to temperature dependence of Rubisco, the enzyme involved in the first major step of carbon fixation, to the two substrates, carbon dioxide and oxygen. At high temperatures, the solubility of oxygen is decreased to a lesser extent than CO_2, resulting in increased photorespiration and lower photosynthesis (Leegood, 2002). In addition, the activation and activity of Rubisco are also decreased at high temperatures (Prasad et al., 2011). Heat stress primarily deactivates Rubisco by inhibiting the enzyme Rubisco activase (Salvucci, 2008). The mechanism responsible for inactivation of Rubisco under heat stress is related to inability of activase to overcome the inherently faster rates of Rubisco inactivation (Law, Crafts-Brandner, & Salvucci, 2001).

Sorghum genus description

Sorghum belongs to the family Poaceae, subfamily Panicoideae, the tribe Andropogoneae, subtribe Sorghinae and genus Sorghum (Liu et al., 2014; Price et al., 2005, Soreng et al., 2015;) further segmented the genus into five subgenera: *Eu-sorghum* Stapf emend Snowden, *Chaetosorghum*, *Heterosorghum*, *Parasorghum* and *Stiposorghum*. Genus *Sorghum* Moench is highly heterogeneous and together with the genus *Cleistachne* Bentham they form Sorghastrae (Liu, et al), one of the 16 sub-tribes in the tribe Andropogoneae. The seventeenth century saw an increase in the number of references to sorghum with several authors describing the genus (Smith & Frederiksen, 2000) .

Sorghum was first described by Linnaeus in 1753 and was referred to as Holcus. Later on in 1794, Moench distinguished the genus *Sorghum* from the genus *Holcus* (Ahmed, 2015). Several other authors have discussed the systematics, origin and evolution of sorghum after Linnaeus (De Wet & Harlan, 1971; Doggett, 1988).

The subgenus *Sorghum* (*Eu-sorghum*) includes annuallly cultivated sorghum from Africa and perennial taxa from S. Europe and Asia. Three species are recognized under the subgenus *Eu-sorghum* as *S. halepense* (L.) Pers. occurring in India, *S. propinquum* (Kunth) Hitchc found in Southeast Asia and *S. bicolor* (L.) Moench originated in Africa (De Wet & Harlan, 1971) .

Sorghum is divided into five major races: bicolor (b), guinea (g), caudatum (c), kafir (k) and durra (d); and 10 intermediate races with all combination of the basic races: guinea bicolor (gb), caudatum bicolor (cb), kafir bicolor (kb), durra bicolor (db), guinea caudatum (gc), guinea kafir (gk), guinea durra (gd), kafir caudatum (kc), durra caudatum (dc), and kafir durra (kd). These classifications are mainly based on the type of panicle, spikelet, shape, and glumes (Figure 5).

Source: Prasad et al., (2008).

Figure 5: Diversity in panicule size compaction and grain colour in sorghum

Bicolor sorghums have open, loose panicles of medium size with small grains, which are completely covered by large, closed glumes; these are grown throughout Africa and widespread in Asia. Guinea sorghums have long, loose panicles with small to medium grain which is flattened, twisted, and oval in shape, and are covered with open glumes; these are grown mainly in West Africa. Caudatum sorghums have panicles of variable shape with asymmetrical grains, flat on one side and convex on the others, and covered with glumes which are shorter than the grain; these are widely grown in Chad, Sudan, north-eastern Nigeria and Uganda. Kafir sorghums have compact panicles that are cylindrical in shape with elliptical grain tightly enclosed by glumes that are shorter than the grain; they are widely grown in southern Africa. Durra sorghums have highly compact panicles with an erect or curved peduncle with globular grain that is tightly enclosed by small wrinkled glumes; these are mainly grown in East Africa, Middle East, and India. Various intermediate races have combination of characteristics of the main races.

Sorghum characteristics and adaptation

Sorghum is an annual grass species up to 5 m tall, with one to several tillers that originate from the basal stem nodes supported by an extensive and deep root system. The plant has a wide adaptation and can be grown between 40° N and 40°S across the equator at altitudes of up to 2300 m (Doggett, 1988) and tolerates a wide range of soil conditions. Sorghum performs better at temperature range of 25-31°C, but is susceptible to frost. It is mainly a rainfed crop of the lowlands, or semi-arid areas of the tropics and subtropics (Craufurd et al., 1999). Sorghum is adapted to drought conditions due to a number of morphological and physiological characteristics, including an extensive root system, waxy bloom on leaves that reduces water loss, and the ability to stop growth in periods of drought and resume when the stress is relieved (Barmina, 2011). An annual total of 400-800 mm of well distributed rainfall over the cropping season is adequate for the crop to reach maturity. The crop tolerates water logging and can also be grown in high rainfall areas. Naturally, sorghum is a short-day plant (SDP), but a wide genetic variation exists for its adaptation to the wide range of photoperiod and temperature of different environments (Craufurd et al.).

Growing cycle

From seeding to maturity, sorghum goes through several steps. Under optimum soil moisture and temperature conditions, germination occurs in 3 to 5 days. Seed germination begins with the absorption of moisture. As the seed swells, the coat breaks and the radicle and coleoptile emerge. The radicle grows downwards into the soil and forms the first primary seminal roots. The seed remains at the place of sowing and the mesocotyle elongates; a first node is formed at the base of the coleoptile just below the ground level. The coleoptile grows and emerges above ground and remains as a sheath at the base of the seedling.

As a C_4 crop, sorghum does not tolerate cool temperature regimes. For seed germination, the minimum temperature is about 8 ºC, and optimum temperature, 21-35 ºC (Peacock, 1982). Under field conditions, a minimum soil temperature in the range of 15-18 ºC is required for 80% emergence in 10-12 days. Under suitable conditions, field emergence takes 5-10 days. Panicle initiation takes place after approximately one-third of the growth cycle, after the last leaf has initiated and about one-third of total leaf area has developed. Rapid leaf development and stem elongation follow panicle initiation. Rapid growth of the panicle starts after all leaves have emerged, by the time the flag leaf is visible, all but the final 3 to 4 leaves are fully expanded and light interception is approaching its maximum ; a few lower leaves may begin to senesce if nitrogen is not plentiful or the crop is planted very densely. The rate of leaf appearance in sorghum is closely related to thermal time. When temperature is not limiting, it takes about 2 days for each new leaf to emerge.

For a cultivar with 16 leaves, in Mali a typical phenology and growth stages of 0 to 9 as defined by Vanderlip & Reeves, (1972) are presented in Table 4. Sorghum leaves are upright when young, but tend to bend downwards with maturity. Sorghum leaves develop on either side of the stem, exactly opposite to one another. As for all crops, the rate of dry matter production is strongly affected by radiation intercepted, which depends on leaf area, especially between emergence and panicle initiation. The number of leaves per plant varies widely, from 7 to 24 depending on cultivar and climatic conditions. As a short-day plant, panicle initiation is hastened by short days and longer nights. Since panicle initiates only after all leaves have initiated, the plant would have fewer leaves if panicle initiation and blooming is earlier.

Panicle initiation can be strongly affected by temperature regimes in addition to photoperiod. There are rather complicated interactions between photoperiod and temperature regimes, as well as a dependence on the cultivar's maturity group (Wani, Albrizio, & Rao, 2012).

Table 4: *Grain sorghum developmental stages approximate time intervals between growth stages (days after emergence DAE) and identifying characteristics*

Developmental	Growth	DAE	Visual Characteristics
0	GS1	0	Emergence, coleoptile visible at soil surface
1	GS1	5	Collar of 3rd leaf visible
2	GS1	10-15	Collar of 3rd leaf visible
3	GS1	25-30	Growing point differentiation (approx. 8th leaf visible) or panicle initiation; growing point above soil surface; potential number of kernels per head determined
4	GS2	35-50	Final leaf (flag leaf) visible in whorl; last 3 leaves may not be expanded
5	GS2	40-55	Booting; head extended into flag leaf sheath; potential head size has been determined
6	GS2	55-65	Flowering (bloom); 50% of plants flower
7	GS3	65-80	Soft dough; grain can be easily squeezed between the fingers; 8 to 10 functional leaves; one half of the grain weight accumulated
8	GS3	80-90	Hard dough; cannot squeeze grain between fingers; three-fourths of the grain dry weight has accumulated
9	GS3	90-110	Physiological maturity; dark spot at the tip of the kernel; maximum total dry weight accumulated; grain has 25 to 35% moisture.

Source: Based on (Vanderlip & Reeves, 1972 & Rao et al., 2004).

Generally within the temperature range favourable for growth, leaf number tends to decrease as temperature decreases in growth stage I, especially when the decrease is in night temperature (Quinby, Hesketh, & Voigt, 1973). As for all crops, leaf area index (LAI) depends on plant density, leaf number per plant, and the stage of growth. Maximum light interception, hence full canopy cover, is reached at LAI of 4 to 5.

With sowing of grain sorghum farmers like to achieve a full canopy cover, but avoid excessive LAI since excessive vegetative growth tends to reduce the harvest index. Fodder sorghums exceed LAI of 7 with populations of more than 150 000 plants/ha and high input management in the tropics. In short duration sorghum with reduced leaf number, maximum leaf area (and canopy cover) is achieved at 50 days or earlier after emergence under favourable conditions. However, sowing density must be substantially higher than that for long season cultivars to achieve full canopy cover because of fewer leaves per plant. Sorghum seeds are considerably smaller than those of maize; hence the initial leaf area (initial canopy size per seedling) of sorghum seedling is smaller compared to that of maize. Sorghum develops less leaf area than maize under similar input, environment and plant density because of its smaller leaf sizes (Prasad et al., 2011).

The sorghum head is a panicle, with spikelets in pairs. The inflorescence (panicle) is either compact or open, developed on the main stem (peduncle) with primary or secondary branches on which the florets are borne. The peduncle length varies from 7.5 to 50 cm in different cultivars. The floral structure is suited for self-pollination; however, approximately 6 percent cross-pollination occurs naturally with wind. Hybrid sorghum seed is produced utilizing cytoplasmic male sterility line as the female parent. Sorghum flowers begin to open and pollinate soon after the panicle has completely emerged from the boot (Prasad et al., 2011).

Pollen shedding begins at the top of the panicle and progresses downward for 6 to 9 days. Pollination happens soon after sunrise in the colder part of the day. At maturity, about 600 to 3 000 seeds have developed on the panicle, all enclosed in glumes varying in colour from black, red, brown to tan.

Number of seed per panicle is a key component of which is determined mostly during the periods of panicle initiation and flowering. Under seasonal average daily temperatures greater than 20 °C, early grain cultivars take 90 to 110 days and medium-duration cultivars, 110 to 140 days to mature. A decrease for each 0.5 °C in daily mean temperature below 20 °C will extend about 10 to 20 days in the growing season, depending on cultivar. At an average temperature of 15 °C, grain sorghum takes 250 to 300 days to mature. It follows that in cool climates, sorghum is grown mostly as a forage crop (Prasad et al., 2011).

Like all cereals, the root system has two components, the seminal root system and a secondary root system that develops from nodes below and just above the soil surface. Nodal roots start appearing at the third and fourth leaf stage and branches both laterally and downwards. Roots initiated at nodes close to and above the soil (so called prop roots) develop and penetrate into the soil only when the surface soil is moist. The fully developed root system is approximately 1 m wide laterally and down to about 2 m into the soil, and can reach 3 m in very open subsoils (Prasad et al., 2011). The maximum depth is generally approached at the time of flowering, but the roots continue to extend during the reproductive phase, at least under dryland conditions. When the soil profile is moist, most of the water is taken up from the top one-fifth of the root zone. As the soil water depletes and the upper part of the profile dries out, the uptake zone moves progressively downward. This uptake pattern repeats after each irrigation or heavy rain. Normally, when sorghum is fully grown, nearly all of the water extracted is from the top 1 to 2 m of soil (Prasad et al., 2011).

Response to stress

Sorghum is considered to be drought resistant, especially in comparison to maize. A part of the perceived resistance may be because sorghum cultivars grown in water-limited areas are the short-season type, thus their water requirement is less than that of maize, a crop generally with a longer life cycle (Hsiao, Acevedo, Fereres, & Henderson, 1976). That said, there are real differences in drought-resistance traits. Sorghum with its tillering habit is much less determinante than maize, and therefore is more ‘plastic’ in reproductive development. If water stress during the panicle initiation stage reduces the potential grain number of the main stem panicle, panicles on the tillers that are initiated later, after the stress is over, can produce more grain and make up for much of the loss. If water stress is severe enough at flowering to cause head blast (death of a portion or whole head) tillers may emerge from nodes high on the stem to form branch heads to produce grain and compensate for at least part of the loss, provided that harvest can be delayed (Hsiao et al., 1976). Such compensations are not possible with modern maize cultivars having very limited tillering capacity.

The flip side is that if water is ample during the vegetative period, many sorghum cultivars would tiller excessively, with a high portion of the tillers being barren, leading to high biomass produced, but with a low harvest index. Sorghum accumulates solutes and osmotically adjusts in response to developing water stress, apparently more so than maize (Fereres, Acevedo, Henderson, & Hsiao, 1978). This would allow sorghum to maintain stomatal opening and carry on photosynthesis longer as the soil water depletes, and possibly also aid in delaying canopy senescence induced by water stress. In addition to stomatal closure, sorghum leaves roll noticeably under water stress, reducing the effective transpiration surface. The rolling is attributed to turgor changes in the rows of motor cells along the midrib and veins on the upper surface of the leaf. Motor cells are also present in maize leaves, but maize leaves roll only minimally under water stress. Leaf growth by expansion is highly sensitive to water stress in both sorghum and maize.

In drought-prone areas such as the Sahel region, lodging of dryland sorghum as the crop matures is often a problem. Breeders have developed cultivars that maintain a green canopy longer at maturity, the so called ‘stay-green’ trait. Such cultivars apparently have better lodging resistance, presumably because less of the stalk material is remobilized and translocated to the grain at maturity.

Sorghum is moderately tolerant to salinity. As electrical conductivity (EC) increased from 11 to 18 dS/m, grain yield was reduced from 50 percent to 100 percent. Leaf extension closely parallels air temperature to approximately 34 °C. Pollination and seed setting may fail when night temperatures fall below 12-15 ºC at flowering, and pollen produced below 10 °C and above 40 °C are most likely non-viable. Sorghum grain contains around 1.5 percent nitrogen and 0.25 percent phosphorus. For a high yield of 8 tonnes/ha, the grain alone removes 120 kg of N and 20 kg of P. To achieve this yield, fertilization must account also for the N and P in the stover residue and the efficiency of applied nutrients and native soil supply. For water-limited situations, fertilization rates would be adjusted downward. In areas prone to terminal drought, care must be taken to avoid too much N supply early in the season because the resultant fast early growth would exhaust water stored in the soil and accentuate the terminal drought damage.

Constraints in sorghum production

Sorghum is an important staple in the semi-arid tropics of Asia and Africa for centuries and a reliable producer of energy, protein, vitamins and minerals for millions of people and can be grown under conditions of limited water resources, without an application of any fertilizers or other inputs (FAO, 2015). Despite these characteristics, drought and heat are serious constraints to sorghum production and since drought and heat are expected to occur in West Africa due to climate change and global warming, future sorghum production may be endangered as previously underscored (Nellemann et al., 2009), although admittedly one can at present only guess by how much the production may decrease. Cereal yields in South Africa fell by up to 30 per cent in 30 years due to climate change (Antonio, 2015), which may be an indicator of the expected magnitude in losses. Drought is one of the world’s costliest natural disasters, causing an average US$6–8 billion in global damages annually, and affecting more people than any other form of natural catastrophe (Keyantash & Dracup, 2002).

Plant responses to drought and heat stress are highly complicated, owing to the fact that drought itself is associated with various climatic, soil and agronomic factors, frequently aggravated by a substantial variation in timing of occurrence, duration and intensity. The complexity of drought increases even more under erratic and unpredictable rainfall, by the occurrence of high temperatures, and due to high levels of solar radiation, and poor soil. In addition to its direct effects on yield, drought and heat can suppress the potential benefits of improved crop management practices such as seed priming, *zaï* pits practice or fertilizer application or pest and disease management (Dembele, 2015).

Drought stress may affect sorghum in a number of ways. When the roots experience a period of limited soil moisture, abscisic acid signals the closure of stomata, which in turn reduces transpiration. Since transpiration serves to cool plants, by transporting water and nutrients from the soil throughout the entire plant, a prolonged drought and heat may lead to a reduced plant growth with lesser water uptake, the plant can experience a nutrient deficiency, thereby reducing photosynthesis (Reddy, Chaitanya, & Vivekanandan, 2004). Drought and heat influences disease incidence and severity. For instance, stalk rot diseases in grain sorghum caused by several fungi are aggravated under drought and heat stress conditions (Seetharama, Bidinger, Rao, Gill, & Mulgund, 1987). Charcoal rot (induced by *Macrophomina phaseolina* (Tassi) Goidanich incidence is more devastating when the plants are exposed to prolonged periods of drought and heat stress during grain development (Bita & Gerats, 2013b). *Fusarium* stalks rot (caused by *Fusarium spp*.) is more deleterious when drought and high temperature stress occur during grain development followed by wet, cool conditions near physiological maturity (Yamoah, Clegg, & Francis, 1998). Drought and heat stress spell increase the effect of the devastating weed striga (*Striga spp.)*

Many dry areas that previously relied on sorghum production with recent development underlines that more and more both soil and atmospheric water deficits (heat) can be expected at the beginning of the rainy season (Prasad et al., 2008). The limited availability of water combined with increased temperature at the onset of the season causes moisture stress more than before, which affects various metabolic processes. It is known that growth and yield are reduced directly under water deficits and increased temperatures (Asseng et al., 2004). In sorghum, water stress during the early growth phases reduces the grain number as well as grain size (Prasad et al., 2008), although the reduction in yield used to be more elevated when drought occurs at flowering and grain filling phases (Blum, 2005). Some sorghum genotypes are better adapted to drought conditions exposing little or no injury to heat and drought because leaf cell membranes of these genotypes have the ability to function normally during and after stress periods (Blum, Box, Aviv, & Email, 2016).

Prein and Ahmed, (2000) noted that communities that have lived under drought situations for many generations have developed concurrently coping strategies to lessen the impact of drought. Farmers in Mali have adopted in the past various traditional crop varieties intercropping cereals/legumes still are used as a means to cope with increasing persistent droughts. This is a means of spreading risks of total crop failure, because if one crop fails the other one will survive. Manzungu, Senzanje & Zaag, 1999; Masendeke, & Shoko, (2014) suggested that mixing many seed varieties of the same plant species can reduce the risk of crop failure because some varieties are early and others are late maturing and they react differently to drought. These drought coping strategies include multiple cropping, early planting, planting drought tolerant crops.

The seed coat has an important role to play under stress conditions. An intact seed coat is essential for controlled water uptake and protection from injury to the embryo or other tissues in the seeds (Baskin, 1998, Chachalis, Korres, & Khah, 2009; Dübbern De Souza & Marcos-ilho, 2001; Souza & Marcos-filho, 2001). The testa can also decrease levels of solute leakage resulting from seed water uptake and imbibitional damage. A large seed size is widely thought to improve the chances of germination and emergence under a wide range of environments. Seeds with a greater seed weight have furthermore a greater storage reserves and thereby may have increased seed vigour (Copeland & McDonald, 2001; Mohammadi, Soltani, Sadeghipour, & Zeinali, 2011; Mohammadi et al., 2011).

Seed size classes have also shown differences in imbibition, with small flat seeds having a faster rate of water uptake than large round kernels during initial stages of germination (Copeland & McDonald, 2001). First counts of the standard germination tests showed that smaller seeds germinated more rapidly than larger seeds for the two inbreds tested. Similar findings were reported by Murungu, Nyamugafata, Chiduza, Clark, and Whalley, (2013), who noted that smaller seeds may require less water due to less seed volume.

Impact of priming, organic matter and *zaï* pits practice

Seed priming is a simple and low cost hydration technique in which seeds are partially hydrated to a point where pre-germination metabolic activities start without actual germination, and then re-dried until close to the original dry weight.

Seed priming is employed for better crop stand and higher yields in a range of crops including rice (Farooq et al., 2009; Rahimi, 2013)

Primed seeds, when sown, usually emerge faster with better, uniform, and vigorous crop stand persistent under less than optimum field conditions. Crop stands from primed seeds lead to earlier flowering and higher grain yield than non-primed seeds (Harris et al., 2005). Harris et al., (2001) reported that on-farm priming in direct seeded rice results in a faster rate of germination and emergence, more uniform and vigorous seedling growth, and a wide range of phenological and yield associated benefits. In some other studies, (Farooq, et al., 2006) reported early emergence and seedling growth, better crop stand, allometric response, increased kernel yield, harvest index, and improved quality from seeds primed with KCl and CaCl2 in coarse and fine rice, respectively.

The soil organic matter is an important component of the soil. Soil organic matter consists of living organisms (< 5%), fresh organic residue (< 10%), active organic fraction (33–50%) and stabilized organic matter, also referred to as humus (33–50%). Most soils contain 2-10% organic matter. Even in small amounts, organic matter is very important. Organic matter has a profound impact on soil physical, chemical and biological properties (Carter, Sanderson, & MacLeod, 2004; Önemli, 2004; Six, Conant, Paul, & Paustian, 2002). Organic matter has several functions in soil; it increases nutrient holding capacity of soil, is a pool of nutrients for plants, improves water infiltration, decreases evaporation, increases water holding capacity, reduces crusting, improves aggregation, prevents erosion, and revents compaction (Carter et al).

The *zaï* pits practice is a technique used in dry parts of West and East Africa to harvest water and to help concentrate nutrients where the crops will grow. The use of *zaï* pits originates in the western Sahel where infertile, encrusted soils receive low and often highly variable rainfall (Danjuma & Mohammed, 2015; Roose, Kabore, & Guenat, 2010). On such dry, fragile lands, smallholder farmers face a constant challenge to produce enough food to feed their families and generate much-needed income. Where population growth is high, the challenge is even more difficult due to increased pressure on the land to produce crops. Consequently, innovation is critical to survival in many parts of Sub-Saharan Africa where traditional methods, such as that of long fallow periods, are no longer adequate or feasible.

Zaï pits are an innovation that addresses issues of land degradation, soil fertility, and soil moisture. Through the digging of *zaï* pits, degraded, hard-pan soils impossible to plow can still be productive rather than abandoned (Danjuma & Mohammed, 2015). Organic materials such as compost and manure need only be added to the planting holes instead of spreading them over the entire field area. The improved efficiency makes it easier for farmers to obtain and apply the fertility inputs needed to maintain productive soils. The pits also play an important water harvesting role. Instead of being lost to runoff, rainfall water is trapped in the *zaï* pits close to crop roots. *Zaï* pits are especially relevant to areas receiving 300-800 mm annual rainfall (Danjuma & Mohammed). Higher rainfall amounts could cause water-logging of the pits. In addition the *zaï* system allows farmers to concentrate both fertility and moisture close to crop roots and, in so doing, addresses some of the major challenges to crop production in Sub-Saharan Africa.

The practices of *zaï* pits is by some consider as one way to reduce the risk of crop establishment failure in the region, and thus as an efficient means to cope with droughts in a high temperature prone area. This practice helps farmers in Mali also to conserve moisture and target applications of the often scarce organic soil inputs. The little available water and the little organic soil inputs are used more efficiently when managed through *zaï* pits resulting in better grain and biomass yields (Kabore, & Reij, 2004). A number of case studies reported e.g. improved yields of millet when grown using the *zaï* pits system in West Africa (Nicol, Langan, & Victor, 2015). Using the *zaï* pits system versus the normal planting on the flat increased millet yields in Niger by 3 to 4 times (Nicol, et al). Kabore and Reij (2004) summarized some less obvious advantages of planting pits.

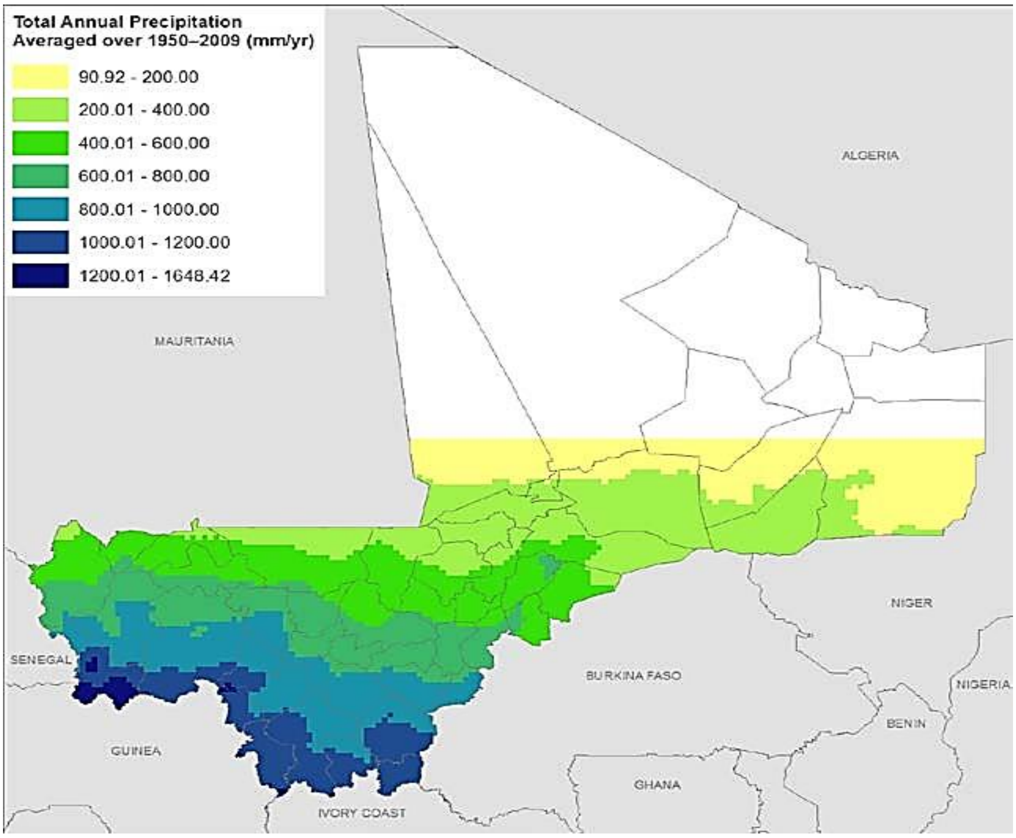
The rehabilitating of land enables farmers to expand the size of their farms with areas previously abandoned and where nothing grew before. But yields augmented to 300-400 kg ha^{-1} in years of low rainfall, and up to 1,500 kg ha^{-1} in a good rainfall year (Reij, Tappan, & Smale, 2009). The reasons for this impact was attributed to a water retention in the pits which enabled plants to survive longer dry spells or dry spells after the first plantings (Kabore and Reij). Because more water is harvested and conserved and fertility is improved due to the organic matter in the pits, conditions in general are improved and increase yields and biomass production can be expected (Roose et al., 2010).

CHAPTER THREE

MATERIALS AND METHODS

Description of study area

The climate of Mali is characterised by alternating dry and wet seasons of variable durations (UNDP, 2013). The duration of the dry season varies between six months in the south and nine month in the north. The rainy season falls in the period between May/June and September/October. Annual precipitation ranges between 1200 mm in the south and less than 100 mm in the north (Figure 6), with considerable inter-annual variations in rainfall (UNDP, 2013).Rainfall/evaporation for Agro Ecological Zones of Mali is presented in Table 5.



Source: (Williams et al., 2012)

Figure 6: Average annual precipitation from 1950-2009

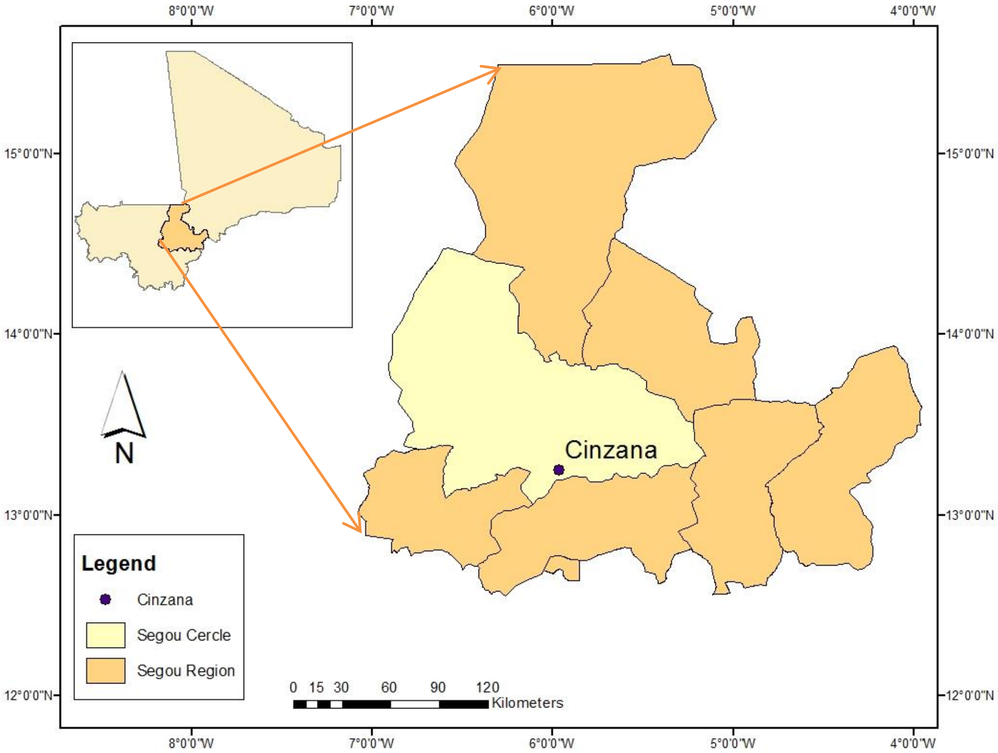
Table 5: *Rainfall and evaporation for agro ecological zones of Mali*

Zone	‡R/E_o (%)	Classification	R (mm)	E_o (mm)	Potential for plant growth	Risk of crop failure
I	65-80	Guinea savannah	1000-1200	1300-2100	High	Very low (1-5%)
II	50-65	Sudan savannah	800-1000	1450-2200	High to medium	Low (6-20%)
III	40-50	Sahel savannah	600-800	1500-2200	Medium	Average (21-50%)
IV	25-40	Semi-arid	400-600	1650-2300	Medium to low	High (51-75%)
V	15-25	Arid	200-400	1900-2400	Low	Very high (76-95)
VI	<15	Very arid	<200	2100-2500	Very low	Extremely high (95-100%)

R-Average annual rainfall; E_o-Average annual evaporation; ‡-Assuming soil conditions are not limiting

The Segou region is located within Latitude 11º 18´ N, Longitude 5º 40´ W. The elevation above sea level is 413 m in Sudano-Sahelian savanna zone of Mali (Figure 7) and receives an average annual rainfall about 500 mm (Grabs, Tyagi, & Hyodo, 2007). It is characterized by a semi-arid climate. Aside from rainfed agriculture, the important river in the region is Niger and it tributary Bani, allow for irrigated agriculture to some extent in the regions flanked by these rivers. The main economic activities of the Segou region are agri-business, cattle farming and fishing. The economy is essentially informal and oriented towards the population's primary needs, while industrial production is modest and focused on the food industry only. Farmers' practices are essentially traditional, but the Segou region produces nevertheless a major part of Mali's national food including sedentary cattle farming.

The Segou region represents the transition zone between the desert ecology of the North and the more intensive agriculture zone of the South. The Sahelian zone is 281,000 km^2 in size, which ranges from a growing season of 45 to 90 days with 350 to 600 mm rainfall in the South down to 25 to 45 days and 150 to 350 mm rainfall in the North. The North Sudan zone of 215,000 km^2 has a growing season of 80 to 120 days with rainfall of 550 to 800 mm (Sivakumar, 1992). Soils in the region are both of sandy and clayey sand texture suitable for the production of predominant cereals and legumes including pearl millet (*Pennisetum glaucum* L.), sorghum, cowpea (*Vigna unguculata* L. Walp), groundnut (*Arachis hypogea* L.), and Bambara groundnut (*Vigna subterranea* (L.) Verdc (Sivakumar & Virmani, 1984). The screening for suitable sorghum varieties and silvicultural practices to counterbalance early-season heat and water stress should result in options suitable for the Segou region.



Source: (Dembele, 2017)

Figure 7: Segou region Mali

General approach for screening sorghum cultivars against drought and heat stress

The research frame involved a three step approach in which the selected, promising findings of the trials conducted in the previous step formed the input for the design for the next step.

Sorghum varieties screened

An effort was made to screen a series of sorghum varieties that on the one hand were most appreciated by farmers and having a reputation to be more drought and heat stress resistant than others and on the other hand varieties recommended by breeders as being potentially suitable for coping

with drought and heat stress. Therefore, six sorghum varieties were provided for by IER and three varieties had been obtained from farmers. The characteristics of the nine sorghum varieties used are presented in Table 6.
These varieties potentially fit the weather and climate prediction in the semi-arid zone of Mali, e.g. CSM63E has been released since 1984, it remainbeen appreciated by farmers in all drought prone area. Three groups of experiments viz. laboratory, pot and field were carried out in 2014 and 2015 at Cinzana Agricultural Station. Laboratory experiments were used to evaluate (i) the performance of differentes varieties to (ii) different piming methods. Nine varieties were used in 5 differents water sources either tepid or heated at 70 ºC. Pots experiments experiments were set to assess the effect of heat generated by different level of charcoal and imposition of diferrent levels of drougt stress at germination and seedling growth stage. Finaly field experiments was set to evaluate the best varieties screened from laboratory, post in addition with different culturals practices to prevent crops establisement failure at early season in field conditions.

Germination performance and assessment parameters.

The impact of heat and drought treatments was assessed using a wide series of parameters commonly used when aiming at screening germination performance (Table 6).

Table 6: *Selected characteristics of the sorghum varieties used during the screening experiments*

Sorghum variety	Sorghum race	Days to mature	Type	Optimum rainfall requirement	Source
Banidoka	Guinea	120	Land race	600-800	Farmer
CSM63E	Guinea	100	Cultivar	400-700	IER
Nieleni	Caudatum-Guinea	110	Hybrid	700-1000	IER
Saba-soto	Caudatum	100	Land race	*Receding flood	Farmer
Saba-tienda	Durra	90	Land race	*Receding flood	Farmer
Seguifa	Durra	100	Cultivar	400-700	IER
Sewa	Caudatum-Guinea	110	Hybrid	800-1000	IER
Tiandougou	Guinea	120	Cultivar	800-1000	IER
Tiandougou-coura	Caudatum-Guinea	120	Cultivar	800-1000	IER

Source: AGRA, (2013); * Grown after flood water has receded

An additional effort was made to include as well parameters that are less commonly used worldwide but still important for performance assessments in temperate regions. Hence used was a combination of germination percentage, mean germination time, germination rate index, germination index, seedling vigour index, root vigour index and seedling dry weight. The description of the above parameters is presented in Table 7.

Data management and statistical analysis

The data management and processing followed a stepwise approach in all three types of experiements (Table 8). The experiments had been set up in a factorial arrangement in a Completely Randomized Design (CRD) with three replicates for laboratory and pots trials, while an Umbalanced Randomized Complete Block Design (RCBD) with four replicates was used for the field experiemnts. As a first step, data was collected and entered in a database created with the Microsoft Excel 2010 version (14.0.4756.1000) software. The data entries were crosschecked with the field observations and errors corrected. In case of blanks, another cross-check occurred. Prior to analyses, the means of the performance parameters (Table 7) were estimated. Data collected during the two years was pooled together. Next, the data was checked for normal distribution before being subjected to ANOVA.

The data sets were subjected to an analysis of variance (ANOVA) using GenStat nineth edition version 9.2.0 (2007). The treatment variables in the laboratory trial included hydro-priming nine sorghum varieties, priming with different water sources (5), priming with a different duration (4, 8 and 12 hours). These were compared to a different set of treatments such as hydro-priming of nine varieties with hot at 70 ºC from five sources whilst the priming duration varied between 10, 20 and 30 minutes.

The treatment variables during the pot trial included sorghum varieties (9), heat stress (5 levels) and drought stress (5 levels) and the ones in the field trial included: sorghum varieties (banidoka, CSM63E and saba-tienda), priming media (well water, solution of 100 ppm of K_2SiO_3 and unprimed), and cultural practice (ridge, *zaï* with compost and *zaï* without compost). Treatments means were considered significantly different at $p \leq 0.05$. The Fisher's Protected Least Significant Difference procedure was used for the mean separation.

The findings of the various studies are presented and discussed in paper form such as the effects of heat and drought stress on seed germination and seedling development of sorghum (*Sorghum bicolor*, L. Moench) in the Semi-arid Sahel of Mali (chapter 4), accelerating seed germination and seedling development of sorghum through hydro-priming in Mali (chapter 5) and the effect of osmo-priming on seed germination and seedling development of sorghum in Mali (chapter 6) on seed germination and seedling development under laboratory conditions. Chapter 7 presents seed priming and z*aï* pits practice on field performance of sorghum in Mali.

Table 7: *Seed germination assessment parameters*

Assessment parameter	Abbre-viation	Calculation base	Explanation of assessment parameter	Source
Germination Percentage	GP (%)	GP=(Number of seed germinated)/(number of seeds sown) x 100	(Number of total seed germinated over the number of total seeds sown time hundred	(AOSA, 1991)
Mean Germination Time	MGT (Days)	MGT=(∑(Dn)/(∑n)	n is the number of seeds germinated on each day whilst D is the day of counting n.	(Ellis et al., 1986)
Seedling Vigour Index	SVI	SVI=TSL x GP	TSL is the total seedling length (cm), and GP is the germination percentage (%).	(Abdul-Baki & Anderson, 1973)
Root Vigour Index	RVI	RVI=RL x GP	RL is the root length (cm), and GP is the germination percentage	
Germination Rate Index	GRI (%/day)	GRI=∑(GP1 + GP2…GPn)/n	Summation of the germination percentage at each day (GP) divided by the total days (n) of germination	(Nelson & Hsu, 1985)
Seedling Dry Weight	SDW (g/plant)	Dry samples weighted and expressed in g.	Weight determined after drying seedling samples at 105 ^{o}C for 24 hour	Dezfuli et al., (2008)
Germination Index	GI	GI=∑(d8xn1) + (d7xn2) + (d1xn8)	∑(day8xno seeds germinated day1) + (day7xno seeds germinated day2)+…+(day1xno seeds germinated day 8)	(AOSA, 1983)

Table 8: *General overview of types of experiments conducted and statistics used*

Type of trial	Implementation year	Tested for	Treatment factors and (levels)	Performance criteria	Type of statistical analyses
Laboratory	2014, 2015	drought stress	Sorghum varieties (banidoka, CSM63E, nieleni, saba-soto, saba-tienda, seguifa, sewa, tiandougou and tiandougou-coura), priming sources (distilled, rain, river, tap and well water); priming duration in hot water at 70 ºC (10, 20 and 30 min), in tepid water at 25 ºC (4, 8 and 12	Germination percentage, mean germination time, germination rate index, germination index, seedling vigour index, root vigour index and seedling dry weight	ANOVA
Pot	2014, 2015	heat and drought stress	Sorghum varieties (banidoka, CSM63E, nieleni, saba-soto, saba-tienda, seguifa, sewa, tiandougou and tiandougou-coura) heat stress (no charcoal, 0.5, 1, 2 and 3 cm depth of charcoal layer); drought stress (0, 1, 2, 3, and 4 weeks water stress).	Germination percentage, mean germination time, germination rate index, germination index, seedling vigour index, root vigour index and seedling dry weight	ANOVA, correlation
Field	2014, 2015	Yield performance	Sorghum varieties (banidoka, CSM63E and saba-tienda), priming stress (hydro-priming in well water, osmo-priming in 100 ppm of K_2SiO_3); cultural practice (ridge, *zaï* with compost and *zaï* without compost).	Germination percentage, mean germination time, germination rate index, germination index, grain yield and straw yield.	Umbalanced ANOVA

Source: Experiments conducted in 2014 and 2015.

Soil characteristics at the experimental site

An effort was made to use a soil in the pot trials representative for the region and hence showing all the characteristics that farmers usually face and have to cope with. Therefore the soil selected was topsoil (0-10 cm depth) collected from a non-cultivated area. Prior to its use, samples of the soil were taken for analysis. The soil was a sandy loam, very low in organic carbon (1%), in available N (0.04 ppm) and P_2O_5 (7.76 ppm) and at critical level for K_2O (0.19 ppm) and pH was acid (5.56).

The soil used for the field trial is classified as an Alfisol (FAO, 2003). According to Juo, (1987), these soils are coarse to medium textured soils overlying clayey subsoils with a base saturation over 50 percent. The selected field had been cultivated more than 30 years without fallow prior to the experiment. The soil was very poor in organic C (0.21%) in 2014 under critical level. The digging of z*aï* pits was done at least one month before the onset of rainy season. Making digging of z*aï* pits less stressful to trigger organic matter decomposition, should be done at the end of the rains season.

Water collection and storage

The water sources used for the laboratory and pot trials originated from several sources. The distilled water was collected from an electrical distillatory device in 20 liters gallons at the Segou regional hospital, while rain water was initially collected in a wide open container put outside during rainfall. The amount collected was filtered and kept in 20 liter gallons. The river water collected from the Bani river was kept in 20 liter gallons. The tap water was collected from the tap of the Agricultural Research Station of

Cinzana. The average depth of a well in Cinzana district is around 18 m. Extracted water was collected from a well and kept in 20 liter gallons for the duration of the laboratory experiments.

With regards to the pot experiments, only tap water from the Agricultural Research Station was used for watering. The water was kept in two containers of 200 liters each to avoid water shortages.

Simulating heat and drought stress in the laboratory and during the pot trials

In the absence of suitable research facilities to impose heat and drought stress during the planned series of laboratory and pot trials was conducted to evaluate their effecfs on seed and seedling growth parameters. Special efforts had been made to simulate these critical treatment factors.

Charcoal for heat stress

Everything that has a temperature gives off electromagnetic radiation (light). The sun is extremely hot and has a lot of energy to give, so it gives off shortwave radiation. The total amount of energy received at ground level from the Sun at the zenith depends on the distance to the Sun and thus on the time of year. Then the direct sunlight at Earth's surface when the Sun is at the zenith is about 1050 W/m^2, but the total amount (direct and indirect from the atmosphere) hitting the ground is around 1120 W/m^2. In terms of energy, sunlight at Earth's surface is around 52-55% infrared (above 700 nm), 42-43% visible (400 to 700 nm), and 3-5% ultraviolet (below 400 nm). In order to simulate to a certain extend this process, wood charcoal was used in this study.

Wood charcoal is associated with high sun radiance available in the tropics particularly in the Sahel of West Africa and charcoal powder is able to increase temperatures on soil surface. It therefore is effective and suitable especially in the driest and hottest months in the West African Sahel for screening seedlings to heat stress. Wood charcoal is a light, black residue, consisting of carbon and any remaining ash, obtained by removing water and other volatile constituents from animal and vegetation substances. Wood charcoal is usually produced by slow pyrolysis, the heating of wood or other substances in the absence of oxygen. In the developing world, wood charcoal is mainly used in the households to heat water either to cook food or provide hot water for tea or washing etc. Some food is cooked by direct heating without immersion in water, such as when corn or meat or fish is roasted (https://en.wikipedia.org/wiki/Activated_carbon).

A gram of activated carbon can have a surface area in excess of 500 m^2, with 1500 m^2 being readily achievable (https://en.wikipedia.org/wiki/Adsorption). Adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. This process creates a film of the adsorbate on the surface of the adsorbent. Adsorption is a surface-based process. Similar to surface tension, adsorption is a consequence of surface energy. Adsorption is present in many natural, physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, capturing and using waste heat to provide cold water for air conditioning and other process requirements (adsorption chillers), synthetic resins, increase storage capacity of carbide-derived carbons, and water purification.

The properties of the charcoal produced depend on the material charred. The charring temperature is also important. Charcoal contains varying amounts of hydrogen and oxygen as well as ash and other impurities that, together with the structure, determine the properties. The approximate composition of charcoal for gunpowder is sometimes empirically described as C_7H_4O. To obtain a charcoal with high purity, source material should be free from non-volatile compounds. In addition wood charcoal with its black colour is known to absorb sun radiation. It is specific heat capacity is 0.24 kcal/kg ºC (Roy, Dutta, Corscadden, & Havard, 2011).

CHAPTER FOUR

HEAT AND DROUGHT STRESS EFFECTS ON SEED GERMINATION AND SEEDLING DEVELOPMENT OF SORGHUM (*Sorghum bicolor*, L. Moench) IN THE SEMI-ARID SAHEL OF MALI

Introduction

The semi-arid sub-region in West Africa is characterized by unpredictable weather, long dry and hot seasons, erratic and inconsistent rainfall, high temperatures and soils that are poor in nutrients (Howden et al., 2007). Maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), millet (*Pennicetum glaucum* L.), cowpea (*Vigna unguiculata* L.), groundnut (*Arachis hypogea* L.) and sesame (*Sesamum indicum* L.) are the dominating, rain-depending staple crops on which the poor people inhabiting the sub-region live on. Hence, the predicted changes in climate for the region, including higher temperatures, decreasing precipitation patterns, changing water availability and increased frequency of extreme weather events (Intergovernmental panel on climate change [IPCC], 2007), will alter the growing conditions and hence represent a challenge to the farming population that have insufficient knowledge about dealing with these new vagaries.

This however is of uttermost importance because CC&CV are highly likely to threaten the food security in this, and similar, regions (Howden et al). In the semi-arid, tropical regions, changes in rainfall and certainly when coupled with rising temperatures, are likely to reduce the length of the growing season, which usually is determined by the duration of soil water availability (Singh et al., 2015). In the future, the growing period spanning from seeding to harvesting of crops, must therefore be matched again to the periods of water availability to gain stable yields.

In the semi-arid tropics of West Africa, the mean cropping-season temperatures are thus most often above these optimum temperatures thus leaving not much room for adaptation in case indeed future temperatures rise. Although it has recurrently been stated that increased CO_2 rates in the air due to greenhouse gas emissions may have beneficial effects on the growth and yield of sorghum (being a C_4 type of plant), scientists agree that these benefits will only partially negate the detrimental effect of rising temperatures, although this obviously depends on the degree of temperature rise also (Soni, Chadha, & Saini, 2008).

Soil temperatures other than the optimum temperature for germination, irrespective if being higher or lower, affect sorghum germination. According to Peacock, (1982), the optimum soil temperature for sorghum germination is 23°C whilst higher soil temperatures reduces emergence. Barbosa et al., (2004) observed similar drawbacks in emergence due to soil temperatures above the optimum, but underlined differences between genotypes under such abiotic stress, which was in line with previous conclusions (Mortlock & Vanderlip, 1989). Also soil temperatures lower than the optimum range affect germination and emergence (Anda & Pinter, 1994; Harris, Hamdi, & Terry, 1987; Meyers, Nelson, & Horrocks, 1984). According to Anda and Pinter, (1994) although again cultivars differences have been reported as well, underlining however a complete absence of germination with soil temperatures below 10 ^{o}C.

Field emergence generally increases with later planting dates, which reflect in essence higher soil temperatures. The highest percentage emergence occurred at about 18 ^{o}C, but did not increase significantly with temperature ranges higher than 21 to 27 ^{o}C (Wilson & Eastin, 1982). On the other hand, soil temperatures above 45 ^{o}C inhibited the overall emergence of sorghum seedlings, resulting in a general poor crop stand (Peacock, 1982). However, Peacock, (1982) concluded that sorghum genotypes showed clear differences in emergence even at 50 °C, at least when not facing water stress. According to Ougham & Stoddart, (1986), the observed failure in germination of some sorghum lines at very high temperatures was closely correlated with the inhibition of embryo protein synthesis in the first hours of imbibition.

The emergence ability of sorghum and its consequent capacity to germinate and grow was impacted by soil moisture conditions. After studying the effect of moisture stress on sorghum seed germination, (Bijagare, Ghuge, Hudge, 1994) concluded that germination decreased with increases in levels of water stress, although cultivars variations were observed concurrently. According to Nivedita (1992) the optimum soil moisture requirement for sorghum germination is between 25 to 50% of field capacity. While modeling sorghum seedling establishment using six temperatures and three matric potentials (-0.03 to -3 MPa), (Brar, Steiner, Unger, & Prihar, 1992) reported on optimal sorghum emergence (>80%) obtained at 20 ^{o}C to 30 ^{o}C and -0.03 to -0.1 MPa.

Obviously, a reduced seed germination owing to drought and heat stress conditions limits in turn plant establishment and therefore is considered the most critical phase in plant development (El-Keblawy & Al-Rawai, 2005;

Macar, Turan, & Ekmekçi, 2009). In order to assess germination performance under imposed experimental conditions, various parameters have been developed (Table 7): namely Germination percentage (GP), Mean germination time (MGT), Germination rate index (GRI), Germination index (GI), Seedling vigour index (SVI), Root vigour Index (RVI) and Seedling dry weight (SDW). Based on the environmental characteristics in Mali, physiological requirements of the sorghum varieties and their physical interrelations to cope with the environment including climatic conditions are of utmost importance in enhancing germination and stand establishment. Therefore, a pot experiment was designed to evaluate the effects of heat and drought stress and a combination thereof on germination and seedling development of nine sorghum varieties. A further objective was to screen for the most promising varieties that could be used in consequent field trials while assuming future climate variability and change.

Materials and Methods

Location, experimental design and treatments

Two pot experiments studies were implemented as a factorial arranged Completely Randomized Design (CRD) at the Agricultural Research Station of Cinzana (Longitude: 5° 57’ W, Latitude: 13° 15’ N, and Altitude: 280 m), Institut d’Economie Rurale (IER), Mali during the 2014 and 2015 dry seasons. Pot preparation was the same for the two experiments.

Pot preparation

The experiments were conducted in black plastic pots with 30 cm diameter at the top and 20 cm at the bottom and 20 cm depth from bottom to top. Drainage holes were perforated at the botton of the pots having a volume of 10 L. The soil was collected from a nearby, non-cultivated area. Prior to filling the pots, the collected soil was air dried, sieved to pass through a 5-mm mesh sieve to get rid of roots, leaves, and other coarse material, and hence thoroughly mixed during drying and sieving to reduce heterogeneity. An A4 paper barrier was placed in each pot prior to addition of soil to prevent loss of soil through the drainage holes. Each pot was filled with 9 kg of soil to about 5 cm below the brim without compaction.

Both pot experiments were set up during the dry season (Driest and hottest months) when temperatures were at a maximum reflecting the true field conditions at early rainy season. After filling, the pots were placed in an open area, arranged according to a factorial Completely Randomized Design (CRD) of two factors (varieties and heat levels) for experiment 1 and the same arrangement was adopted for experiment 2 with also two factors (varieties and water stress levels). Three replications, adjacent rows were used and about 5 cm within rows and while putting them in rows with 50 cm space between Twenty seven pots were used for the nine varieties and eighteen pots for the 6 levels of charcoal layers making a total of Fourty five pots per replication. The total pots in the experiments were 135 pots for each individual experiment.

The same varieties were used in heat and drought experiments i.e A1 to A9 were Banidoka, CSM63E, Nieleni, Seguifa, Saba-soto, Saba-tienda, Sewa, Tiandougou and Tiandougou-coura respectively (Table 6). Six sorghum varieties were provided by IER whilst the three others collected from local farmers in the vicinity of the research station and used in the receded flood zone (Table 6).

Pot experiment 1 (PT1)

Pot experiment 1 comprised two main treatments to simulate heat stress. Aside from the nine sorghum varieties, different levels of heat stresses were mimicked. While assuming that the thicker the charcoal layer, the greater the heat stress, the preparation included the filling of charcoal layers of different thickness in the pots. To simulate heat stress five treatment layers/thickness of charcoal (B1 to B5) were included: no charcoal, 0.5, 1, 2, and 3 cm thick respectively. The charcoal was previously pounded in a mortar, sieved through a 5 mm mesh, and added to a depth of 0.5, 1, 2, and 3 cm thick to each of the four pots marked B2, B3, B4 and B5 respectively.

Watering, sowing and monitoring under heat stress conditions (Pot experiment 1)

Prior to the start of the experiment, the soil was soaked to saturation by applying 3.18 liters of water (or the equivalent to 45 mm of rainfall) to each pot. Once at field capacity, thirty seeds of each sorghum variety were sown to a depth of 2 cm with one seed per hole. Water was not applied to the pots that received charcoal treatments. The control treatments were watered with 0.730 liters per pot, which was sufficient to keep the soil water close to field capacity every two days in both heat and drought stress experiments. The others treatments with charcoal layers were not waterd till the end at 15 days after sowing.

Pots were observed daily for seedling emergence until day eight after sowing (DAS) whilst seedlings were thinned leaving 10 plants per pot at 10 DAS. Soil temperature was recorded at 1 and 7 DAS with the help of a soil thermometer. Temperature was measured at 1, 5 and 10 cm soil depth. Manual weeding was done only when needed. The impact of heat treatments was assessed using parameters presented in Table 7. The experiment was terminated at 15 DAS the experiments simulating heat stress. Data was collected during two dry seasons of 2014 and 2015.

Pot experiment 2 (PT2)

In experiment 2, the same materials were used for simulating drought stress. Hence, next to the same nine varieties previously used in heat stress, different intervals of watering were imposed to induce drought stress. Assuming rainfall irregularity interval at early season in the study area is 7 days without rain was considered to impose water stress on seed and seedling growth. The greater the interval without rain days, the greater the drought stress. Consequently five levels of water stress was used i.e no water stress, one, two, three and four week water stress. Then pots preparation was as in heat stress and the same 9 varieties were used.

Watering, sowing and monitoring under drought stress conditions (Pot experiment 2)

The same procedure was used for pot preparation, sowing, data collection and management, except watering and moisture measurement.

To simulate drought stress, 7 days intervals were used for watering. Therefore, the five treatments mimicking water stress (week) included no water stress, 1, 2, 3 and 4 weeks water stress respectively. Soil moisture was measured with a moisture sensor at 1, 7, 15 22 and 29 DAS. The experiments were terminated at 30 DAS. The impact of drought treatments were assessed using the parameters presented in Table 7. Data was collected during the dry seasons of 2014 and 2015.

Data analysis

The results were evaluated as stated in data management and statistical analysis section. The indicators tested included germination percentage (GP), mean germination time (MGT), germination rate index (GRI), germination index (GI), seedling vigour index (SVI), root vigour index (RVI) and seedling dry weight (SDW). These were tested using Fisher's Protected Least Significant Difference (LSD) at $p \leq 0.05$ probability level.

Results

The effect of drought and heat stress on the germination of sorghum showed a considerable range and variability as evidenced by the different germination performance parameters (Table 7). Varieties, heat stress and their interaction had a significant effect on germination percentage (GP), Mean germination time (MGT), Germination rate index (GRI), Germination index (GI), Seedling vigour index (SVI), Root vigour index (RVI) and Seedling dry weight (SDW) at $p \leq 0.05$ probability level. In general soil temperature increasing with thickness of the charcoal layers increasing, but decreased with soil depth (Table 9).

Effects of heat stress on germination and seedling parameters

Germination percentage (GP) for heat stress

The effects of variety, charcoal layer and their interaction were significant on germination percentage (GP) at $p<0.01$, 0.01 and 0.05 probability level respectively (Table10). Increasing heat stress as mirrored in the increasing thickness of the charcoal layer was associated with decrease in GP for all varieties. There were significant differences between the varieties CSM36E (63.5%), banidoka (30.4%), saba-tienda (26.7%) and the remaining varieties.

Table 9: *Soil temperature (ºC) under different depth at 1 and 7 days after sowing in 2014 and 2015*

Year	Days after sowing (DAS)	Soil Depth (cm)	Depth of charcoal layer (cm) above soil 0.0	0.5	1.0	2.0	3.0
2014	1	1	46	46	46	47	51
	✓	5	45	45	45	45	47
	✓	10	44	45	45	45	45
	7	1	39	44	44	46	51
	✓	5	38	42	42	43	45
	✓	10	38	41	41	42	43
2015	1	1	40	47	50	51	54
	✓	5	42	45	45	47	46
	✓	10	42	44	46	45	45
	7	1	41	53	51	52	53
	✓	5	43	50	49	48	48
	✓	10	44	50	48	47	47

All charcoal layers increased soil temperature, but the highest increase occurred as expected due to the thickest charcoal layer. Hence, germination percentage reduced most in the layer with a 3 cm depth of charcoal (6%) and the lowest reduction at a depth of 0.5 cm (16%). All drought stress levels significantly decreased germination percentage compared to the control without drought stress.

Increasing heat stress as mirrored in the increasing thickness of the charcoal layer was associated with decrease in GP for all varieties. There were significant differences between the varieties CSM36E (36.5%), banidoka

(30.4%), saba-tienda (26.7%) and the remaining varieties. All the charcoal treatment was significantly different from the control. Increase charcoal layer to 0.5, 1, 2 and 3 cm led to 72, 76, 81, and 89% decreasing in all varieties respectively (Table 10). The lowest GP was found in tiandougou under all charcoal layer conditions (Table 10). There were no difference between nieleni, tiandougou-coura, seguifa and sewa. The group of varieties seguifa, saba-soto, nieleni, sewa and tiandougou-coura were not significantly different from the lowest tiadougou. The performance of the different varieties indicates a great genetic variability to cope with heat stress. Significant interaction of varieties with treatments supported the differential behavior of used varieties under heat stress. The performance of different varieties indicates a great genetic variability to cope with heat stress (Table 10).

Table 10: *Germination percentages of 9 varieties of sorghum sown under different layers of charcoal*

Variety	Charcoal layer (cm)					Mean GP for Varieties
	0.0	0.5	1.0	2.0	3.0	
Banidoka	73.9	24.6	22.9	13.6	17.1	30.4
CSM63E	70.2	32.7	27.2	33.6	18.8	36.5
Nieleni	37.9	8.4	6.4	8.3	0.0	12.2
Saba-soto	64.1	25.0	8.6	9.2	5.0	22.4
Saba-tienda	85.2	19.0	15.3	9.9	3.9	26.7
Seguifa	65.2	23.3	11.6	5.1	3.3	21.7
Sewa	52.6	5.8	15.8	6.8	6.4	17.5
Tiandougou	20.3	3.3	9.0	7.2	2.0	8.4
Tiandougou-coura	39.3	1.8	5.6	1.2	1.1	9.8
Mean GP for Char Layer	56.5	15.9	13.6	10.54	6.4	
	P-VALUE	SED	LSD			
Variety	<0.01	4.35	8.56			
Charcoal layer	<0.01	3.24	6.38			
Variety x charcoal layer	0.049	9.72	19.15			

P-VALUE at $p \leq 0.05$, SED: Standard errors of differences of means, LSD: Least significant differences of means.

Mean germination time (MGT) for heat stress

As shown in Table 11; charcoal layer (*p*<0.01), and the interaction between varieties x charcoal layer (*p*<0.05), had significant effects on mean germination time (MGT). No significant different was found among varieties. The simulated temperature effect on germination increase with thickness of charcoal layer in one hand but charcoal layer 0.5 cm was not significantly different from control. Charcoal layer 1, 2 and 3 cm delay MGT compare to control without charcoal layer (Table 11). The increase in charcoal layer decrease MGT compare to control. The interaction varieties x charcoal layer showed that eventhough the varieties are responding differently some are able to germinate under severe heat stress situation.

Germination rate index (GRI) for heat stress

The GRI significantly different among varieties (*p*<0.01), charcoal layer (*p*<0.01), and their interaction (p<0.04), (Table 12). Except CSM63E With highest GRI (23.1) in both years was signicantly different from Tiandougou (6.1), Tiandougou-coura (7.3) and Nieleni (8.2) the remain varieties were not statistically different among themselves.

The thicker the charcoal layer the higher the temperature generated and the greater the effect of heat stress on germination rate index. Indepth analyses showed that the findings on GRI of the varieties tested responded differently to heat stress (Table 12).

Table 11: *Mean germination time of 9 varieties of sorghum sown under different layers of charcoal*

Variety	Charcoal layer (cm) 0.0	0.5	1.0	2.0	3.0	Mean MGT for Varieties
Banidoka	4.8	6.2	5.5	5.5	5.8	5.5
CSM63E	5.7	4.9	6.4	6.4	6.9	6.0
Nieleni	5.9	3.8	2.9	5.7	0.0	3.7
Saba-soto	5.8	6.2	6.1	4.6	3.3	5.2
Saba-tienda	5.6	6.1	4.5	5.1	3.6	5.0
Seguifa	5.8	6.1	6.2	2.1	1.1	4.3
Sewa	5.7	3.9	6.0	5.1	3.5	4.8
Tiandougou	6.0	4.1	4.2	3.3	2.0	3.9
Tiandougou-coura	4.6	2.7	2.1	3.3	1.2	2.8
Mean MGT for Charcoal layer	5.55	4.88	4.85	4.57	3.03	
	P-VALUE	SED	LSD			
Variety	<0.01	0.64	1.26			
Charcoal layer	<0.01	0.48	0.94			
Variety x charcoal layer	0.05	1.43	2.83			

P-VALUE at p≤0.05, SED: Standard errors of differences of means,
LSD: Least significant differences of means.

The GRI of charcoal layer 3 cm was significantly different from layer 0.5 cm and control but not different from layers 1 an 2 cm in both years. Which suggest that charcoal layers 1, 2 and 3 cm heat similarly the soil (Table 12). Beyond the optimum temperature, germination rate decreased linearly with increased temperature to a temperature maximum and no germination. For seeds to germinate, they need to imbibe water. For this to occur, sufficient moisture must be present. A warmer climate may increase evaporation and decrease moisture, which would negatively affect germination. An increase of heat may increase evaporation and decrease moisture, which would negatively affect germination.

Germination index (GI) for heat stress

The GI was significantly different among varieties ($p<0.01$), Charcoal layer ($p<0.01$). The interaction between varieties and charcoal layer were not significant (Table 13). The GI ranged from 2.5 – 9.6. Varieties CSM63E, Banidoka, Seguifa, Sewa, Saba-soto and Saba-tienda, performed better than the varieties such as Nieleni and Tiandougou (Table 13). The GI was impacted as well by heat stress both in 2014 and 2015.

Table 12: *Germination rate index of 9 varieties of sorghum sown under different layers of charcoal*

	Charcoal layer (cm)					Mean
Variety	0.0	0.5	1.0	2.0	3.0	GRI for Varieties
Banidoka	48.7	16.8	11.6	5.9	6.4	17.9
CSM63E	45.6	24.7	17.3	20.0	7.7	23.1
Nieleni	24.2	8.5	4.9	3.6	0.0	8.2
Saba-soto	43.8	19.5	2.2	4.4	2.1	14.4
Saba-tienda	60.5	10.4	6.3	5.5	1.3	16.8
Seguifa	45.1	15.2	6.4	2.8	1.4	14.2
Sewa	38.4	6.8	8.6	5.5	1.6	12.2
Tiandougou	17.2	1.4	6.9	3.4	1.6	6.1
Tiandougou-coura	28.5	3.6	3.1	0.7	0.4	7.3
Mean GRI for charcoal layer	39.1	11.9	7.5	5.7	2.5	
	P-VALUE	SED	LSD			
Variety	<0.01	2.32	4.57			
Charcoal layer	<0.01	3.11	6.13			
Variety x charcoal layer	0.04	6.96	13.71			

P-VALUE at $p\leq0.05$, SED: Standard errors of differences of means, LSD: Least significant differences of means.

The increase in charcoal layer from 0.5, 1, 2 and 3 cm generate more heat on GI 5.1, 2.9, 2.9 and 0.9 respectively. The GI of charcoal layer 3 cm was significantly different from layer 0.5 cm and control but not different from layers 1 an 2 cm in both years. Which suggest that charcoal layers 1, 2 and 3 cm heat similarly the soil (Table 13). Indepth analyses showed that the findings on GI of the varieties tested responded differently suggeting genetic variation to cope to heat stress. Germination occurs when the embryo elongates and the radical protrudes from the seed coat.

Table 13: *Germination index of 9 varieties of sorghum sown under different layers of charcoal*

	Charcoal layer (cm)					Mean
Variety	0.0	0.5	1.0	2.0	3.0	GI for Varieties
Banidoka	20.4	7.2	4.6	2.0	2.3	7.3
CSM63E	19.1	10.7	6.8	8.4	2.7	9.6
Nieleni	10.0	3.7	2.0	1.2	0.0	3.4
Saba-soto	19.7	8.9	0.7	1.6	0.8	6.3
Saba-tienda	26.4	4.0	2.2	2.0	0.4	7.0
Seguifa	19.8	6.4	2.4	1.0	0.4	6.0
Sewa	17.0	3.0	3.3	2.2	0.5	5.2
Tiandougou	7.0	0.6	3.0	1.2	0.6	2.5
Tiandougou-coura	13.5	1.7	1.2	0.2	0.1	3.4
Mean GI for charcoal Layer	17.00	5.13	2.92	2.21	0.87	
	P-VALUE	SED	LSD			
Variety	<0.01	1.50	2.95			
Charcoal layer	<0.01	1.11	2.20			
Variety x charcoal layer	0.09	3.34	6.59			

P-VALUE at $p \leq 0.05$, SED: Standard errors of differences of means, LSD: Least significant differences of means.

For many species, enzymes are required to facilitate this process. For example, enzymes degrade endosperm tissue and rupture the seed coat (Finch-Savage and Leubner-Metzger 2006). Chemical signaling regulates production of enzymes, which is in turn regulated by temperature (Finch-Savage and Leubner-Metzger 2006). If the temperature window is breached, then these enzymes may become inactive (Peterson et al. 2007). Due to the temperature dependency of hormones and enzymes, a drastic change in temperature will significantly affect germination.

Seedling vigour index (SVI) for heat stress

The effects of variety, charcoal layer and their interaction were significant on seedling vigour index (SVI) at $p<0.01$, 0.01 and 0.01 probability level respectively (Table14). Increasing heat stress as reflected in the increasing thickness of the charcoal layer was associated with decrease in SVI for all varieties. There were significant differences between the varieties CSM36E (438.7), Banidoka (341.9), Saba-tienda (321.1%) and Nieleni (105.2%), Tiandougou (102.0%) and Tiandougou-coura (106.5%) but were not significant different from the remaining varieties. All the charcoal treatments were significantly different from the control. Increase charcoal layer to 0.5, 1.0, 2.0 and 3.0 cm led to 67.5, 92.5, 90.1, and 48.0 decreasing in SVI of all varieties respectively compare to the control (Table 14). The lowest SVI was found in 3.0 cm (48.0) charcoal layer conditions (Table 14). The lowest SVI was observed in the varieties Tiandougou (SVI=102.0) Nieleni (SVI=105.2) and Tiandougou-coura (SVI=106.5) which this confirms the hypothesized varietal difference to heat stress (Table 14). Heat (as represented by the depth of the charcoal layer) reduced SVI of all varieties significantly in both years.

Analyses showed that the findings on SVI of the varieties tested responded differently to heat stress, especially Saba-tienda, CSM63E, Banidoka and Seguifa performed better compared to their suggesting high tolerance to heat stress (Table 14).

Table 14: *Seedling vigour index of 9 varieties of sorghum sown under different layers of harcoal*

	Charcoal layer (cm)					Mean SVI for Varieties
Variety	0.0	0.5	1.0	2.0	3.0	
Banidoka	1.13E+03	1.38E+02	1.82E+02	1.11E+02	1.53E+02	341.9
CSM63E	1.09E+03	1.70E+02	3.35E+02	4.04E+02	1.92E+02	438.7
Nieleni	4.92E+02	2.33E+01	-1.42E-14	1.06E+01	0.00E+00	105.2
Saba-soto	8.89E+02	6.27E+01	8.89E+00	8.34E+01	5.78E+01	220.4
Saba-tienda	1.27E+03	1.71E+02	1.15E+02	5.17E+01	-5.68E-14	321.1
Seguifa	1.08E+03	1.11E+01	8.45E+01	4.00E+01	-7.11E-15	242.5
Sewa	7.66E+02	2.50E+01	3.20E+01	4.83E+01	1.39E+01	177.1
Tiandougou	4.01E+02	-7.11E-15	4.67E+01	6.28E+01	-1.42E-14	102.02
Tiandougou-coura	4.81E+02	7.00E+00	2.92E+01	3.55E-15	1.58E+01	106.5
Mean SVI for charcoal layer	843.7858	67.45	92.51	90.10	48.02	

	P-VALUE	SED	LSD
Variety	<0.01	62.34	122.8423
Charcoal layer	<0.01	46.46	91.56123
Variety x charcoal layer	0.01	139.39	274.6837

P-VALUE at $p \leq 0.05$, SED: Standard errors of differences of means, LSD: Least significant differences of means.

Root vigour index (RVI) for heat stress

The Root vigour index (RVI) was significantly impacted by varieties ($p<0.01$), charcoal layer ($p<0.01$). No significant interaction between varieties x charcoal layer was found in both 2014 and 2015. For instance, the RVI of all varieties decreased, although some varieties such as CSM63E and Banidoka, perfomed better compared to others (Table 15). It therefore can be expected that in particular the seedling size as a proxy of seed reserves is a critical factor explaining the monitored differences in RVI.

Table 15: *Root vigour index of 9 varieties of sorghum sown under different layers of charcoal*

Variety	Charcoal layer (cm) 0.0	0.5	1.0	2.0	3.0	Mean RVI for Varieties
Banidoka	299.1	48.9	69.2	43.9	62.3	104.7
CSM63E	275.1	54.6	114.0	136.2	71.1	130.2
Nieleni	117.7	12.6	0.0	0.0	0.0	26.1
Saba-soto	199.1	23.1	3.9	35.1	25.0	57.2
Saba-tienda	310.7	55.4	40.3	20.6	0.0	85.4
Seguifa	258.8	3.3	28.5	10.0	0.0	60.1
Sewa	239.6	0.0	21.3	17.9	6.1	57.0
Tiandougou	101.1	0.0	20.2	21.2	0.0	28.5
Tiandougou-coura	120.2	3.2	9.7	0.0	6.7	
Mean RVI for charcoal layer	213.5	22.4	34.1	31.7	19.0	28.0

	P- VALUE	SED	LSD
Variety	<0.01	18.66	36.78
Charcoal layer	<0.01	13.91	27.41
Variety x charcoal layer	0.13	41.73	82.24

P-VALUE at $p \leq 0.05$, SED: Standard errors of differences of means, LSD: Least significant differences of means.

Charcoal layers did impacte RVI in both years was significantly different from the control but was not different among them (Table 15). The results showed that these varieties have the potential to well adapt to heat prone environment.

Seedling dry weight (SDW) for heat stress

Significant difference was observed among varieties (*p*<0.01), charcoal layer (*p*<0.01) and their interaction in both year. Increasing charcoal layer thickness was associated with decrease in SDW for all varieties. An increase of charcoal layer from 0.5, 1.0, 2.0, and 3.0 cm led to a decrease of 0.03, 0.02, 0.02, and 0.01g in SDW respectively. The SDW decreased in all charcoal layer but they were not different among them. Charcoal layer 3.0 cm did not enable high biomass accumulation in any of the varieties tested, suggesting that high level of heat generated in both years (Table 16).

The SDW varied from 0.05 to 0.13 g/plant. Seedling dry weight with varieties responded differently, only banidoka, CSM63E and saba-tienda showed significant difference from the remaining varieties (Table 16). The lowest seedling dry weight was obaseved in varieties Tiandougou and Tiandougou-coura (0.05 g/plant). The charcoal powder layer introduced affected significantly all germination parameters, suggesting thus that the use of charcoal layers is an effective mean to increasing soil temperature even under the driest and hottest months in the Sahel which would allow for screening for heat and drought tolerant varieties.

Effect of drought stress on germination and seedling parameters

Germination percentage (GP) for water stress

Varieties ($p<0.01$) and water stress ($p<0.01$) had significant effect on germination percentage (GP) in 2014 and 2015 (Table 17). No significant interaction was found between variety and water stress. High drought stress as reflected by imposition weeks of water stress decreased GP in all sorghum varieties used; however varieties responses were different. The lowest GP was recorded in variety tiandougou-coura (GP=13.2%). The highest GP was observed in Banidoka (50%), CSM63E (47%) were not different from each other in both years but were significantly different from varieties nieleni, saba-soto, saba-tienda, seguifa, sewa tiandougou and tiandougou-coura.

Table 16: *Seedling dry weight of 9 varieties of sorghum sown under different layers of charcoal*

	Charcoal layer (cm)					Mean SDW for Varieties
Variety	0.0	0.5	1.0	2.0	3.0	
Banidoka	0.44	0.14	0.04	0.01	0.03	0.13
CSM63E	0.42	0.07	0.07	0.07	0.03	0.13
Nieleni	0.28	0.00	0.00	0.00	0.00	0.06
Saba-soto	0.35	0.02	0.01	0.01	0.01	0.08
Saba-tienda	0.52	0.04	0.01	0.02	0.01	0.12
Seguifa	0.35	0.02	0.00	0.01	0.00	0.07
Sewa	0.34	0.00	0.00	0.02	0.01	0.07
Tiandougou	0.22	0.00	0.01	0.01	0.01	0.05
Tiandougou-coura	0.19	0.02	0.02	0.00	0.02	0.05
Mean GP for charcoal layer	0.35	0.03	0.02	0.02	0.01	
	P-VALUE	SED	LSD			
Variety	<0.01	0.02	0.04			
Charcoal layer	<0.01	0.02	0.03			
Variety x charcoal layer	<0.01	0.05	0.09			

P-VALUE at p≤0.05, SED: Standard errors of differences of means, LSD: Least significant differences of means.

Change in water stress from 1, 2, 3 and 4 weeks caused 94, 98, 98 and 99 % GP reduction, respectively. This results shows that drought occurred after sowing reduces significantly germination percentage and seedling establishment (Table 17). Water and temperature are determinant factors for seed germination. Both factors can, separately or jointly, affect the germination percentage and germination rate.

Mean germination time (MGT) for water stress

According to result of analysis of variance (Table 17) the water stress effect on mean germination time (MGT) was significant at $p<0.01$. No significant effect were found in varieties and the interaction variety x water stress (Table 17). Water stress caused increased of mean germination time from 4.3 to 5.3 days. Means comparisons analysis (Table 17) showed that under control and drought stress conditions drought stress 4 weeks water stress (5.3 days) had the most highest effect on mean germination compared to control with no water stress (4.3 days), which recorded had the lowest value. Under drought stress conditions more time is needed for germination. First counts of the standard germination tests showed that smaller seeds germinated more rapidly than larger seeds for the two inbreds tested.

Germination rate index (GRI) for water stress

Significant difference was observed among varieties ($p<0.01$), drought stress ($p<0.01$) on germination index. There was no significant difference found among the interaction on varieties x water stress on germination rate index (Table 17). Varieties banidoka, CSM63E, saba-soto and seguifa, performed better than the others varieties such as nieleni, saba-tienda, tiandougou and tiandougou-coura in both observation years.

GRI of the varieties tested responded differently to drought stress (Table 17). All water stress levels was statistically different from the control. The GRI was decreased in general for one week water stress and two, three and four weeks water stress respectively compared to the control (Table 17).

Germination index (GI) for water stress

Varieties ($p<0.01$), water stress ($p<0.01$) were significant different effect on germination index. There was no significant interaction on germination index (GI). The GI varied from 5.7-18.1 in both years, but a indepth analyses showed that the findings on GI of the varieties tested responded differently to water stress variety banidoka and CSM63E perfomed better (Table 17). In contrast, water stress did lower the GI significantly in 2014 and 2015. All water stress levels was statistically different from the control. The GI was decreased about 81% for one drought stress compared to the control and 75% for two, three and four weeks water stress compared to the control (Table 17).

Seedling vigour index (SVI) for water stress

The Seedling vigour index (SVI) was significantly affected by varieties ($p<0.01$), drought ($p<0.01$) (Table 17). No significant interaction was found on varieties and water stress on SVI in both years. Variety CSM63E was statistically different from nieleni, sewa, tiandougou and tiandougou-coura. The varieties banidoka and CSM63E recorded the highest SVI values (Table 17) but did not differered from saba-soto, saba-tienda and seguifa. The lowest SVI was observed in tiandougou-coura. Water stress reduced SVI of all varieties significantly in both years.

Table 17: *Effects of drought stress on seed germination and seedling growth of 9 varieties of sorghum*

Treatments	Growth parameters						
Variety	GP	MGT	GRI	GI	SVI	RVI	SDW
Banidoka	50.0	5.1	40.5	18.1	266.2	54.3	0.4
CSM63E	47.0	4.8	35.1	15.8	297.4	59.4	0.3
Nieleni	18.5	4.6	15.3	7.3	102.5	21.6	0.3
Saba-soto	22.7	5.3	21.2	10.0	182.9	41.3	0.2
Saba-tienda	22.5	4.6	19.4	9.7	164.1	29.5	0.2
Seguifa	23.8	5.1	23.4	11.4	218.0	33.3	0.3
Sewa	19.4	4.7	20.5	10.3	135.5	34.1	0.2
Tiandougou	19.9	4.8	19.8	9.9	129.6	25.1	0.2
Tiandougou-coura	13.2	4.4	11.7	5.7	40.8	8.7	0.02
P-values	<0.01	0.19	<0.01	<0.01	0.02	0.10	<0.01
LSD	12.7		9.0	4.1	149.3		0.1
Water stress (week)							
No_WS	59.6	4.3	43.8	20.1	502.4	102.1	0.3
1_WWS	22.3	4.7	18.9	8.5	302.7	51.8	0.3
2_WWS	19.0	4.8	19.6	8.9	19.8	8.0	0.2
3_WWS	14.4	5.1	17.4	7.8	23.8	6.6	0.1
4_WWS	16.5	5.3	15.2	9.2	5.3	2.1	0.1
P-values	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	9.5	0.5	6.7	3.1	111.3	25.1	0.1
P-values for variety x water stress	1.00	0.31	1.00	1.00	0.60	0.80	0.62

LSD values at $p \leq 0.05$ GP: Germination percentage, MGT: Mean germination time, GI: Germination index, SVI: Seedling vigour index, RVI: Root vigour index, SDW: Seedling dry weight. No: No water stress, 1_WWS: One week water stress, 2_WWS: One week water stress, 3_WWS: One week water stress, 4_WWS: One week water stress.

It therefore can be expected that in particular the seedling size as a proxy of seed reserves is a critical factor explaining the monitored differences in SVI. Significantly difference was observed among water stress levels. In both years the decrased SVI in one week water stress was not statistically different from the control but was significantilly different from two, three and four weeks drought stress (Table 17). The incease in water stress levels as imposition of water stress for 1, 2, 3 and 4 weeks decrease observed SVI about 11%, 93%, 94% and 98% respectivelly compared to the control (Table 17).

Root vigour index (RVI) for water stress

The root vigour index was significantly impacted by water stress levels (p=0.01), but was not significant for varieties treatments and thevarieties x water stress interaction in both years. Root vigour index varied among water stress treatments. Water stress treatments 2, 3 and 4 weeks were significantly different from one week water stress and the control. Water stress treatments decreased RVI about 95 %, 92%, 94 and 98% respectively for one, two, three and four water stress (Table 17). Water stress is determinant factor and can seriously affect root vigour index.

Seedling dry weight (SDW) for water stress

Significant difference was found among varieties (p<0.01), water stress levels (p<0.01) on seedling dry weight (Table 17). There was significant interaction between varieties x water stress on seedling dry weight (Table 17). Seedling dry weight with varieties responded differently, a decrease in all varieties was observed compared with the control (Table 17). SDW varied from 0.02 – 0.40 g/plant. Variety banidoka was statistically different from CSM63E, nieleni, saba-soto, saba-tienda, seguifa, sewa, tiandougou and tiandougou-coura. CSM63E, nieleni, seguifa were not significantly different among them but different from saba-soto saba-tienda, sewa, tiandougou and tiandougou-coura (Table 17). One week water stress was significantly different from other water stress treatments but not significant different from the control (Table 17).

Under 3 and 4 weeks drought stress was too severe did reduce biomass accumulation (Table 17). Water stress at the initial stage is very critical for seedling growth and development.

Relationship among growth parameters

Analysis of correlation among the parameters was performed. For heat stress high positive correlation were found among germination percentage (GP) and the germination rate index (GRI, R^2=0.96), germination index (R^2=0.93), seedling vigour index (R^2=0.92), root vigour index (R^2=0.90) and seedling dry weight (R^2=0.79) while low positive was observed among mean germination time (MGT) and the others parameters (Table 18).

Table 18: *Pearson correlation coefficient among germination performance parameters examined under heat stress in 2014 and 2015 N=270*

	GP	MGT	GRI	GI	SVI	RVI	SDW
GP	1.00						
MGT	0.4**	1.00					
GRI	0.96**	0.32**	1.00				
GI	0.93**	0.29**	0.99**	1.00			
SVI	0.92**	0.26**	0.91**	0.89**	1.00		
RVI	0.90**	0.28**	0.88**	0.84**	0.96**	1.00	
SDW	0.79**	0.22**	0.78**	0.77**	0.85**	0.80**	1.00

For R^2 *P<0.05; **P<0.01; GP: Germination percentage, GI: Germination index, GRI: Germination rate index, MGT: Mean germination index, SVI: Seedling vigour index and RVI: Root vigour index, SDW: Seedling dry weight.

With regards to the findings on drought stress, highly significant difference (p<0.01) was found among germination performance parameters (Table 19). The correlations were high but between germination percentage (GP) and germination rate index (GRI), germination index (GI), seedling vigour index (SVI), root vigour index (RVI), GI and GRI, RVI and SVI only, whereas low, negative correlations were estimated between the mean germination time (MGT) and GRI (R^2= -0.35), GI (R^2= -0.35), SVI (R^2= -0.55), RVI (R^2= -0.51) , and SDW (R^2= -0.26) in both years (Table 19). Average positive correlations were found between SVI and GRI (R^2= 0.67), RVI and GRI (R^2= 0.68) and SVI and GRI (R^2= 0.67), SDW and GP (R^2= 0.48), SDW and GRI (R^2= 0.49) and SDW and SVI (R^2= 0.58), while the remaining was positively low between SDW and GI (R^2= 0.42), SDW and RVI (R^2= 0.41) (Table 19).

Table 19: *Person correlation coefficient among germination performance parameters examined under drought stress in 2014 and 2015 N=270*

	GP	MGT	GRI	GI	SVI	RVI	SDW
GP	1.00						
MGT	-0.38**	1.00					
GRI	0.95**	-0.35**	1.00				
GI	0.90**	-0.35**	0.95**	1.00			
SVI	0.74**	-0.55**	0.67**	0.62**	1.00		
RVI	0.75**	-0.51**	0.68**	0.65**	0.88**	1.00	
SDW	0.48**	-0.26**	0.49**	0.42**	0.58**	0.41**	1.00

For R^2 *P<0.05; **P<0.01; GP: Germination percentage, GI: Germination index, GRI: Germination rate index, MGT: Mean germination index, SVI: Seedling vigour index and RVI: Root vigour index, SDW: Seedling dry weight. SVI: Seedling vigour index and RVI: Root vigour index, SDW: Seedling dry weight.

Discussion

The effect of heat and drought

The germination of all nine sorghum varieties tested was inhibited by both heat and drought (related directly to water/moisture stress), and reflected in seedling growth responses and quantified as seedling dry weight (SDW) and root vigour index (RVI). After seed reserves are exhausted, the size and activity of the young root system plays a major role in determining the rate of early seedling growth and dry matter accumulation (Hoad, Russell, Lucas, & Bingham, 2001). Hence, it can be postulated here that sorghum varieties with a high germination percentage, longer roots, sustained root growth and a large root density have a higher potential to cope with drought and heat stress (Wright & Westoby, 1999; Hameed, & Iqbal, 2010; Kaydan & Yagmur, 2008; Abdul-Baki, 1972).

And indeed, in particular the germination rate index (GRI), root vigour index (RVI), and seedling vigour index (SVI) were very well correlated with overall germination percentage GRI and/or GI underlining concurrently that some varieties tested are more susceptible than others to drought and heat stress at the onset of the growing season.

Overall, the results revealed that the varieties banidoka, CM63E, saba-tienda and seguifa are potentially the more promising varieties able to cope with early season droughts and heat conditions as usually occurs at the onset of the rainy season in the Sahel. In the end, these varieties may also be considered potential candidate parents in breeding programmes screening for drought and heat tolerance. A short and accurate selection could be made on the basis of GRI, GI, RVI and SVI at early growth stage to climate variability and change.

The reasons explaining the varietal differences may lie in the seed reserves and environmental factors that largely determine the initial patterns of germination and seminal root growth (Chachalis et al., 2009). It has been reported also that drought and heat deficits are sensed in particular by plants roots, which begin to synthesize Abscisic acid (ABA) within 1 hour of the onset of the drought and heat stress (Prasad et al., 2008) and next transported via the xylem from the roots to the leaves within minutes or hours after germination. Although it went beyond the scope of this study to measure the

ABA dynamics, it is highly likely that ABA synthesis could explain the monitored varietal differences. Also, it generally is accepted that heat tolerance and drought tolerance often goes hand in hand (Prasad & Staggenborg, 2008). And indeed this was the case with the varieties saba-tienda, CSM63E, banidoka and seguifa but not conclusive for all. Germination and seedling establishment are the end results of a complex and interactive process. Therefore, it often is difficult to identify the separate impact of physiological, morphological, environmental, and/or cultural factors on germination per se. For instance, seed coat, seed size, constituents' such as proteins, seed vigour and seed pre-treatment are known to play an important role in germination under stress conditions (Prasad & Staggenborg).

Drought and heat stress had the highest impact on seedling dry weight (SDW) whilst the MGT was least affected by these two stressors.With regards to the RVI, the findings confirmed the hypothesized varietal differences which offers the farming population in drought and heat prone areas options to cope better with early season drought and heat stress.

From preliminary information provided by the breeders from IER, combined with visual observations saba-tienda seeds are large in size compared to CSM63E, banidoka and seguifa. On the other hand, CSM63E and banidoka have a hard seed coat compared to saba-tienda and seguifa, suggesting thus a higher hurdle for moisture to enter the seed and trigger germination under high temperature and water stress. This was confirmed also by the results of the pot trial (Table 10 &17).

Overall, CSM63E, saba-tienda, banidoka and seguifa ranked among the most promising varieties under heat and drought conditions owing to the high positive correlation between all measured parameters. A negative correlation was observed only between germination time mean germination time (MGT) and GRI (R^2= -0.35), GI (R^2= -0.35), SVI (R^2= -0.55), RVI (R^2= -0.51), and SDW (R^2= -0.26) in both years (Table 19).

Crop physiology and management studies often describe and quantify the changes plant breeders and geneticists have delivered in new germplasm, but rarely address the specific changes needed to advance crop establishment, yield potential, or other agronomic goals (Snape, Butterworth, Whitechurch, & Worland, 2001). The findings of the pot trial may support sorghum breeders in West Africa aiming at screening for early season heat and drought stress with the choice of identifying suitable parents for their breeding programs.

Although it went beyond the scope of this study to identify the causes leading to the significant differences in RVI, numerous indications can be gained from previous studies.

It has repeatedly been stated that both seed reserves and environmental factors largely determine the initial patterns of germination and seminal root growth (Bibi, Sadaqat, Tahir, & Akram, 2012). After seed reserves are exhausted, however, the size and activity of the young root system plays a major role in determining the rate of early seedling growth and dry matter accumulation (Shitole & Dhumal, 2012). In the small grains, primary (seminal) roots develop from the radicle and comprise approximately 5 to 10 percent of the total root volume at full growth. Secondary roots (also referred to as nodal, adventitious, or crown roots) arise from nodes at the stem or tiller base (Bibi et al., 2012).

Results from the heat test have been compared to observations on different plant species and varieties with known drought resistance from field experience. Those with greater field drought resistance also had the highest heat tolerance (Sullivan, Norcio, & Eastin, 1977). Others have also found positive correlations between heat and drought resistance (Bouslama & Schapaugh, 1984; Biesaga-Kościelniak et al., 2014; Myers, Yopp, & Krishnamani, 2011). Use of alternating or fluctuating temperatures may be more appropriate mix for predicting or interpreting field germination and emergence data.

Similar findings were reported by (Murungu & Chiduza, 2004) who noted that smaller seeds may require less water due to less seed volume. The seed coat has an important role to play under stress conditions. An intact seed coat is essential for controlled water uptake and protection from injury to the embryo or other tissues in the seeds (Chachalis et al., 2009; Baskin, 1998). The testa can also decrease levels of solute leakage resulting from seed water uptake and imbibitional damage. A large seed size is widely thought to improve the chances of germination and emergence under a wide range of environments. Seeds with a greater seed weight have furthermore a greater storage reserves and thereby may have increased seed vigour (Copeland & McDonald, 2001). Seed size classes have also shown differences in imbibition, with small flat seeds having a faster rate of water uptake than large round kernels during initial stages of germination (Taylor, 1997; Woodstock, 1988; Copeland & McDonald, 2001). Therefore promising varieties should be subject to further tests such as to identify their potential to react to priming and hence if germination can even be accelerated (see chapter 5) and if the advantages from the germination stage can be translated in higher yields in the end. Extreme environmental stresses will always pose limitations for crop establishment, but continued progress in germplasm screening protocols and crop management research should also lead to new varieties with a tailored set of agronomic practices for given environments and cultural practices.

In studies with pearl millet, large diurnal temperature amplitudes (8°C) and temperatures from 15° to < 42°C accelerated the germination rate. Differences were small relative to comparable average constant temperatures but may be important for seeds germination in field environments.

Conclusions

It has been underlined that drought and heat stress decreases seed germination and hence seedling growth development, which was confirmed with the nine sorghum varieties tested. Yet, the findings underlined as well the direct implications of such differences. On the one hand, the use of promising varieties such as CSM63E, banidoka and saba-tienda could be promoted to the farming population in case a further favorable development is reflected in higher yields. Once promising sorghum varieties with a higher drought and heat tolerance are identified, greater progress can be expected in easing the anticipated food insecurity.

On the other hand, a better understanding of cultivar interactions allows improving the selection and use of a wider range of crop species adapted to challenging field environments. This in turn would offer breeders to include this material in their programs in anticipation of improving their basic plant material for maximum yield in an environment prone to CC&CV. From this point of view, the varieties banidoka, CSM63E and saba-tienda showed superior characteristics and therefore could be recommended as potential candidate parents in breeding programmes for drought and heat tolerance. The breeding programmes could benefit also from the screening procedures and methods applied since in particular the high germination percentage, Germination rate index, root vigour index and seedling vigour index turned out to be rapid indicators reflecting the environmental conditions in the study region. A focus on such parameters would thus become a more cost effective, less time consuming and less laborious procedure to screen germplasm at early stages. It should be noted that good germination performance despite heat and drought stress is a compulsory factor, albeit not the only factor to sustain yields in the study region.

CHAPTER FIVE

ACCELERATING SEED GERMINATION AND SEEDLING DEVELOPMENT OF SORGHUM (*Sorghum bicolor* L. Moench) THROUGH HYDRO-PRIMING IN MALI

Introduction

The farming population in the West African Sahel region experiences frequent droughts during the unimodal rainy season. Especially at the onset of the growing season, this increases the risks of crop establishment. More and more, farmers experience little rainfall amounts to make water available to plants whilst gradually the periods between rainfall events are increasing gradually. High temperatures are common at the onset of the growing season, provoking increased soil evaporation and hence moisture loss, of which 90 - 95% usually occurs in the 5-10 cm topsoil layer, the usual depth for crop sowing (Tian et al., 2014a). Under these conditions, it appears important to improve the germination speed and rate as enable seedlings using as fast as possible any available soil moisture. Seed priming is regarded as one way to increase crop yield under such drought-prone conditions (Abid et al., 2015; Suleiman & Ritchie, 2003).

Seed priming is a pre-sowing treatment that exposes seeds to a certain solution that allows partial hydration, and consequently not a complete germination (Heydecker, Higgins, & Gulliver, 1973). Although the germination is triggered before sowing, the idea of priming is to initiate the metabolic activities that prepare seeds for radicle protrusion (Heydecker et al., 1973; Passam & Kakouriotis, 1994). It has been regularly stated that seed priming can thus accelerate and improve germination and early seedling growth, which is particularly appropriate under the stress conditions occurring at the onset of the season in the Sudan savannah zones of West Africa (Chen & Arora, 2013; Seyed & Khavazi, 2005). Various priming procedures have been developed and most of them aimed at increasing the speed of seed germination (Dell'Aquila, 2009; Finch-Savage & Leubner-Metzger, 2006; Seyed et al., 2005; Tian et al., 2014b), and securing emergence through improved water absorption capacity (Matsushima, Ken-Ichi & Sakagami, 2013).

Well-known priming techniques include (a) hydro-priming where seeds are soaked in a fluid such as water, (b) osmo-priming where seeds are soaked into an osmotic solution such as polyethylene glycol 6000 (PEG-6000), (c) halo-priming where seeds are soaked in salt solutions, and (d) priming with growth-stimulating hormones. The beneficial effects of priming have been demonstrated for various field crops such as maize (Parera & Cantliffe, 1994), and sunflower (Kaya, 2009). Previous findings underscored that the success of seed priming was determined by the complex interactions of plant species, the water potentiality (i.e. water chemical composition) of the priming agent, the duration of priming, temperature, seed vigour and storage conditions of the primed seeds (Parera, & Cantliffe, 1994). Chiu, Chen, and Sung, (2002) emphasized that hydro-priming is the simplest approach to hydrating seeds while concurrently minimizing the use of chemicals. But key is that imbibed seeds show a decreased lag period before radical emergence, which is initially reduced but at the end, improves the rate and uniformity of germination (Farooq et al., 2011; Sharaf et al., 2016). Previous findings underlined further that hydro-priming may improve field emergence and ensure early flowering and harvesting under stress conditions, especially in dry areas (Farooq et al., 2011; Rahimi, 2013). Hydro-priming is therefore a well-recognized means to reduce germination time, get synchronized germination, improve germination rates and better seedling establishment in many crops, including maize, soybean, wheat, lentil, chickpea, mungbean, cowpea, etc. (Farooq et al., 2011). Indeed, by soaking seeds of sorghum, rice, maize and cowpea in water and planting these the same day (presoaking treatment), the germination rate was increased and seedling emergence improved (Harris et al., 2001). Better emergence of seedlings from hydro-primed seeds suggests that proper priming duration can ensure optimum plant establishment of sorghum in the field. Rapid emergence of seedlings could lead to the production of vigorous plants (Ghassemi-Golezani & Mazloomi-Oskooyi, 2012; Maguire, 1962).

In Mali, seed priming experiences are rare and only few research works such as those by (Aune & Coulibaly, 2015; Aune and Ousman, 2011) have been reported. Moreover, these studies were focused on Microdosing based on an application of 0.3 g fertilizer per planting hill which has given a cost-benefit ratio (CBR) well in excess of four in both Sudan and Mali (Aune, Doumbia, & Berthe, 2007; Aune & Ousman, 2011). The CBR can be further increased if it is combined with seed priming, which consists of soaking millet and sorghum seeds for 8 h in water prior to sowing (Aune & Coulibaly, 2015). In the Mopti region of Mali a CBR of 32 was found with microdosing (0.3 g pocket) and seed priming in pearl millet. The gross margin could be doubled through the use of microdosing in Mali (Aune et al., 2007). There is therefore ample evidence that this represents an economically attractive method for farmers. The objective was therefore to assess the hydro-priming effects through seven germination parameters, on nine sorghum cultivars by using different sources of water and priming duration under controlled conditions.

Materials and Methods

The study was conducted in the Agronomy laboratory of the Agricultural Research Station of Cinzana (Longitude: 5° 57’ W, Latitude: 13° 15’ N, and Altitude: 280 m), Institut d’Economie Rurale (IER), Mali. Three out of the nine sorghum cultivars examined were obtained from farmers, the remainders from the IER sorghum breeding program. Banidoka was used as a ckeck (Table 6).

The effect of priming on the nine Sorghum cultivars was assessed by comparing the impact of priming with untreated sorghum seeds (control). The effect of the water sources on priming performance was assessed by comparing the five sources of water including distilled, rain, river, tap and well water. Three different priming durations were compared for heated water. The soaking included 10, 20 and 30 minutes, whilst in the case of the tepid water, the seeds had been soaked for 4, 8 and 12 hours. Seeds were soaked in these water sources which had been treated: either as tepid water at 25 ºC or in water previously heated till 70 ^{o}C.

Evaluation of hydro-priming in tepid water

The effect of priming on the nine Sorghum cultivars in tepid water was assessed by comparing the impact of priming with untreated sorghum seeds (control). The effect of the water source on priming performance was assessed by comparing the five sources of water that farmers in Mali could have access to, including distilled, rain, river, tap and well water. In the case of the tepid water priming, the seeds had been soaked for 4, 8 and 12 hours. Hence, each of the seeds of the 9 Sorghum varieties was subjected to 40 different priming treatments. There was a control treatment where no priming was carried out for each variety. An illustration of hydro-priming treatment combination is shown in Table 20.

Evaluation of hydro-priming in hot water

The effects of hydro-priming on the performance of nine variety of sorghum were evaluated. The water used was from the same five sources mentioned above. The water used was boiled to 70 ºC before use. Seeds were submerged in warm water for duration of 10, 20 and 30 minutes before sowing (Table 20). Each seed treatment was soaked in an open contenant about 125 ml and kept at room temperature for the duration of the priming.

Prior to the implementation of the soaking treatments, all seeds had been surface-sterilized with 5% sodium hypochlorite (NaOCl) for 5 minutes to avoid fungal infections. This treatment was followed by washing, with distilled water, which occurred twice to wash away the chemicals (Basra et al., 2003).

Table 20: *Hydro-priming treatment combinations*

Water sources	Duration (min.) of seed submergence in hot water at 70 ºC				Duration (hr.) of seed submergence in water at room temperature (25 ºC)		
	(0)	10	20	30	4	8	12
Distilled	X	X	X	X	X	X	X
Rain	-	X	X	X	X	X	X
River	-	X	X	X	X	X	X
Tap	-	X	X	X	X	X	X
Well	-	X	X	X	X	X	X

Twenty-five of these pre-treated seeds of each variety were placed in a 9-cm diameter Petri dish on two Whatman filter papers that had been moistened at the time of sowing and on the fourth day after sowing with 3 ml of water obtained from each of the five sources (Table 20). The seeds of the control were moistened with 3 ml distilled water at the onset and at the 4th day after sowing. All seeds were kept in a germinator. The temperature of both the germinator and room were recorded daily. A factorial arranged completely randomized design with three replications was used to assess the impact of the priming treatments through keys parameters as previously cited (Table 7).

Statistical analysis

The data were analyzed through the analysis of variance (ANOVA) using GenStat nine edition version 9.2.0 (2007). The data were checked for normal distribution before being subjected to ANOVA. The means of germination percentage, mean germination time, germination rate index, germination index, seedling vigour index, root vigour index and seedling dry weight were compared with treatments of the nine sorghum varieties, water sources (6 levels) soaking duration in tepid water (4 levels) and in hot water (4 levels). Multiple comparisons among treatments means were considered significantly different at $p \leq 0.05$. The Fisher's Protected Least Significant Difference (LSD) was used for the mean separation. Samples of each water source were sent for chemicals analysis in the laboratory in 2014 and 2015. Means values of the two years were used for comparison.

Results

Chemical composition of various sources of water

Water chemical composition varied according to various sources. In general highest concentration was found in river and well water followed by tap, rain and distilled water respectively (Figure 9) The pH was high in river (7.7) and well (7.2) water, while lower in tap (6.5), rain (6.7) and distilled (6.7). Water is a basic requirement for germination. It is essential for enzyme activation, breakdown, translocation, and use of reserve storage material (Shaban, 2013). Every enzyme shows maximum activity at an optimum pH. Their activity is slow above or below the optimum pH. Enzymes have active sites where the substrates bind. These active sites are damaged or in other words their shape is changed by changing the pH. Substrates no longer fit the active site and the reaction does not occur. A pH of about 7 is the optimum and as the pH moves further away from the optimum pH the enzyme activity starts to slow down.

The total disolved solid (TDS) influence pH level towards alkalinity and was higher in well (139.7 mg L^{-1}), river (82.9 mg L^{-1}) while was low in rain (13.0 mg L^{-1}) and distilled water (8.9 mg L^{-1}). The concentration of Calcium carbonate was high in well and river water lower in rain and distilled water. The highest concentration of calcium was found in well (17.5 mg L^{-1})

followed by river water (8.5 mg L^{-1}) the remaining was low. The Bicarbonate (HCO_3) concentration was also higher in well (77.5 mg L^{-1}) and river water (46.9 mg L^{-1}) (Table 21). Micronutrients copper and zinc were slightly present only in rain water which suggests the side effect on seed growth parameters. The presence of these micronutrients seems to inhibit seed germination and growth parameters which go beyond the scope of this study (Table 21).

Table 21: *Chemical composition of various water sources*

Parameters	Distilled	Rain	River	Tap	Well
pH	6.7	6.7	7.7	6.5	7.2
$CaCO_3$ (mg/l)	2.0	3.5	38.5	16.0	63.5
TDS (105ºC) (mg/l)	8.9	13.0	82.9	61.6	139.7
Calcium, Ca^{2+} (mg/l)	0.5	0.5	8.5	2.8	17.5
Magnesium, Mg2+ (mg/l)	1.0	0.9	4.1	2.6	4.7
Sodium, Na+ (mg/l)	0.2	0.2	3.4	3.3	7.3
Potassium, K+ (mg/l)	0.3	0.7	2.7	1.4	8.3
Bicarbonates, HCO_3 (mg/l)	2.6	4.4	46.9	19.1	77.5
Sulphates, SO4 $^{2-}$ (mg/l)	0.6	0.9	5.2	3.4	2.3
Chlorine, Cl^{-} $^{(}$mg/l)	0.3	0.3	2.5	2.6	1.9
Nitrates, NO_3- (mg/l)	0.1	0.1	0.9	1.2	0.6
Copper, Cu^2+ (mg/l)	0.0	0.1	0.0	0.0	0.0
Zinc, Zn (mg/l)	0.0	0.1	0.0	0.0	0.0

Values are means for chemical composition in 2014 and 2015

Effect of tepid hydro-priming on seed germination and seedling gowth parameters

Germination percentage (GP)

The GP was significantly affected by varieties in tepid water *(p*=0.01), while water sources, priming duration and their interaction were not significant different on germination percentage (Table 22). Among varieties, CMS63E, banidoka, followed by saba-tienda and seguifa were statistically higher and different from others varieties in tepid water (Table 22) while tiandougou was significantly different from nieleni, sewa, tiandougou-coura and saba-soto.

Mean germination time (MGT)

The effect of tepid water on mean germination time of varieties (*p*<0.01), water sources (*p*<0.01), priming duration (*p*<0.01) were significant. No significant interaction was found among varieties x water sources x priming duration (Table 22). Lower values of MGT, which refer to an increase of germination speed, were observed in tepid hydro-priming. Among different water sources, tepid (25 ºC) significantly improved the mean germination time compared to the unprimed (Table 22). Priming duration in 12 hour revealed that mean germination time was reduced in all water sources compared to the control and 8 hours (Table 22). Analysis in deep showed that different water sources revealed that varieties respond differently while all water sources significantly improved mean germination time compared to control (Table 22).

Germination rate index (GRI)

Highly significant differences in GRI were found among varieties (*p*<0.01), water sources (*p*<0.01) and priming duration treatments (*p*<0.01). No significant interaction was found among their interaction. The highest GRI was observed with CSM63E (98.5 %/day) and banidoka (96.2%/day) followed by saba-tienda (92.5%/day) and seguifa (91.6%/day). Varieties nieleni, sewa, saba-soto and tiandougou-coura were not significantly different among them but were different from tiandougou (Table 22). Among different water sources, tepid (25 ºC) significantly improved the germination rate index compared to the unprimed (Table 22). Priming duration in 12 hours increased germination rate index in all water sources compared to the control and 8 hours (Table 22).

Germination index (GI)

Significant differences in GI were found among varieties (*p*<0.01), water sources (*p*<0.01) and priming duration (*p*<0.01) in tepid water (Table 22). The highest GI was observed with CSM63E (882) and banidoka (850) followed by saba-tienda (815.5) and seguifa (801.5) (Table 22). Nieleni was not significantly different from sewa but significantly different from tiandougou, saba-soto and tiandougou-coura in tepid water (Table 22).

All water sources in tepid (25 ºC) significantly improved the germination index compared to the unprimed (Table 22). Priming duration in 12 hours increased germination rate index in all water sources compared to the control and 8 hours (Table 22).

Table 22: *Effect of tepid water priming at different durations and with water from different sources on seed germination and other growth parameters of nine varieties of sorghum*

Treatments	Growth parameters						
Variety	GP	MGT	GRI	GI	SVI	RVI	SDW
Banidoka	99.0	4.6	96.2	850.1	974.9	532.7	0.13
CSM63E	99.2	4.5	98.5	882.5	1067.1	436.0	0.12
Nieleni	87.2	4.6	84.0	735.8	434.5	268.2	0.07
Saba-soto	82.1	4.7	78.3	674.8	456.5	230.1	0.10
Saba-tienda	94.8	4.6	92.5	815.5	766.4	467.1	0.10
Seguifa	94.8	4.6	91.6	801.5	669.6	455.6	0.11
Sewa	84.9	4.6	81.8	716.1	502.2	293.8	0.08
Tiandougou	91.6	4.6	89.1	785.6	598.8	363.0	0.09
Tiandougou-coura	85.2	4.7	81.1	706.2	344.1	186.4	0.07
P-values	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	2.50	0.04	2.90	28.80	103.20	63.20	0.01

Table 22 continuted

Water sources							
Control	91.0	4.7	85.1	730.1	507.0	278.1	0.08
Distilled	90.1	4.6	87.6	771.6	730.4	402.5	0.10
Rain	90.1	4.6	88.1	779.7	522.6	288.0	0.08
River	91.2	4.6	89.2	787.5	769.1	434.2	0.10
Tap	91.0	4.6	89.6	790.5	636	351.2	0.10
Well	91.6	4.6	89.2	786.1	710.9	401.2	0.11
P-values	0.40	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD		0.03	2.30	23.50	84.20	51.60	0.01
Priming duration (hr.)							
4	90.7	4.6	87.0	759.5	533.4	306.8	0.08
8	90.7	4.6	87.8	770.8	654.1	352.9	0.11
12	91.5	4.5	89.6	792.4	764.8	426.2	0.10
P-values	0.40	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD		0.02	1.70	16.60	59.60	36.50	0.01
P-values for variety x water sources	1.00	1.00	1.00	0.99	1.00	0.99	0.18
P-values for variety x duration	0.80	0.70	0.90	0.97	0.47	0.57	0.05
P-values for water x duration	0.50	0.90	0.50	0.63	0.04	0.04	0.23
P-values for variety x water x duration	1.00	1.00	0.28	0.27	0.54	0.99	0.54

LSD values at $p \leq 0.05$ GP: Germination percentage, MGT: Mean germination time, GI: Germination index, SVI: Seedling vigour index, RVI: Root vigour index, SDW: Seedling dry weight.

Seedling vigour index (SVI)

Effect of hydro-priming with tepid water on seedling vigour index (SVI) as a function of seedling length and germination percentage was also significantly affected by varieties (*p*=0.01), water sources (*p*=0.01), and priming duration (*p*=0.01), in tepid water (Table 23). There was significant interaction in tepid water sources and priming duration (*p*<0.04) on seedling vigour index but no significant (Table 23).

Table 23: *Seedling vigour index of 5 water sources under different priming duration*

Water sources	Priming duration (hr.)			Mean SVI for water sources
	4	8	12	
Control	335.4	509.8	675.7	507.0
Distilled	626.4	731.9	833.1	730.5
Rain	507.6	482.5	577.7	522.6
River	696.5	728.3	882.5	769.1
Tap	513.2	722.3	672.4	636.0
Well	506.0	716.5	910.4	710.9
Mean SVI for priming duration	530.8	648.6	758.6	
	P-value	SED	LSD	
Water sources	<0.01	42.9	84.2	
Priming duration	<0.01	30.3	59.6	
Water sources x priming duration	0.04	74.3	145.9	

P-VALUE at p≤0.05, SED: Standard errors of differences of means, LSD: Least significant differences of means.

There was no interaction effect on varieties x priming duration and varieties x water sources x priming duration. Increase of priming duration increase seedling vigour index. Among varieties, the maximum SVI was observed with CSM63E, Banidoka, Seguifa and Saba-tienda which were statistically different from others varieties in tepid water (Table 23). Saba-soto recorded the lowest SVI value (230.1), which was not statistically different from nieleni, sewa and tiandougou-coura in tepid water (Table 23). With different water sources, the maximum SVI was observed in distilled, river and well water, which were statistically equal. Tap water was not significantly different from well water but distilled, river, tap and well water sources significantly increased SVI compared to rain water and the unprimed seed treatment However, the water sources did induce statistical differences (Table 23).

With different priming duration in tepid water at 4, 8 and 12 hours, with an increase of priming duration, this trait has shown a sharp significant improvement in comparison to control (Table 23). The highest SVI was recorded with 12 hours (SVI of 764.8) followed by 8 hours (SVI=654.1) and when soaked at 4 hours (553.4) in tepid water.

Root vigour index (RVI)

Root vigor index (RVI) as a function of root length and germination percentage was also significantly affected by varieties (p=0.01), water sources (p=0.01), and priming duration (p=0.01) in tepid water. Significant difference was found between tepid water sources and priming duration (p<0.04) but no interaction was found with varieties x priming duration and varieties x water sources x priming duration. The maximum RVI was observed with variety banidoka. Varieties saba-tienda, seguifa and CSM63E, were not different but statistically different from other varieties in tepid water (Table 24). In tepid water, varieties respond differently.

The maximum RVI was observed in distilled, river and well water, which were statistically equal. Tap water were not significantly different from distilled and well water but except rain water the remaining water sources improved RVI compared to unprimed seeds. Rain water was not significantly different from the control in tepid water study.

Priming duration in tepid water at 4, 8 and 12 hours, with an increase of priming duration this trait has shown a significant improvement in comparison to control (Table 24). The highest RVI was recorded with 12 hours (RVI of 426.2) statistically different from other priming duration, followed by 8 hours (RVI=352.9) and when soaked at 4 hours (306.8) in tepid water (Table 24). Interaction effects of water sources treatment × priming duration on root vigour index were significant. Distilled, river and well in duration 12 hour showed the highest impact on root vigour index (Table 24).

Seedling dry weight (SDW)

Significant differences in SDW were found among varieties (p<0.01), water sources (*p*<0.01) and priming duration (*p*<0.01). There was significant interaction effect of varieties and priming duration (*p*<0.05) on SDW. Average seedling dry weight was significantly higher in banidoka and CSM63E. SDW significantly increased with increase of priming duration (Table 25).

Table 24: Root vigour index of 5 water sources under different priming duration in tepid water

Water sources	Priming duration (hr.)			Mean RVI for water sources
	4	8	12	
Control	188.3	277.8	368.2	278.1
Distilled	362.7	375.4	469.4	402.5
Rain	286.7	267.9	309.5	288.0
River	400.7	395.5	506.4	434.2
Tap	292.2	398.0	363.3	351.2
Well	300.8	382.2	520.5	401.2
Mean RVI for priming duration	305.2	349.5	422.9	
	P-value	SED	LSD	
Water sources	<0.01	26.3	51.6	
Priming duration	<0.01	18.6	36.5	
Water sources x priming duration	0.04	45.5	89.3	

P-VALUE at p≤0.05, SED: Standard errors of differences of means, LSD: Least significant differences of means.

There was no difference between priming duration 8 and 12 hour. There was no interaction found with varieties x water sources, water sources x priming duration and varieties x water sources x priming duration (Table 25). In tepid water, the highest SDW was observed with banidoka (0.12 g) and CSM63E

(0.12 g), which was however statistically not different from the SDW of seguifa (0.11 g). Varieties saba-soto and saba-tienda (0.10 g) were not significantly different from seguifa (Table 25). The lowest SDW was observed with Nieleni and Tiandougou-coura (0.07 g).

All water sources except rain water significantly improved SDW compared to unprimed (Table 25) Distilled, river, tap and well water were statistically equal in performance on SDW. Rain water was not statistically different from control. Priming duration in tepid water, 8 hours recorded the highest SDW (0.11 g/plant) which was statistically different from 4 and 12 hours soaking. Priming duration from 4 hour was not statistically different to the control (Table 25). The optimum priming duration is 8 hours, when incrasing after 8 hours the seedling dry weight decrease. Significant interaction was found between varieties x priming duration, suggesting differencial responses to priming duration.

Table 25: *Seedling dry weight of 9 varieties of sorghum sown under different priming duration in tepid water*

Variety	priming duration (hr.) 4	8	12	Mean SDW for varieties
Banidoka	0.11	0.13	0.14	0.13
CSM63E	0.11	0.13	0.10	0.12
Nieleni	0.06	0.07	0.06	0.07
Saba-soto	0.10	0.12	0.08	0.10
Saba-tienda	0.08	0.11	0.10	0.10
Seguifa	0.08	0.12	0.12	0.11
Sewa	0.08	0.09	0.07	0.08
Tiandougou	0.07	0.10	0.10	0.09
Tiandougou-coura	0.05	0.08	0.08	0.07
Mean SDW for priming duration	0.08	0.11	0.10	
	P-value	SED	LSD	
Varieties	<0.01	0.01	0.01	
Priming duration	<0.01	0.01	0.01	
Varieties x priming duration	0.05	0.01	0.02	

P-VALUE at p≤0.05, SED: Standard errors of differences of means, LSD: Least significant differences of means.

Effect of hot hydro-priming on seed germination and seedling gowth parameters

Germination percentage (GP)

Varieties (*p*<0.01), water sources (*p*<0.01) were significant in hot water on germination percentage (Table 26). There was no significant interaction effect on germination percentage. Saba-soto, tiandougou and tiandougou-coura recorded the lowest GP in hot water; the highest was recorded in CSM63E, banidoka, saba-tienda and seguifa (Table 26) in hot water at 70 ºC. Sources of water did significantly influence seed germination percentage. The highest germination was recorded in control water at 70 ºC did not increase germination percentage, suggesting an inhibition of some enzymes needed for germination (Table 26).

Mean germination time (MGT)

Significant difference was found in varieties ($p<0.01$).There was no signifiant effect of hydro-priming at 70 ºC on mean germination time with water sources, priming duration and all interactions (Table 26). Varieties CSM63E, banidoka and saba-tienda (4.5 days) showed reduced mean germination time compared to Nieleni, Saba-soto, Seguifa, Sewa, Tiandougou and Tiandougou-coura (4.6 days). The highest MGT was recorded in saba-soto (4.7 days). Varrieties respond differently to heated water sources at 70 ºC (Table 26).

Table 26: *Effect of water priming at different durations and with water from different sources on seed germination and growth parameters of nine varieties of sorghum in hot water*

Treatments	Growth parameters						
Variety	GP	MGT	GRI	GI	SVI	RVI	SDW
Banidoka	98.3	4.5	488.3	453.6	537.0	226.0	0.10
CSM63E	98.3	4.5	485.6	457.0	582.0	292.7	0.07
Nieleni	83.2	4.6	427.3	349.7	267.9	130.9	0.06
Saba-soto	77.8	4.7	457.0	239.0	210.0	80.6	0.06
Saba-tienda	90.9	4.5	426.7	408.6	423.5	219.5	0.05
Seguifa	92.1	4.6	454.1	399.7	306.9	168.2	0.06
Sewa	85.4	4.6	460.0	331.2	268.9	128.5	0.06
Tiandougou	78.7	4.6	438.0	277.7	158.1	79.4	0.03
Tiandougou-coura	78.2	4.6	461.2	241.0	147.3	63.0	0.03
P-values	<0.01	<0.01	0.96	<0.01	<0.01	<0.01	<0.01
LSD	4.1	0.03	111.5	101.0	92.6	48.8	0.01
Water sources							
Control	91.6	4.6	451.5	390.9	237.2	122.7	0.04
Distilled	86.0	4.6	456.6	340.4	343.9	158.3	0.06
Rain	81.5	4.6	449.4	301.0	239.6	109.3	0.05
River	85.8	4.6	453.9	334.3	397.6	185.3	0.07
Tap	87.6	4.6	458.1	362.8	374.2	181.9	0.07
Well	89.5	4.6	462.8	375.7	342.0	168.4	0.06
P-values	<0.01	0.80	1.00	0.31	<0.01	<0.01	<0.01
LSD	3.3	0.03	91.0	82.4	75.6	39.9	0.01

Table 26 continued

Priming duration (min.)							
10	87.3	4.6	449.4	353.9	206.3	101.9	0.05
20	87.1	4.6	459.2	350.9	350.6	170.7	0.06
30	86.6	4.6	457.5	347.8	410.3	190.3	0.06
P-values	0.83	0.33	0.95	1.0	<0.01	<0.01	0.01
LSD	2.4	0.02	64.4	58.3	53.4	28.2	0.01

LSD values at $p \leq 0.05$ GP: Germination percentage, MGT: Mean germination time, GI: Germination index, SVI: Seedling vigour index, RVI: Root vigour index, SDW: Seedling dry weight.

Germination rate index (GRI)

No signifiant difference was found in hydro-priming at 70 ºC on germination rate index with varieties, water sources, priming duration and their interaction (Table 26).

Germination index (GI)

There was significant effect varieties ($p<0.01$) on germination index. No signifiant difference was found in hydro-priming at 70 ºC on germination index with water sources, priming duration and their interaction (Table 26). Varieties CSM63E, banidoka, saba-tienda and seguifa were significantly higher compared to nieleni and sewa but were not significantly different from saba-tienda and seguifa. Varieties saba-soto and tiandougou-coura showed the lowest GI. Varieties responded differently to different sources of hot water at 70 ºC (Table 26).

Seedling vigour index (SVI)

Significant difference was found in varieties ($p<0.01$), water sources ($p<0.01$) and priming duration ($p<0.01$). There was no significant effect hydro-priming at 70 ºC on seedling vigour index. Varieties CSM63E and banidoka recorded the highest SVI while the lowest was found in tiandougou and tiandougou-coura (Table 26). Except rain water, the others water sources increased SVI when heated at 70 ºC compared to unprimed control. Rain water was not significantly different from control suggesting low pH and high temperature which could influence some enzymes needed at seed germination (Table 26). Higher significant effect of SVI was observed in priming duration 30 mn (410.3), followed by priming duration 20 mn (350.6) and 10 mn (206.5). There was an increase of Seedling vigour index when the when priming duration increased in water at 70 ºC.

Root vigour index (RVI)

Significant difference was found in varieties (p<0.01), water sources (p<0.01) and priming duration (p<0.01) on root vigour index. There was no significant interaction of hydro-priming at 70 ºC on root vigour index. Varieties CSM63E, banidoka, and saba-tienda recorded the highest RVI while the lowest was found in tiandougou and tiandougou-coura (Table 26). Varieties nieleni, sewa and seguifa were not signifantly different but were statistically different from tiandougou and tiandougou-coura. River, tap and well water at 70 ºC were significantly different from rain water but were not significantly different from distilled water. Distilled and rain water were not significant different from the unprimed control. Priming duration increased RVI from 10 to 20 mm. There was no significant effect of priming duration 20 and 30 mn in water at 70 ºC (Table 26).

Seedling dry weight (SDW)

The seedling dry weight significantly varied with varieties (p<0.01), water sources (p<0.01) and priming duration (p<0.01) in water at 70 ºC. There was no significant interaction of hydro-priming at 70 ºC on seedling dry weight (Table 26). Varieties CSM63E and banidoka, recorded the highest SDW while the lowest was found in varieties nieleni and tiandougou-coura (Table 26). Varieties nieleni, saba-soto, sewa and seguifa were not signifantly different but were statistically higher compared to tiandougou and tiandougou-coura (Table 26). All water sources significantly improved seedling dry weight compared to unprimed control in water at 70 ºC. Distilled, river, tap and well water were significantly different from rain water which was also different from unprimed control (Table 26). Priming duration of 10, 20 and 30 mn in water at 70 ºC increased seedling dry weight compared to unprimed control. Priming duration 20 and 30 mn was significantly higher than 10 mn soaking in water 70 ºC (Table 26), but which was not statistically different between themselve. Seed primed in water at 70 ^{o}C during 10, 20 and 30 minutes was not significantly different from tepid water, suggesting that hydro-priming in tepid or water at 70 ºC lead to similar seed germination levels. Overview of assessment parameters affected by water sources, priming duration and varieties, in tepid and water at 70 ^{o}C.

Discussion

Given that water through interacting with all the components of natural landscape and being influenced by natural and man-made factors, is enriched by a wide gamut of various substances in gaseous, solid and liquid states, this creates an enormous variability of natural water types from the perspective of their chemical composition (Nikanorov et al., 1989). In terms of varieties performance, varieties banidoka and CSM63E were the best in either hydro-primed in tepid water (25 ºC) or heated water at 70 ºC followed by saba-tienda mainly in tepid water (25 ºC). With regards of priming duration in water heated at 70 ºC 30 minutes recorded the higest effect compared to others treatments on SVI, RVI and SDW.

Compared to the unprimed treatment (control), the germination percentage, germination time, germination rate index, germination index, seedling vigour index, seedling root index and seedling dry weight increased considerably after sorghum seeds has been primed with different sources of water. The findings showed that the improvements of germination and seedling growth as expressed by all monitored parameters, were reduced when soaked in rain water for most of the parameters including SVI, RVI, SDW etc. (Table 22, 24 & 26).

Natural water is a dynamic chemical system containing in its composition a complex group of gases, mineral organic substances in the form of true solutions, and suspended and colloidal matter as well (Nikanorov & Brazhnikova, 1989). The differences in their composition explain why sorghum seed priming with various sources/types of water influenced differently the seed germination performance. Indeed, after eight days, remarkable differences were observed for seed germination and seedling growth of CSM63E, banidoka, saba-tienda and seguifa. Germination and early seedling establishment are critical stages, which can affect both quality and seedling growth parameters (Yanrong, Jianquan, Huixia, & Xiaowen, 2003). This is suggesting some inhibition effect on seed and seedling growth parameters. Due to their imbibition in water solutions, seeds benefit from permanent and sufficient moisture thus take short time to germinate; however, non-primed seeds have to expect from soil moisture for their imbibition, which may lead to longer time for their germination if soil moisture is not suffisant. This explains the increased germination performance with the hydro-priming technique (Imtiaz, Tunio, & Rajpar, 2013).

It is evident that hydro-primed seeds exhibit activation of cellular defense responses, due to which they can better tolerate subsequent biotic or abiotic stresses in the field (Nakaune et al., 2012). Seed priming enhances speed and uniformity of germination (Khalil et al., 2010), extend many biochemical modification which are basically needed for starting germination process viz. dormancy breaking, hydrolysis, enzyme creation and seed imbibition (Nakaune et al). Thus, seed priming could contribute to facilitating emergence phage with vigorous root and shoot of sorghum which is very important at the beginning of rainy season in the Sahelian zone. A deep and thick root system is helpful for extracting water from considerable depths (Tekle & Alemu, 2016). Similar findings have been reported on the improved germination of sunflower cultivars through accelerated imbibition by seed priming (Farahani, Moaveni, & Maroufi, 2011).

Seed priming significantly increased a series of seedling performance parameters such as the GP, MGT, GRI, GI, SVI, RVI and SDW of sorghum. The improvement of these parameters might be due to the fact that the seeds soaked in water had rapid translocation of nutrients after hydrolysis of the cotyledon reserves to growing seedling. Also, primed seed known to be closely associated with their high imbibition rate and mtDNA damaged reparation, which could be the reason for the increased germination percentage. When compared with different sources of water, distilled, river, tap and well water of all duration showed greater influence on final germination percentage seedling development. River and well water showed high influence on seed and seedling growth parameters suggesting favorable pH at germination (Carter et al., 2004). During seed germination, various stored substrates are reactivated, repaired if damaged, and transformed into new building materials necessary for the initial growth of the embryo, its subsequent growth, and seedling establishment in its natural habitat (Koller & Hadas, 1982).

The improvement in seed germination and seedling development due to seed priming treatment is in line with previous research work (Basra, Farooq, & Tabassam, 2005; Murungu, et al., 2004. Also, Yanrong et al., (2003) reported that both fresh and hot water primed seeds showed significant increase in germination performance.

As far, we know it is the first time in Mali that physicochemical composition of well water can boost sorghum seedling germination and development. The results show also that tepid hydro-priming treatment was comparatively superior to heated at 70 ºC in seedling vigour index and root vigour index among all water sources applications. These findings are in agreement with previous studies (Ashraf & Foolad, 2005; Ghassemi-golezani, Chadordooz-jeddi, & Zafarani-moattar, 2011; Koller & Hadas, 1982). Several researchers reported the positive effect of hydro-priming on seedling emergence rate, seedling establishment, early vigour, and the faster development of the seedling (Kibite & Harker, 2011).

Various seed priming techniques using different sources of water and either tepid or water heated at 70 ºC can significantly improve seed germination and seedling plant development of sorghum varieties, although the overall response varied with the different sources of water, priming duration and varieties. All the water sources improved seed germination and seedlings growth parameters compared to control, but well, distilled, river and tap water were better than rain water which suggest presence of some element such as Cu and Zn which inhibit seed germination and growth (Table 21).

Conclusions

The results indicated that seed germination and seedling growth parameters of sorghum varieties were affected by tepid water and hot hydro-priming with various water sources and priming durations. Tepid or hot water increased seed germination percentage, mean germination time, seedling growth rate, seedling vigour index, roots vigour index and seedling dry weight compared to the unprimed control. Our results showed that hydro-priming in tepid or hot water is an effective technique to improve seed germination and seedling growth parameters. River and well water sources were the most promising sources in this study. The 8 hours priming duration with fresh water is the most promising option, although seeds have to be immediately sown to benefit from the hydrated effect. The promising duration in hot water was 30 minutes which have significantly impacted germination percentage, mean germination time and germination rate index. When immediate sowing is possible, tepid or hot hydro-priming of sorghum seed is recommended as an effective way to reduce risk of crop failure regularly resulting from the unpredictable rainfall situation in Mali. Varieties banidoka, CSM63E and saba-tienda could be recommended in an integrated drought and heat management option for crop establishment failure in Semi-arid zone of Mali.

CHAPTER SIX

EFFECT OF OSMO-PRIMING ON SEED GERMINATION AND SEEDLING DEVELOPMENT OF SORGHUM (*Sorghum bicolor* L. Moench) IN MALI.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the most important staple crop in the world and the second most important in West Africa after Maize in term of the total cereal land coverage (FAO, 2015). It is widely used for feed and industrial raw material. It is also a C_4 crop, which has a potential to adapt to the weather variability and change, where the climate is a combination of high temperature and irregular rainfall. Rapid and uniform crop emergence is an important factor to achieve high yield under climate variability and change, especially in Mali agro-systems.

Many research studies have demonstrated that under drought stress conditions, seeds osmo-primed with chemicals such as calcium chloride ($CaCl_2$), potassium chloride (KCl), potassium dihydrogen phosphate (KH_2PO_4), polyethylene glycol-6000 (PEG-6000) and potassium silicate (K_2SiO_3) are effective in improving germination, emergence, and seedling establishment of several crops, including rice (*Oryza sativa*) (Chen & Arora, 2013), groundnut (*Arachis hypogaeas*), onion (*Allium cepa*), wheat (*Triticum aestivum*), and sunflower (*Helianthus annus*) (Chen & Arora, 2013; Chen, Zhou, Guo, & Shen, 2007; Farooq, et al., 2006). Similarly, several studies reported silicon (Si) to be an agronomically important fertilizer element that enhances plant tolerance to abiotic stresses such as drought (Vinocur & Altman, 2005). Indeed, silicon is known to increase drought tolerance in plants by maintaining plant water balance, erectness of leaves and structure of xylem vessels under high transpiration rates caused by high temperature and moisture stress (Kobayashi et al., 2005). In the case of sorghum in Mali, most studies focused on soil fertility but mostly on length of cropping cycle of varieties (e.g. short cycle varieties), resistance to pests and diseases (striga, fungi), etc. (Kouyate & Wendt, 1991). However, studies on the use and rates of these chemicals to improve germination and seedling establishment through osmo-priming of sorghum seeds are rare (Basra, et al., 2003).

It is therefore hypothesized that under the context of climate variability with frequent severe droughts in the Sahelian zone of Mali, osmo-priming seed with chemicals could be a good alternative to reduce risk of seed germination and emergence. Indeed, PEG-6000 could reduce the time of imbibition required for the onset of RNA and protein synthesis and polyribosome formation (Khan, Peck, & Samimy, 2013). This may increase the total amount of RNA and protein and enhance speed and uniformity of germination. Similarly, seed primed with $CaCl_2$ may improve percentage seed germination and field establishment, increase free proline accumulation which is an adaptive mechanism of drought tolerance (Cellier, Conéjéro, Breitler, & Casse, 1998). According to Rastin, Madani, and Shoaei, (2013) soaking of seeds in KH_2PO_4 solution significantly increased the germination speed, daily mean germination; shoot length, root length, seedling vigour index of groundnut, which constitute an advantage in early drought spell conditions. Also, seed primed with KCl can increase seed germination speed and uniformity of wheat under dryland conditions. Potassium silicate is a source of highly soluble potassium and silicon. Seed soaked inpotassium silicate could increase yield under dry land condition (Ahmed, Fayyaz-ul-Hassen, Qadeer, & Aslam, 2011; Ahmed, Qadeer, & Aslam, 2011; Sahib, Hamzah, & Hussein, 2013). This research aimed to evaluate the effect of chemicals type at different concentrations on sorghum seeds germination and seedling growth.

Materials and Methods

Experimental design and data collection

The experiment was carried out in the Agronomy laboratory of the Agricultural Research Station of Cinzana, Institut d'Economie Rurale (IER), Mali, during 2014 and 2015 dry seasons. In total 5 different chemicals were used in this experiment. The first three chemicals had the same concentration i.e Control (0), low (50 ppm), intermediate (100 ppm) and high (200 ppm) namely for $CaCl_2$, KCl, and KH_2PO_4, while the remaining two chemicals: K_2SiO_3 and PEG-6000 had also the same level of concentration respectively viz, control (0), low (100 ppm), intermediate (200 ppm) and high (300 ppm), were used to test nine sorghum cultivars. The control treatment was not treated with any of chemicals while the seeds of the others were treated with the five chemicals (Table 27).

Table 27: *Osmo-priming media and their concentrations*

Chemicals treatments	Concentrations (ppm)			
	Control	Low	Intermediate	High
$CaCl_2$	0	50	100	200
KCl	0	50	100	200
KH_2PO_4	0	50	100	200
K_2SiO_3	0	100	200	300
PEG-6000	0	100	200	300

Prior to their soaking, all seeds were surface-sterilized with 5% sodium hypochlorite (NaOCl) for 5 minutes to avoid fungal infection. This treatment was followed by a two-time washing with distilled water (Basra et al., 2003). Then 25 seeds of these pre-treated seeds were placed on two Whatman filter papers in a 9-cm diameter Petri dish. The seeds were soaked in 125 ml pot aerated solutions of the given concentration of each used chemical for 4 h. The ratio of seed weight to solution volume was 1:5 (g/mL) (Basra et al). After setting in the petri dish, seeds were moistened with 3 ml distilled water at the onset and at the 4th day with 3 ml of distilled water for all treatments. All seeds were kept in a germinator, placed in the dark and kept at a temperature between 25-30±2 ^{o}C. The overall experiment was set as a factorial completely randomized block design in a nested concentration to chemicals arrangement with three replications. The impact of the priming treatments was assessed through monitoring the key parameters listed in Table 7.

Data analysis

The data analyzed using the analysis of variance (ANOVA) using GenStat nine edition version 9.2.0 (2007). The mean germination percentage, germination time, germination rate index, germination index, seedling vigour index, root vigour index and seedling dry weight were compared among the nine sorghum varieties, and the nested concentrations to chemicals types. Treatments means were considered significantly different at $p \leq 0.05$. The Fisher's Protected Least Significant Difference (LSD) procedure was used for the mean separation.

Results

Effect of osmo-priming on seed germination and growth parameters

Germination percentage (GP)

Significant differences (p=0.01) were observed among varieties for GP. There was no significant effect of chemicals treatment and their interaction on germination percentage (Table 28). Varieties CSM63E (99%) and banidoka (99%) showed the highest germination percentage and statistically different from others varieties seguifa, tiandougou and saba-tienda followed the first two highest germination percentage but were not significantly different from the control. The lowest percentage, of 84.70%, was recorded by tiandougou-coura. Sewa, saba-soto, and nieleni were also not statistically different for the GP (Table 28).

The chemicals treatments were not statistically different for germination percentage (Table 28). However, KH_2PO_4 50 ppm (GP=92.4%), $CaCl_2$ 100 ppm (GP=92.0%) and KH_2PO_4 100 ppm (GP=91.9%) recorded the highest GP (≈92%), followed by K_2SiO_3 200, 100 ppm (GP=91.2%) and PEG-6000, 100 ppm (≈91%) (Table 28). A continuous decline for KH_2PO_4 and PEG-6000 was observed. Constant to the intermediate concentration followed by a decline.

Mean germination time (MGT)

Significant differences in MGT were observed among varieties (p=0.01) on mean germination time. There was significant effect of chemical treatments (p=0.01) on mean germination time (Table 28). The decrease in mean germination time was important in CSM63E, banidoka, saba-tienda, seguifa, nieleni, sewa and tiandougou but statistically different from those of saba-soto and tiandougou-coura (Table 28).

As the concentration of the chemicals increased from low to high, the trend in percentage germination was as follows: An increase followed by a decline for $CaCl_2$, KCl. Data illustrated in (Table 28) indicate that MGT after 8 days were decreased under low levels of 50, 100, 200 and 300 ppm of $CaCl_2$, KCl, KH_2PO_4, K_2SiO_3 and PEG-600. All the chemicals treatments decrease mean germination time compared to the unprimed (control).

Germination rate index (GRI)

Significant differences in GRI were found among varieties, ($p<0.01$) on germination rate index. There were no significant difference among chemicals treatments and their interaction. The highest GRI was observed with CSM63E and banidoka (99%/day), respectivelly and was statistically different from other varieties (Table 28).

Table 28: *Effect of chemical solution at different concentration on seed germination and other growth parameters of nine varieties of sorghum*

Treatments	GP	MGT	GRI	GI	SVI	RVI	SDW
Varieties							
Banidoka	98.9	4.5	98.5	883.7	648.2	250.1	0.09
CSM63E	99.3	4.5	99.1	890.1	554.8	257.7	0.10
Nieleni	85.2	4.5	84.1	747.7	360.5	205.5	0.04
Saba-soto	88.1	4.6	86.9	772.1	368.6	135.9	0.06
Saba-tienda	88.7	4.5	88.2	789.6	438.3	203.5	0.04
Seguifa	92.4	4.5	91.5	816.1	353.3	210.1	0.04
Sewa	87.9	4.5	87.4	778.8	301.2	147.0	0.04
Tiandougou	90.4	4.5	89.7	802.5	342.5	202.2	0.04
Tiandougou-coura	84.7	4.6	83.1	739.3	171.8	99.3	0.02
P-values	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD	2.6	0.01	2.6	24.1	90.8	53.4	0.01

Table 28 continued

Chemicals (ppm)							
Control_0	90.6	4.6	89.5	796.2	256.3	121.6	0.04
$CaCl_2$_50	89.3	4.5	88.3	789.1	433.3	193.9	0.07
$CaCl_2$_100	92.0	4.5	91.3	815.1	493.2	229.8	0.06
$CaCl_2$_200	90.6	4.5	90.1	806.3	460.6	228.4	0.06
K_2SiO_3_100	91.2	4.5	90.3	806.3	412.1	216.9	0.05
K_2SiO_3_200	91.3	4.5	90.1	803.8	395.5	193.6	0.05
K_2SiO_3_300	89.0	4.5	88.5	791.3	387.3	196.1	0.04
KCl_50	89.1	4.5	88.5	792.7	445.3	206.7	0.06
KCl_100	90.5	4.5	89.7	799.4	483.4	226.1	0.06
KCl_200	90.7	4.5	90.2	807.5	436.6	208.9	0.05
KH_2PO_4_50	92.4	4.5	91.7	820.5	430.7	209.7	0.06
KH_2PO_4_100	91.9	4.5	91.1	812.8	464.1	224.4	0.06
KH_2PO_4_200	90.7	4.5	89.8	803.6	446.2	228.0	0.05
PEG6000_100	90.9	4.5	90.3	806.7	332.9	151.9	0.06
PEG6000_200	90.2	4.5	89.4	797.0	366.3	178.6	0.05
PEG6000_300	89.6	4.5	89.1	798.7	321.9	164.6	0.05
P-values	0.9	<0.01	0.9	0.9	<0.01	0.04	<0.01
LSD		0.02			104.9	61.7	0.01
P-values for variety x chemicals	1.0	1.00	1.00	1.00	1.00	1.00	1.00

Value followed by the same superscript within one column is not significantly different at $p \leq 0.05$ according to the LSD protected test, GP: Germination percentage, MGT: Mean germination time, GI: Germination index, SVI: Seedling vigour index, RVI: Root vigour index, SDW: Seedling dry weight.

On the other hand, there was no significant difference between varieties saba-soto, sewa and saba-tienda. Tiandougou-coura always recorded the lowest GRI (83.1 %/day) was not different the GRI of nieleni. The findings showed that KH_2PO_4 50 ppm recorded the highest values (91.7%/day) followed by $CaCl_2$ 100 ppm (91 %/day), PEG-6000 100ppm (90%/day) and K_2SiO_3 100 ppm (90%/day). The lowest GRI was recorded with $CaCl_2$ 50 ppm (88 %/day).

Germination index (GI)

Significant differences in GI were found among varieties (*p*<0.01) on germination index. No significant difference was found among chemicals teratments, and their interaction with varieties. The highest GI was observed with CSM63E (890), followed by banidoka (884) and the lowest with tiandougou-coura (739) (Table 28). The highest GI was observed in KH_2PO_4 50 ppm (821), $CaCl_2$ 100 ppm (815), KH_2PO_4 100 ppm (813), KCl 200 ppm (808), K_2SiO_3 100 ppm (806), and PEG-6000 100 ppm (807) which however did not statistically differ from the GI when chemicals treatments in the other media and (control) (Table 28).

Seedling vigour index (SVI)

Seedling vigour index as a function of seedling length and germination percentatge was also significantly affected by varieties ($p<0.01$), chemicals treatments ($p<0.01$) on seedling vigour index. There was no significant interaction on seedling vigour index (Table 28). Variety banidoka and CSM63E, was statistically different from other varieties followed by saba-tienda in chemicals teatments. Varieties nieleni, seguifa, tiandougou, saba-soto and sewa were not significantly different from the control but perform better than the SVI Tiandougou-coura which always observed the lowest SVI=172 (Table 28). Significant difference was also found in chemicals treatments (p=0.01) in both chemicals groups. All chemicals treatments were significantly higher compared to unprimed control (Table 28).

Root vigour index (RVI)

Significant differences in RVI were observed among varieties ($p<0.01$), chemicals treatments ($p=0.04$) on root vigour index. There was no significant interaction on root vigour index (Table 28). In term of varieties responses CSM63E, banidoka, saba-tienda, seguifa, nieleni and tiandougou were significant higher from the other varieties. The lowest RVI was measured with the variety tiandougou-coura, which was not statistically different from saba-soto and sewa (Table 28).

Chemicals treatments means values for RVI ranged from 122-230 (Table 28). $CaCl_2$, KCl and KH_2PO_4 (50, 100 and 200 ppm) significantly performed equally in term of recorded highest RVI and was statistically different from the control while $CaCl_2$ and KH_2PO_4 (100 and 200 ppm) was significantly higher comapared to PEG6000 100 ppm which was not statistically different from unprimed control (Table 28).

Seedling dry weight (SDW)

Significant differences in SDW were found among varieties ($p<0.01$), chemicals treatmemts ($p<0.01$). There was no significant interaction between varieties and chemicals on seedling dry weight (Table 28). The highest SDW was observed with CSM63E (0.10 g), followed by banidoka (0.9 g), which was statistically different from the SDW of nieleni, saba-soto, saba-tienda, seguifa, sewa, tiandougou and tiandougou-coura (Table 28). The highest SDW values was recorded in chemicals treatments $CaCl_2$ 50 ppm (0.07 g) while the lowest was observed in K_2SiO_3 at 300 ppm which was not significantly different from unprimed control (Table 28). All the chemicals treatments concentration impacted SDW (Table 28).

Discussion

This study revealed that seed priming with $CaCl_{2,}$ KCl, $KH_2PO_{4,}$ K_2SiO_3 and PEG-6000 at different concentrations significantly improved p=0.01 germination percentage and seedling growth parameters of banidoka, CSM63E, saba-tienda and seguifa compared to the control. Lower concentrations of KCl, KH_2PO_4, $CaCl_2$, and K_2SiO_3 improved all seedling growth parameters which are in agreement with findings of Yari, Khazaei, Sadeghi, & Sheidaei, (2011). $CaCl_2$, KH_2PO_4 and K_2SiO_3 application boosted the germination percentage of CSM63E, banidoka and saba-tienda varieties. The positive effect of $CaCl_2$, KH_2PO_4 and K_2SiO_3 application on germination percentage might be explained by an increase in the activity of key enzymes, such as amylase and proteases (Toklu, Baloch, Karaköy, & Özkan, 2015), which play an important role in the growth and development of the seed embryo. Higher uptake and accumulation of K under drought is regarded as a better strategy to cope with drought. Potassium plays an important role in regulating the stomatal oscillations and osmoregulation under drought in particular (Araújo, Fernie, & Nunes-Nesi, 2011; Dasgan & Koc, 2009;; Kusvuran, 2012). The priming media affected differently the germination percentage of the sorghum varieties. Indeed, our results show that more than 100 ppm of PEG-6000 decrease SVI, RVI and SDW of all varieties. This confirms previous results reported by various authors (Giri & Schillinger, 2003; Faruk et al., 2015; Lemrasky & Hosseini, 2012). The latter indicated that several osmotica, such as PEG-6000, induce positive effects on germination capability.

The develeppment of seedling vigour index and root vigour index due to priming may be due to an increase in water uptake rate to achieve the important moisture content required for germination (Elkoca, 2014) or could be due to the acceleration of the rate of the cell division as calcium plays an important role in cell wall structure and cell division (Caffall & Mohnen, 2009; Farooq et al., 2011) reported that osmo-primed seed treatments produced quick and uniform emergence, and increased the yield of field crops under a variety of environmental conditions such as soil salinity. The reduction of the MGT is probably due to the increased water absorption rate and earlier initiation of metabolic processes (Elkoca, 2014). Our results also revealed a high effect of K_2SiO_3 (100 ppm) and KH_2PO_4 (50 ppm) on seedling root vigour index (Table 28). These results are in accordance with Afzal, Basra, Lodhi, and Butt (2007); Afzal, Rauf, and Basra, (2008) who reported that seeds of wheat subjected to priming with 50 mM $CaCl_2$ significantly decreased MGT compared to control. From this results, it can also be confirmed that $CaCl_2$, KCl, K_2SiO_3, KH_2PO_4 seed treatment as $CaCl_2$ and K_2SiO_3 improved the GP, MGT, GRI,GI, SVI, RVI and SDW at 100 ppm, were the most successful osmo-priming.

Conclusions

Crop establishment failure is one of the serious problems to crop production in drought prone areas Osmo-priming may provide a simple solution for increasing germination percentage, healthy and vigorous seedling at the beginning of the season. This study indicate that osmo-priming was much effective with 50 ppm of KCl and KH_2PO_4 and 100 ppm of K_2SiO_3 PEG6000 and $CaCl_2$ on sorghum seed germination, seedling growth, as compared to control under unfavorable sowing conditions such as dry sowing. For example, low concentration of 50 ppm of KH_2PO_4 increased by 12 % the seedling dry weight compared to unprimed seeds. Osmo-priming treatments are simple and effective methods to improve seed germination and seedling growth in early drought conditions. These represent promising results that may need further investigation how these positive effects could be translated into farmers' fields.

CHAPTER SEVEN

EFFECTS OF SEED PRIMING AND *ZAÏ* PIT PRACTICE ON FIELD PERFORMANCE OF SORGHUM (*Sorghum bicolor* L. Moench) IN MALI

Introduction

Water scarcity is becoming an increasingly important issue in many parts of the world. Under rain-fed agriculture, an increased water use-efficiency for enhanced drought and heat tolerance can be achieved by different strategies such as change of crops capable of producing acceptable seedling and yields (Farré & Faci, 2006) or by strategies involving agronomic practices like different seed-priming and farm land preparation methods (Harris et al., 2001; Harris et al., 2005). Sorghum (*Sorghum bicolor* L. Moench) is a potential rain-fed crop widely grown in many arid and semi-arid areas of the world thanks to its ability to yield low rainfall and high temperature conditions (Prasad & Staggenborg, 2008). Sorghum is reported to be more tolerant than many cereals crops (e.g. maize) to water deficit (Ananda, Vadlani, & Prasad, 2011; Blum, 2005)

Significant seedling and yield losses of sorghum as a consequence of drought and heat are expected to increase with global climatic change (Rippke et al., 2016). As for most rain-fed crops in the semi-arid climatic zones, sorghum often suffers from drought and heat stress at the early stage of plant growth, translating into 30 - 90% seedling loss (Dembele, 2015) and later between flowering and grain filling with about 40-80% yield loss (Simsek, Can, Denek, & Tonkaz, 2011; Soltani, Waismoradi, Heidari, & Rahmati, 2013). Thus, drought and heat are considered to be major factors affecting plant growth and yield in rain-fed cropping in the semi-arid tropics. In Mali, where sorghum is a major rain-fed crop, its ability to emerge often depends on its capacity to germinate and grow under limited soil moisture conditions. Bijagare et al., (1994) studied the effect of moisture stress on sorghum seed germination and concluded that germination decreased with increases in levels of water stress; while also genotype variations were observed. According to Nivedita, (1992), the optimum soil moisture requirement for sorghum germination is between 25 to 50% of field capacity.

Also, soil organic matter is the key to soil fertility and productivity in the Sahel. In the absence of organic matter, the soil is a mixture of sand, silt and clay. Organic matter induces life into this inert mixture and promotes biological activities. In traditional agriculture, the use of plant and animal wastes as a source of plant nutrient has been practiced over generations in Mali. Most commonly used organic materials include farm yard manure (FYM), animal wastes, compost, green manures and crop residues. In addition to improving the physical, chemical and biological properties of the soil, organic matter also increases the soil water holding capacity.

The *zaï* pits practice is a technique used in dry parts of West and East Africa to harvest water and to help concentrate nutrients where the crops will grow. A typical *zaï* pits have a diameter of 15 to 30 cm and a depth of 10 to 20 cm to collect rainfall and runoff. *Zaï* pits concept captures rainfall and runoffs, promotes the efficient use of limited quantities of organic matter and ensures the concentration of water and soil fertility at the beginning of the rainy season.

The use of the *zaï* method increases the amount of water stored in the soil profile by trapping rain water. It retains moisture in-situ and holds water long enough to allow it to infiltrate. This means that more water infiltrates so that water will be available to plant roots. Farmers put a handful of organic matter in each pit (ranging from about 150 - 300 gram per pit). This system can help farmers to conserve moisture and to target application of the often scarce organic soil inputs. The little available water and the little organic soil inputs are used more efficiently resulting in better grain and biomass yields.

In this regard, the *zaï* pits practice for planting could be a sound option to maintain sufficient soil moisture (Figure 8) and plant nutrients that may help crops to bear drought and heat stresses (Kabore, and Reij, 2004). The *zaï* traditional system, born in Dogon plateau in Mali was revived in the Yatenga province of Burkina Faso in the 1980s after the drought years of the 1970s, which struck the Sahel with a generalized decrease of 30% of average annual rainfall (Kabore & Guenat, 1999).

As far, we know no research has been undertaken on the study of a combined *zaï* pits with or without compost and priming and ridge practice in Mali. Hence, the present idea, seed germination, seedling growth and yield are being influenced by this research work undertaken with the general objective of evaluating seed priming and *zaï* pits practice on preventing crop establishment failure at early season. The specific objective was to assess the combined effect of priming and *zaï* pits with or without compost on field performance of sorghum in Mali.

Figure 8: Typical *zaï* pits after first rain

Materials and Methods

The field experiment was conducted during the rainy season of 2014 and 2015 at the Centre d'Animation Rural (CAR) of Cinzana-gare District, (Longitude: 5° 58' W, Latitude: 13° 15' N, and altitude: 280 m) about 7 km to the Agricultural Research Station of Cinzana, Institut d'Economie Rurale (IER), Mali. The climate is semi-arid. Rainfall is monomodal, irregular in time and space and lasts for 4 months from June to September, with an average annual rainfall varying between 600 and 800 mm. Mean temperatures vary between 23 and 33°C during the rainy season and may reach 41°C in the dry season. Soils are of tropical ferruginous type, little leached and waterlogged in some area and their surface is crusted with gentle 1-2% slope. The main activities of the local population are crop and livestock productions. Millet (*Pennisetum glaucaum*), Sorghum, cowpea (*Vigna unguiculata*), groundnut

(*Arachis hypogea*) and sesame (*Sesamum indicum*) are the most cultivated crops (Dembele, 2015).

Experimental design

The experiment was carried out as a 3x3x3 factorial based on a randomized complete block design (RCBD) with 4 replications. Factor A consisted of 3 promising varieties (Banidoka, CSM63E and Saba-tienda), Factor B consisted of 3 seed priming methods: untreated sorghum seeds, Hydro-priming with well water (25 ºC), and Osmo-priming with K_2SiO_3 (100 ppm). Factor C involved 3 seeds bed preparation methods: ridge, z*aï* pits with and without compost. The priming was done by soaking seeds in well water at 25±2 ºC for 4 hours while the osmo-priming was done by soaking seeds in K_2SiO_3 (100 ppm) for four hours. The primed seeds were spread out on double layer of Whatman Filter paper for 15-30 minutes to allow surface drying before sowing.

Common seed preparation used in the study area is by far ridge tillage, which is an agricultural technique used to limit the effects of humidity or high rainfall or for cultivation on too clayey soil (Nabhan, Mashali, & Mermut, 1997). It involves growing in rows of small mounds of about 15-20 centimeters high. The mounds are flattened on top to form a sort of trapeze to gently avoiding gully erosion during heavy rains. The sowing is done on the summit plateau.

The experimental plot was prepared in two ways: (a). The ridge was ploughed, using a cattle ridging plough which has two mouldboards facing away from each other, cutting a deep furrow on each pass, with high ridges either side. The dimensions of the ridge were length 4.4 m, width, 0.4 cm and height 0.20 cm with 0.75 m spacing between rows. In contrast with (b) *zaï* pits practice, human power was used with help of pick mattock, hoe and digging bar to dig *zaï* pits. The digging of *zaï* pits should be done at least one month before the onset of rainy season or at the end of the rains available moisture makes digging less stressful to trigger organic matter decomposition (Roose et al., 2010). The size of *zaï* pits vary according to soil type. A planting pit of 20 cm diameter and 20 cm depth was dug; spacing between pits in rows was 0.40 units having in total 12 pits in a row. After digging the pit soil was retuned half of the brim and then was added a compost of 6-9 month old was applied at the rate of 2.5 t/ha or 150 g per hole for *zaï* pits with compost treatment covered with small layer of soil up to 5 cm to the surface. Only soil was returned in *zaï* pits without compost up to 5 cm of ground surface. The sowing was done when soil moisture is suffisant for germination.

Four to five seeds per hill of sorghum were sown to 2-5 cm depth with an intra-row spacing of 0.40 m. Composite soil samples were taken at the beginning of 2014 and end of 2015. Soil samples were analyzed for soil physico-chemical parameters at the IER, Agronomic Station of Sotuba, Bamako. The number of seeds germinated was counted two days after sowing every day up to one week. Two weeks after emergence, seedlings were thinned to maintain two healthy plants per hill. Data was collected on sorghum seed germination, seedling growth, biomass and grain yield parameters. Hand weeding was done at 21 and 50 Days after sowing (DAS). The panicles were harvested at physiological maturity stage from the net plot and were sun dried for one week. After drying, threshing was done to separate the grains.

The combined effect of priming and cultural practice (ridge and *zaï* pits) on the three Sorghum varieties was assessed by comparing the impact of priming with untreated sorghum seeds (the control) on ridge and *zaï* pits with or without compost. The effect of hydro-priming in well water source and osmo-priming using K_2SiO_3 performance was assessed by comparing the two priming methods. Hence, each of the seeds of the 3 sorghum varieties were subjected to 3 different priming, sowed on ridge and *zaï* treatments: 6 (Table 29).

Seeds preparation was the same as described in chapters 5 and 6 before sowing. All seeds were kept in a box of 125 ml to be carried to the field. The impact of the treatments was assessed through a number of selected parameters viz germination percentage (GP), mean germination time (MGT), germination rate index (GRI), germination index (GI), grain yield (GY) and straw yield (SY).

Table 29: *Treatment combinations used in field experiment*

Priming method	Cultural practices		
	Ridge	*zaï* with compost	*zaï* without compost
Control	X	X	X
Hydro-primining[a]	X	X	X
Osmo-priming[b]	X	X	X

[a]= Tepid well water, [b]= K_2SiO_3 (100 ppm)

The rainfall data was accessed from the Meteorology unit of the Agricultural Research Station of Cinzana in Mali.

Statistical analysis

The experimental design comprised a factorially umbalanced arranged randomized complete block design (RCBD) with four replicates. The results were evaluated by the analysis of an unbalanced design using GenStat nine edition version 9.2.0 (2007). The data was checked for normal distribution before being subjected to ANOVA. The means germination percentage, mean germination time, germination rate index, germination index, grain yield and straw yield were compared with treatment variables sorghum varieties (3), and the combination of hydro and osmo-priming treatments (3 levels) and cultural practices (3 levels). Treatment means were considered significantly different at $p \leq 0.05$. The Fisher's Protected Least Significant Difference (LSD) procedure was used for the mean separation.

Results

Soils characteristics at the experimental site

Initial properties of experimental plots in 2014

Chemical characteristics of soil in 2014 are presented in (Table 30) when the experiment was initiated. From this analysis, we concluded that the experimental plots had similar initial soil characteristics and the experimental block was homogeneous. Initial chemical characteristic of the soil (0-20 cm) collected from experimental site revealed that the pH (H_2O) was slightly acid (6.07) for all plots. The soil was very poor in organic C (0. 21%) in 2014 under critical level. All experimental plots had very low N concentration under critical level (0.02%). Available P was also very low (5.54 ppm). Calcium concentration was normal for the region but under critical level for those for Mg, K and Na, suggestive of very poor fertility.

Changes in soil characteristics between 2014-2015

Soil pH (H_2O), organic C and N concentrations increased from 2014 to 2015 (Table 30). Except N and Na levels were identical for the two years, all the remaining elements increased in the second year i.e available P, K, Ca and Mg, but the C: N ratio was higher in 2015 than in 2014. The percentage of N and Na did not change significantly with time. Overall, nutrient concentrations increased between 2014 and 2015, suggesting a slightly increase in soil chemical fertility due to *zaï* practice (Table 30).

Table 30: *Soil chemical characteristics before (2014) and after zaï treatment (2015)*

Parameters	2014	2015
pH (H_2O)	6.10	6.04
C:N (Ratio)	10.50	17.50
SOC (%)	0.21	0.35
N (%)	0.02	0.02
P_2O_5 available (ppm)	5.54	7.82
SEB	4.83	11.31
Ca (Cmol kg^{-1})	2.57	6.37
Mg (Cmol kg^{-1})	1.28	3.18
K (Cmol kg^{-1})	0.08	0.19
Na (Cmol kg^{-1})	0.09	0.09
Sand (%) > 0.05 mm	70.67	76.47
Silt (%) 0.05-0.002 mm	21.11	18.00
Clay (%) < 0.002 mm	8.00	5.67

Note. C:N: Carbon/Nitrogen; SOC:Soil Organic Carbon; N: total nitrogen; P2O5 avail: available phosphorus; SEB: Sum of exchangeable bases, Ca: Calicium available, Mg: magnesium available, Na: Sodium available.

Rainfall situation during experimentation

The rainy season in 2014 began in May, and in 2015 in April, and the latest rains were recorded in October in both 2014 and 2015 (Figure 9). The cumulated rainfall was 725 mm in 2014, and 822 mm in 2015 with 52 and 57 rain events in the two years, respectively. Rainy events higher than 20 mm represent 63% of total rainfall recorded in 2014 and 53% in 2015. The distribution of rainfall was more regular with some dry spell at the beginning and end of both rainy seasons.

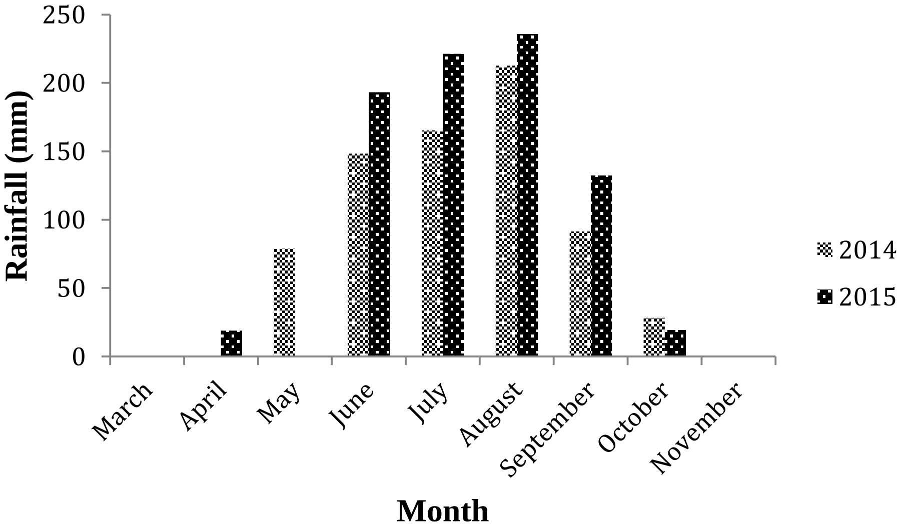


Figure 9: Rainfall (mm) at the experimental site in 2014 and 2015

No significant interaction was found among all treatments in this study i.e varieties x priming, varieties x cultural practice, priming x cultural practice and finally varieties x priming x cultural practice. Hence the result is focused on single factor effect (Table 31).

Effect of priming and cultural practices on field performance of sorghum

Germination percentage (GP)

The GP was significantly affected by varieties ($p<0.03$) and cultural practice ($p<0.04$) (Table 31). Variety banidoka and CSM63E recorded the maximum GP (54.0%) was significantly higher from saba-tienda (48%). The priming treatments were not significant for germination but showed slight improvement in GP for primed compared to unprimed (48%). Cultural practices was significantly higher in *zaï* practice without (55%) and with compost (55%) compared to ridge (48%) (Table 31). Soil moisture, pH levels, and organic matter content may all influence the actual amount of chemical taken up by a young plant. A compost incompletely decomposed added to *zaï* pits and immediately sown my reduce germination percentage due to it high temperature during decomposition.

Mean germination time (MGT)

Significant differences in MGT were observed due to priming $p<0.01$ and cultural practice treatments $p=0.01$. No significant difference was found among varieties treatments (Table 31) for mean germination time. The lowest MGT was observed with osmo-primed method K_2SiO_3 and well water (4.2 days) statistically different from unprimed treatment (4.30 days) (Table 31). Significant differences were also observed among cultural practices. *Zaï* pits without compost (4.1 days) were significantly lower than *zaï* with compost (4.2 days) and ridge (4.20 days) (Table 31). All priming methods and cultural practices *zaï* either with compost or not, siginificantly improved the MGT compared to the control (4.3 days).

Germination rate index (GRI)

Varieties significantly varied among treatment in GRI (*p*<0.01), priming (*p*=0.05), cultural practice (p=0.05) on germination rate index (Table 31). The highest GRI was observed in both banidoka and CSM63E (44 %/day) and the lowest in Saba-tienda (35%/day) (Table 31). A priming treatments hydro-primed in well water recorded the highest GRI (43%/day) significantly different from the control and unprimed, followed by osmo-primed in K_2SiO_3 (40%/day), which was not statistically different but far better than the control (36%/day). A priming treatments hydro-primed in well water recorded the highest GRI (43%/day) significantly different from the control and unprimed, followed by osmo-primed in K_2SiO_3 (40%/day), which was not statistically different but far better than the control (36%/day). Cultural practices varied significantly among treatments, the highest GRI was observed with *zaï* pits with compost (45%/day) followed by *zaï* pits without compost (42%/day) did not significantly differ from each other but statistically different from ridge practice (38%/day), which recorded the lowest value (Table 31).

Germination index (GI)

Significant differences in GI was found among varieties (*p*<0.01), priming (*p*<0.01), cultural practice (*p*<0.03) on germination index (Table 31). The highest GI was observed with CSM63E (186), and was statistically different from GI of saba-tienda (146) but not different from GI of banidoka (183) (Table 31). Priming methods significantly varied among treatments. Hydro and osmo-primed well water (179) and K_2SiO_3 (171) recorded the highest values and was significantly different from control (141), however the GI when primed in K_2SiO_3 or well water gave better results compared to unprimed, control (Table 31). Cultural practices showed significant differences among treatments. The highest GI were observed with *zaï* pits with compost (191) followed by those without compost (181) but was not statistically different among them. Cultural practice ridge recorded the lowest GI (157) which was statistically different from *zaï* pits practice either without or with compost (Table 31).

Table 31: *Effect of seed priming and cultural practices on the field performance of three varieties of sorghum*

Treatments	Growth parameters					
Variety	GP	MGT	GRI	GI	GY	SY
Banidoka	54.0	4.2	44.1	183.1	961.0	2157.0
CSM63E	54.0	4.2	44.0	186.1	874.3	1629.0
Saba-tienda	47.3	4.2	35.0	148.6	671.6	1633.0
P-values	0.03	0.41	<0.01	<0.01	0.04	0.05
LSD	5.96		5.30	21.85	185.8	505.7
Priming						
Control	47.8	4.3	35.9	141.0	730.6	1590.0
K2SiO3	50.4	4.2	40.1	170.5	787.5	1719.0
Well	53.7	4.2	42.7	179.3	900.3	1928.0
P-values	0.15	<0.01	0.05	0.01	0.2	0.47
LSD		0.06	5.75	23.73		
Cultural practice						
Ridge	48.0	4.2	38.0	157.1	742.1	1501.0
Zai+Com	55.0	4.2	45.1	190.9	1131.1	2744.0
Zai-Com	55.0	4.1	42.0	181.2	694.6	1374.0
P-values	0.04	0.01	0.05	0.03	<0.01	<0.01
LSD	5.94	0.05	5.30	21.71	185	503.7
Variety x priming	0.62	0.55	0.38	0.46	0.81	0.56
Variety x Cultural practice	0.88	0.69	0.25	0.2	0.5	0.3
Priming x cultural practice	0.72	0.91	0.68	0.68	0.5	0.65
Variety x priming x cultural practice	0.62	0.17	0.89	0.92	0.97	0.7

LSD values at $p \leq 0.05$ GP: Germination percentage, MGT: Mean germination time, GI: Germination index, SVI: Seedling vigour index, RVI: Root vigour index, SDW: Seedling dry weight.

Grain yield (GY)

Grain yield varied significantly among variety treatments (p<0. 04) and cultural practice (p<0. 01) on grain yield (Table 31). There was no significant difference among priming treatments on grain yield, (Table 31). Variety banidoka produced the highest grain yield (961 kg ha^{-1}) followed by CSM63E (874 kg ha^{-1}) and lastly saba-tienda (671 kg ha^{-1}). Banidoka was statistically different from saba-tienda but did not differ from CSM63E (Table 31). Among cultural practices treatments. *Zaï* pits practice with compost observed the highest GY (1131 kg ha^{-1}) statistically different from the GY of *zaï* pits practice without compost (695 kg ha^{-1}) and ridge practice (742 kg ha^{-1}). *Zaï* pits practice without compost did not statistically differe from ridge practice, (Table 31).

Straw yield (SY)

Significant differences in SY were recorded among varieties treatments (p<0.05), cultural practices (p<0.01) on traw yield, (Table 31). Priming treatments was not significant for straw yield (Table 31). The highest SY was observed for variety banidoka (2157 kg.ha^{-1}) which was statistically different from SY of saba-tienda (1633 kg.ha^{-1}) and CSM63E (1629 kgha^{-1}) (Table 31). Differences were also observed among the cultural practices. *Zaï* pits with compost recorded the highest SY (2744 kg ha^{-1}) which was significantly different from straw yield of ridge practice (1501 kg ha^{-1}) and the one of *zaï* without compost (1374 kg ha^{-1}). In general the straw yield was impacted by varieties and cultural practices, for example, all the three varieties, banidoka, CSM63E and saba-tienda perform better in *zaï* with compost suggesting again more moisture and nutrients available a root zone. It was the combined practice of capturing surface runoff, adding composted organic matter and, seed primed that resulted in the production of 695 - 1131 kg ha^{-1} of grain yield and 1374-2744 kg ha^{-1} of sorghum straw as compared to the control treatment, which yielded only 731 kg ha^{-1} of grain and 1590 kg ha^{-1} of straw (Table 31).

Discussion

Drought and heat stress are major limiting factors at the initial phase of plant growth and establishment. The usual effects of drought and heat on the development of a plant are a lowered production of biomass and/or a change in the distribution of this biomass among the different organs. In addition, plant productivity under drought and heat stress is strongly related to the processes of dry matter partitioning and temporal biomass distribution (Jaleel et al., 2009). At the early seedling stages of the crop, lack of water and high temperature can adversely affect seedling growth and occasionally kill seedlings and reduce the plant population (Krishnamurthy, Zaman-Allah, Purushothaman, Ahmed, & Vadez, 2011).

***Zaï* pits cultural practice with compost**

Zaï pits cultural practice with compost increased the soil nutrient concentration between 2014 and 2015 (Table 31). From a biological perspective, the *zaï* soil practice system, a cropping system concentrating runoff water and manure in micro-watersheds, may be a simple solution in addition to seed priming techniques for crop establishment under early drought and heat prone areas and increased productivity of crusted soil. *Zaï* pits practice, a very complex soil restoration system using organic matter localization, termites to bore channels in the crusted soils, runoff capture in micro-watersheds, and seed hole cropping of sorghum on various soils (Roose et al., 2010). Kabore and Reij, (2004) reported that experimental improvements of *zaï* system on two soils confirm the possibility not only to increase the production of cereal grains from 150 to 1700 kg ha^{-1}) and straw from 500 to 5300 kg ha^{-1}). In addition the concentration of runoff water, organic manure, and a complement of mineral nutrients in micro-watersheds increased biomass production without significant change in soil properties after 2 years (Roose et al., 2010). This system allows for the maintenance of organic manure in the seed holes, which the farmer covers with a handful of soil, it may be also useful not only to restore soil productivity but also for crop establishment at the early season drought in many drylands of the tropics.

Germination percentage

Use of limited soil moisture will cause reduction in seed germination, seedling establishment and further growth. The adverse effects of low available soil moisture condition on seed emergence and related traits had also been well documented by (Arjmand, Sharafi, Jouyban, & Akhlaghi, 2014; Ashraf, 2014; Eskridge, 2014; Kazem, Jabbarpour, & Zehtab-Salmasi, 2013). The germination was generally low for all varieties, ranging from 48% to 55% in field condition, but in constrast with laboratory conditions the same varieties i.e CSM63E (99%); banidoka (98%) and saba-tienda (94%) had the highest germination percentage respectively. Nevertheless, the findings showed that seed priming in addition to *zaï* pits practice improves seed germination and seedling development of sorghum very likely by accelerating imbibition and providing continuous moisture during the germination phase. This could contribute to facilitate emergence phase and reduced mean germination time with vigorous root and shoot of sorghum which is very important at the beginning of the rainy season in the Sahel zone. Similar findings have been on an improved germination of sunflower cultivars by accelerating imbibition through priming (Farahani et al., 2011). *Zaï* pits with compost suggests keeping more moisture compare to *zaï* pits without compost and ridge because of the presence of compost, which increase the water holding capacity of soil (Table 31).

Germination time

The results revealed also significant reduction in mean germination time due to optimum moisture availability during initiation of germination. Due to imbibition seeds take short time to germinate, however, non-primed seeds take longer time in relation with soil moisture for imbibition. Therefore, it is suggested that seed germination might be increased by hydro-priming technique (Ghassemi-Golezani & Mazloomi-Oskooyi, 2012). The available soil moisture combined with primed seed affects emerging seedlings, growth and yield of many crops and depend on readily available soil moisture in the root zone.

Seed priming

Hydro-priming with well water and osmo-priming with low concentration of K_2SiO_3 (100 ppm) gave a significantly higher germination percentage than the unprimed treatment. Giri and Schillinger, (2003) reported that, both hydro-primed and osmo-primed seeds showed significant increase in germination performance. The improvement in seed germination and seedling development due to seed priming treatment is in conformity with other researchers (Basra et al., 2005; Murungu et al., 2003). Other workers including Hussain, Farooq, Basra, and Ahmad, (2006); Khan et al., (2008) also reported that germination and growth of seedlings were significantly affected with changes in available soil moisture conditions and primed seeds especially when combined with *zaï* pits with compost.

Our results showed that various hydro-priming techniques using well water, osmo-priming using low concentration (100 ppm) of K_2SiO_3 significantly enhanced seed germination and seedling growth parameters and grain yield of sorghum. Also the cultural practice of using ridge and *zaï* pits with or without compost gave a greater advantage in providing continuous moisture environment for crop establishment in drought and heat prone areas. This agricultural managemenet option are simple and could be implemented by resource poor farmer in the Semi-arid Sahel of Mali and related environments to address crop establishment failure.

Grain and straw yield

Plant response to abiotic stress is one of the most active research topics in plant biology due to its practical implications in agriculture, since abiotic stresses (mainly drought and high temperature) are the major cause for the reduction in crop biomass and yield worldwide, especially in the Semi-arid tropics. Plants are extremely sensitive to changes resulting from drought a high temperature, which commonly occur together. They do not generally adapt quickly (Josine, Ji & Guan, 2011). Significant differences were found in grain and straw yield for *zaï* pits practice. This high grain and straw yield could be explained by continuous provision of moisture and favorable nutrients environment due to *zaï* pits and rapid decomposition of compost for the standing plant during dry spell period (Fatondji et al., 2009). Organic matter decomposition and nutrient release are enhanced in the *zaï* pits due to moisture conservation. Therefore, the *zaï* pits technique should be used under dryer conditions (Fatondji et al). Also farmer's organic matter management, surface or broadcast applied organic matter is exposed to wind and water erosion and are rapidly comminuted by termites. In such cases, nutrients are easily lost and not available to the standing crop (Fatondji et al). Incorporating the compost or organic matter into *zaï* pits could remedy this problem, but in the dry regions of the Sahel, the upper soil layer dries very quickly even during the rainy season. Under such conditions, decomposition may not proceed continuously and the *zaï* pits might be preferred (Fatondji et al). The surface of the ridge dry rapidly due to it exposure to sun and wind compared to *zaï* pits, this may suggest that during long drought spell, plants on ridge suffer more than those in *zaï* pits.

The results of this study confirm the possibility of increasing the productivity of sorghum on drought, heat stress in poor soils by using the combined hydroor osmo-priming and *zaï* pits techniques. The capture of runoff water (and its solid load) allowed only a limited increase of biomass production as long as the nutrient level was slightly improved after two years of experimentation. The results showed that priming using well water or a low concentration of K_2SiO_3 combined with *zaï* pits cultural practice plus compost improved sorghum grain yield due to significant concentrated nutrients and moisture available for the crop.

Seed priming and *zaï* pits techniques significantly improved a series of seedling performance parameters such as the germination percentage, mean germination time, germination rate index, germination index, grain and straw yield of sorghum compared to unprimed. These options give a comparative advantage for crops seed germination, seedling growth and yield under extreme drought and heat situations; therefore these could be recommended as early drought management strategies under climate change and variability in drylands.

Conclusions

The current findings suggest that combination of priming using well or K_2SiO_3 and *zaï* pits with compost significantly improved grain yield about 34 % and straw yield about 42 % in a poor soil in reference with unprimed seed on ridge. The germination and seedling development can be enhanced by the application of hydro-priming using well water, osmo-priming using low concentration (100 ppm) of K_2SiO_3 and *zaï* practice with or without compost or the combination of all of them to improve seed germination, seedling growth, crop establishment and final grain yield of sorghum in drought and heat prone area, but under regular heavy rain *zaï* pits practice could be harmful to germination and seedling growth as it can create water logging conditions.

CHAPTER EIGHT

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Early season rainfall insecurity, commonly resulting in early-season drought and heat stress, is a serious threat to germination, crop establilshment and hence yields and thus increases food insecurity in Mali, West Africa. The findings of this study revealed however the efficiency of a series of simple, but improved crops management technologies to enhance seed germination, seedling growth and crop establishment, which in the end significantly increased crop yields. Hence small-scale, sorghum producers in Mali have more options for improving sorghum productivity then realized thus far.

This study was carefully designed to explore different characteristics of sorghum varieties to cope with weather variability causing drought and heat stress. Since obviously at the onset of the season seedings are most susceptible to drought and heat, seed vigour and seedling performance is very important for maximum crop establishment under the predicted climate change and climate variability for West Africa. Therefore the design allowed testing if seed germination and seedling growth can be boosted with priming methods alone as well as in combination with a more extended cultural practice, the so-called *zaï* pits practice.

Conclusions

The sorghum varieties banidoka, CSM63E and saba-tienda showed to be superior to all others and therefore can in the first place be offered as potential candidate parents in breeding programmes. With the use of key performance indicators indicative for the predicted situation in the Sahel such as GRI, SVI, RVI and SDW, it would become cost effective, less time consuming and less laborious to screen germplasms at an early stage. Hence, the present findings are in any case helpful in the selection of drought and heat stress in sorghum under the selected traits.

The results of hydro-priming indicated that seed germination and seedling growth parameters were affected by variety, water sources and priming duration. The hydro-priming with tepid or hot water sources increased seed germination percentage, seedling growth rate, root vigour index and seedling dry weight compared to the unprimed seeds. Hence, hydro-priming in tepid or hot water is an effective and low-cost technique to improve seed germination and other seedling growth parameters such as germination rate index, seedling vigour index, root vigour index and seedling dry weight.

The final priming effect depends on the variety, source of water as well as priming duration. For instance, river and well water sources were the two most promising water sources and were superior to priming with tap, rain or distilled water. Priming with tepid water and during 8 hour was also a most promising management option, but farmers should be aware that these pre-treated seeds should afterwards be immediately sown since the drying of such pre-treated seeds would be destroyed them. A promising duration in hot water on all parameters measured was 30 minutes although only to gain similar results than priming with 8 hours. Hence, it can be recommended to sow immediately when sowing becomes possible, tepid or hot hydro-primed seeds and despite the unpredicted rain situation. Primed seed performs in tepid water superior compared to hot water at 70 ºC and unprimed seed.

Osmo-priming may also provide a simple solution for increasing germination percentage, and gaining healthy and vigorous root and seedlings at the onset of the growing season. Osmo-priming was much effective with 50 ppm of KH_2PO_4, KCl and 100 ppm of $CaCl_2$, PEG6000 and K_2SiO_3 and increased sorghum seed germination, and seedling growth, even under unfavorable sowing conditions. Seedling growth rate could be enhanced also by priming seeds with other priming agents.

Overall, priming treatments appeared to have a practical value; yet, further work is needed on transferability. The varieties banidoka, CSM63E and saba-tienda performed better than the others as evidenced by various performance parameters such as seedling vigour index, root vigour index and thus showed the highest seed germination and seedling growth under unpredicted rainfall in arid and semi-arid environment.

The findings underscored as well that a combination of priming options in the *zaï* practice has a synergetic effect on germination, seedling growth and yield of sorghum in irregular rainfall situation. The use of *zaï* pits goes hand in hand with an application of external sources of nutrients (organic matter) and hence the soil nutrient availability in pits was improved. Consequently, the combination of both treatments boosted final yields by 34-42% compared to the control.

The combination of both cultivation practices does not only help reduce crop establishment failures, but also enables farmers for increasing food security in a (permanent) risky environment. Innovative farmers may play a major role in the adaptation of innovations, as will be the case with the practices tested. But knowing that about 80% of the currently cultivable land in Mali is located in the semi-arid, drought and heat prone areas, the findings of the most promising management options should be made known to all as potential methods to overcome crop establishment failure and increased sorghum grain yield.

Recommendations

Overall, the findings permit recommending that the varieties banidoka, CSM63E and saba-tienda can benefit sorghum breeding programmes as additional sources of resistance genes for sorghum germplasm to drought and heat. Such promising varieties could be crossed with other suitable varieties to enhance their genetic base for drought and heat stress tolerance/resistance and high yield varieties under this changing environment.

The cultivation of the most promising varieties subjected to hydro-priming or/and osmo-priming can be encouraged in the study area and in similar zones and certainly in that the combination of *zaï* pits. Crop establishment and yield gains can therefore become feasible also for small-scale farmers with limited means. Digging z*aï* pits is hard and labour consuming at the dry season; therefore it is recommended to make digging at the end of the season.

REFERENCES

Abdelghafor, R. (2015). *Quality of bread from composite flour of sorghum and hard white winter wheat*. University of Khartoum Khartoum-Sudan. Retrieved from http://khartoumspace.uofk.edu/handle/123456789/12526

Abdul-Baki, AA., A. J. (1972). Physiological and biochemical deterioration of seeds. *New York: Academic Press*, (2), 283–315.

Abdul-Baki, A. A., & Anderson, J. D. (1973). Vigor Determination in Soybean Seed by Multiple Criteria1. *Crop Science*, *13*(6), 630. http://doi.org/10.2135/cropsci1973.0011183X001300060013x

Abid, G., Muhovski, Y., Mingeot, D., Watillon, B., Toussaint, A., Mergeai, G., … Jebara, M. (2015). Identification and characterization of drought stress responsive genes in faba bean (Vicia faba L.) by suppression subtractive hybridization. *Plant Cell, Tissue and Organ Culture (PCTOC)*, *121*(2), 367–379. http://doi.org/10.1007/s11240-014-0707-x

ACSD. (2007). *Africa Review Report on Agriculture and Rural Development*. Addis Ababa. Retrieved from https://sustainabledevelopment.un.org/content/documents/eca_bg2.pdf

Afzal, S. Rauf, S.M.A. Basra, G. M. (2008). Halopriming improves vigor, metabolism of reserves and ionic contents in wheat seedlings under salt stress. *Plant Soil Environ*, *54*(9), 382–388.

Afzal, I., Basra, M. A., Lodhi, T. E., & Butt, J. (2007). Improving Germination and Seedling Vigour in Wheat by Halopriming under Saline Conditions. *Pak. J. Agri. Sci*, *44*(1).

AGRA. (2013). Catalogue official des especes et varieties, tome I cultures vivrieres.

AGRHYMET. (2009). Climate change in the Sahel, A challenge for sustainable development.

Ahmed, A. (2015). Characterization of Sudanese Sorghum (Sorghum bicolor L. Moench) Germplasm for Some Morphological and Yield Traits. Retrieved from http://repository.sustech.edu/handle/123456789/13112

Ahmed, M., Fayyaz-ul-Hassen, Qadeer, U., & Aslam, M. A. (2011). Silicon application and drought tolerance mechanism of sorghum. *African Journal of Agricultural Research*, *6*(3), 594–607. http://doi.org/10.5897/AJAR10.626

Ahmed, M., Qadeer, U., & Aslam, M. (2011). Silicon application and drought tolerance mechanism of sorghum. *African Journal of*. Retrieved from http://www.academicjournals.org/journal/AJAR/article-abstract/5BC15E634738

Ananda, N., Vadlani, P. V., & Prasad, P. V. V. (2011). Evaluation of drought and heat stressed grain sorghum (Sorghum bicolor) for ethanol production. *Industrial Crops and Products*, *33*(3), 779–782. http://doi.org/10.1016/j.indcrop.2011.01.007

Anda, A., & Pinter, L. (1994). Sorghum Germination and Development as Influenced by Soil Temperature and Water Content. *Agronomy Journal*, *86*(4), 621. http://doi.org/10.2134/agronj1994.00021962008600040008x

Antonio M. De Ron. (2015). *Grain Legumes*. Springer Science+Business Media LLC. http://doi.org/DOI10.1007/978-1-4939-2797-5

AOSA. (1983). *Seed Vigor Testing Handbook. Contribution No. 32 to the handbook on Seed Testing.* Retrieved from https://scholar.google.fr/scholar?q=Association+of+Official+Seed+Analysis+%2528AOSA%2529.+1983.+Seed+Vigor+Testing+Handbook.+Contribution+No.+32+to+the+handbook+on+Seed+Testing.&btnG=&hl=fr&as_sdt=0%252C5

AOSA. (1991). Rules for testing seeds. J. Seed Technol. 12: 18-19.

Araújo, W. L., Fernie, A. R., & Nunes-Nesi, A. (2011). Control of stomatal aperture: a renaissance of the old guard. *Plant Signaling & Behavior*, *6*(9), 1305–11. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/21847028

Arjmand, H. S., Sharafi, S., Jouyban, Z., & Akhlaghi, S. (2014). Effects of Priming on Seed Germination, Emergence and Field Performance. *Journal of Applied Science and Agriculture J. Appl. Sci. & Agric*, *9*(94), 1569–1573. Retrieved from www.aensiweb.com/jasa/index.html

Ashraf, M., & Foolad, M. (2005). Pre- sowing seed treatment—A shotgun approach to improve germination, plant growth, and crop yield under saline and non- saline conditions. *Advances in Agronomy*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0065211

30588006X

Ashraf, M. Y. (2014). Ahmad R., Waraich E.A., Ashraf M.Y., Ahmad S., Aziz T. 2014. Does nitrogen fertilization enhance drought tolerance in sunflower? a review. Journal of Plant Nutrition, 37: 942–963. *Journal of Plant Nutrition*, *37*, 942–963.

Asseng, S., Jamieson, P. ., Kimball, B., Pinter, P., Sayre, K., Bowden, J. ., & Howden, S. . (2004). Simulated wheat growth affected by rising temperature, increased water deficit and elevated atmospheric CO2. *Field Crops Research*, *85*(2), 85–102. http://doi.org/10.1016/S0378-4290(03)00154-0

Aune, J. B., & Coulibaly, A. (2015). Microdosing of Mineral Fertilizer and Conservation Agriculture for Sustainable Agricultural Intensification in Sub-Saharan Africa. In *Sustainable Intensification to Advance Food Security and Enhance Climate Resilience in Africa* (pp. 223–234). Cham: Springer International Publishing. http://doi.org/10.1007/978-3-319-09360-4_11

Aune, J. B., Doumbia, M., & Berthe, A. (2007). Microfertilizing sorghum and pearl millet in Mali: Agronomic, economic and social feasibility. *Outlook on Agriculture*, *36*(3), 199–203.

Aune, J. B., & Ousman, A. (2011). Effect of Seed Priming and Micro-Dosing of Fertilizer on Sorghum and Pearl Millet in Western Sudan. *Experimental Agriculture*, *47*(3), 419–430. http://doi.org/10.1017/S001 447 9711000056

Badu-Apraku, B., Annor, B., Oyekunle, M., & Akinwale, R. (2015). Grouping of early maturing quality protein maize inbreds based on SNP markers and combining ability under multiple environments. *Field Crops*. Retrieved from http://www.sciencedirect.com/science/article/pii/S03784 29015300186

Barbosa, N., Neto, M., Custódio, C. C., Gatti, A. B., Priolli, M. R., José, V., & Cardoso, M. (2004). Proline : use as an indicator of temperature stress in bean seeds. *Crop Breeding and Applied Biotechnology*, *4*(4).

Barmina, G. G. (2011). Metabolites produced during different growth conditions of *Sorghum bicolor* (L.) Moench.

Baskin, & B. (1998). *Seed, Ecology, Biogeography, and Evolution of Dormancy and Germination*. Retrieved from https://books.google.fr/ books?hl=fr&lr=&id=vXfNCgAAQBAJ&oi=fnd&pg=PP1&dq=Baskin, +%2526+Baskin,+1998&ots=-pklVgFSyb&sig=UxyVC26xnbumkuDyShoBwd40Vso#v=onepage&q= Baskin%252C %2526 Baskin%252C 1998&f=false

Basra, S., Farooq, M., & Tabassam, R. (2005). Physiological and biochemical aspects of pre-sowing seed treatments in fine rice (Oryza sativa L.). *Seed Science and*. Retrieved from http://www.ingentaconnect.com/ content/ ista/sst/2005/00000033/00000003/art00009

Basra, S. M. A., Ahmad, N., Khan, M. M., Iqbal, N., & Cheema, M. A. (2003). Assessment of cottonseed deterioration during accelerated ageing.

Bein, P., Burton, I., Chiotti, Q., Demeritt, D., Dore, M., Rothman, D., & Vandierendonck, M. (1999). Costing Climate Change in Canada: Impacts and Adaptation.

Bernier, J., Kumar, A., Ramaiah, V., Spaner, D., & Atlin, G. (2007). A Large-Effect QTL for Grain Yield under Reproductive-Stage Drought Stress in Upland Rice. *Crop Science*, *47*(2), 507.http://doi.org/10.2135/cropsci 2006.07.0495

Bibi, A., Sadaqat, H., Tahir, M., & Akram, H. (2012). Screening of sorghum (Sorghum bicolor var Moench) for drought tolerance at seedling stage in polyethylene glycol. *J. Anim. Plant Sci*. Retrieved from http://thejaps. org.pk/docs/v-22-3/26.pdf

Biesaga-Kościelniak, J., Ostrowska, A., Filek, M., Dziurka, M., Waligórski, P., Mirek, M., & Kościelniak, J. (2014). Evaluation of Spring Wheat (20 Varieties) Adaptation to Soil Drought during Seedlings Growth Stage. *Agriculture, 4*(2), 96–112. http://doi.org/10.3390/agriculture4020096

Bijagare, M. N., Ghuge, S. B., & Hudge, V. S. (1994). Effect of moisture stress on seed germination in sorghum. *Ann. Pl. Physiol.,* (8), 39–41. Retrieved from https://scholar.google.fr/scholar?q=Bijagare+et+al.+%2 81994%29+&btnG=&hl=fr&as_sdt=0%2C5

Bita, C. E., & Gerats, T. (2013a). Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. *Frontiers in Plant Science, 4*(July), 273. http://doi.org/10.3389/fpls.2013.00273

Bita, C. E., & Gerats, T. (2013b). Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. *Frontiers in Plant Science*, *4*, 273. http://doi.org/10. 3389/fpls.2013.00273

Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential—are they compatible, dissonant, or mutually exclusive? *Crop and Pasture Science*. Retrieved from http://www.publish.csiro.au/?paper =AR05069

Blum, A., Box, P. O., Aviv, T., & Email, I. (2016). Drought Resistance , Water-Use Efficiency , and Yield Potential — Are They Compatible , Dissonant, or Mutually Exclusive ?, (January),1159–1168. http://doi.org/ 10.1071/AR05069

Bouslama, M., & Schapaugh, W. T. (1984). Stress Tolerance in Soybeans. I. Evaluation of Three Screening Techniques for Heat and Drought Tolerance1. *Crop Science*, *24*(5), 933.http://doi.org/10.2135/cropsci1984. 0011183X002400050026x

Brar, G. S., Steiner, J. L., Unger, P. W., & Prihar, S. S. (1992). Modeling Sorghum Seedling Establishment from Soil Wetness and Temperature of Drying Seed Zones. *Agronomy Journal*, *84*(5), 905.http://doi.org/10. 2134/agronj1992.00021962008400050026x

Brown, P. (2008). Cotton heat stress.

Caffall, K. H., & Mohnen, D. (2009). The structure, function, and biosynthesis of plant cell wall pectic polysaccharides. *Carbohydrate Research*, *344*, 1879–1900. http://doi.org/10.1016/j.carres.2009.05.021

Campos, H., Cooper, M., Habben, J. E., Edmeades, G. O., & Schussler, J. R. (2004). Improving drought tolerance in maize: a view from industry. *Field Crops Research*, *90*, 19–34. http://doi.org/10.1016/j.fcr.2004.07. 003

Carnemark, C. (2013). African and Latin American Resilience to Climate Change Project The ARCC West Africa Regional Climate Change Vulnerability Assessment.

Carter, M. R., Sanderson, J. B., & MacLeod, J. A. (2004). Influence of compost on the physical properties and organic matter fractions of a fine sandy loam throughout the cycle of a potato rotation. *Canadian Journal of Soil Science, 84*, 211–218. http://doi.org/10.4141/S03-058

Cellier, F., Conéjéro, G., Breitler, J. C., & Casse, F. (1998). Molecular and physiological responses to water deficit in drought-tolerant and drought-sensitive lines of sunflower. Accumulation of dehydrin transcripts correlates with tolerance. *Plant Physiology*, *116*(1), 319–28. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9499218

Chachalis, D., Korres, N., & Khah, E. M. (2009). Factors Affecting Seed Germination and Emergence of Venice Mallow (Hibiscus trionum). *http://dx.doi.org/10.1614/WS-07-144.1*.

Chaves, M. M., Flexas, J., & Pinheiro, C. (2009). Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. *Annals of Botany*, *103*(4), 551–60. http://doi.org/10.1093/aob/mcn125

CHEN, G., ZHOU, Y., GUO, S., & SHEN, Q. (2007). The Regulatory Mechanism of Different Nitrogen Form on Photosynthetic Efficiency of Rice Plants Under Water Stress. *Scientia Agricultura Sinica*. Retrieved from http://en.cnki.com.cn/Article_en/CJFDTOTAL-ZNYK200710008.htm

Chen, K., & Arora, R. (2013). Priming memory invokes seed stress-tolerance. *Environmental and Experimental Botany*, *94*, 33–45.http://doi.org/10.1016/j.envexpbot.2012.03.005

Chiu, K. Y., Chen, C. L., & Sung, J. M. (2002). Effect of Priming Temperature on Storability of Primed Sweet Corn Seed. *Crop Science*, *42*(6), 1996. http://doi.org/10.2135/cropsci2002.1996

Copeland, L. O., & McDonald, M. B. (2001). Seed Vigor and Vigor Testing. In *Principles of Seed Science and Technology* (pp. 165–191). Boston, MA: Springer US. http://doi.org/10.1007/978-1-4615-1619-4_8

Craufurd, P. Q., Mahalakshmi, V., Bidinger, F. R., Mukuru, S. Z., Chantereau, J., Omanga, P. A., … Hammer, G. L. (1999). Adaptation of sorghum: characterisation of genotypic flowering responses to temperature and photoperiod. *TAG Theoretical and Applied Genetics*, *99*(5), 900–911. http://doi.org/10.1007/s001220051311

Dameris, M., Godin-Beekmann, S., Bekki, S., Perlwitz, J., Alexander, S., Braesicke, P., … Santee, M. L. (2014). Update on Polar Ozone : past, Present, and Future, Chapitre 3, (70).

Dasgan, H., & Koc, S. (2009). Evaluation of salt tolerance in common bean genotypes by ion regulation and searching for screening parameters. *J. Food Agric. Environ*. Retrieved from https://www.researchgate.net/profile/H_Dasgan/publication/229439428_Evaluation_of_salt_tolerance_in_common_bean_genotypes_by_ion_regulation_and_searching_for_screening_parameters/links/0fcfd500e4f675a692000000.pdf

De Wet, J. M. J., & Harlan, J. R. (1971). The origin and domestication ofSorghum bicolor. *Economic Botany*, *25*(2), 128–135. http://doi.org/10. 1007/BF02860074

Dell'Aquila, A. (2009). Development of novel techniques in conditioning, testing and sorting seed physiological quality, *37*(3), 608–624.

Dembele, S. unpublished. (2015). *Rapport d'activites*. Agricultural Reseach Station of Cinzana, Mali.

Dembele, S. (2017). Map of Segou region shown Cinzana district. Agricultural Reseach Station of Cinzana, Mali.

Dezfuli, P. M., Sharif-Zadeh, F., & Janmohammadi, M. (2008). Influence of Priming Techniques on Seed Germination Behavior of Maize Inbred Lines (Zea mays L.), *3*(3).

Dicko, M. H., Gruppen, H., Traore, A. S., Voragen, A. G. J., & Berkel, W. J. H. Van. (2006). Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. *African Journal of Biotechnology* , *5*(5), 384–395. http://doi.org/10.5897/AJB05.060

Doggett, H. (1988). Sorghum. Retrieved from http://www.cabdirect. org/abstracts/19891607421.html

El-Keblawy, A., & Al-Rawai, A. (2005). Effects of salinity, temperature and light on germination of invasive Prosopis juliflora (Sw.) DC. *Journal of Arid Environments*. Retrieved fromhttp://www.sciencedirect.com/science article/pii/S0140196304002162

Elkoca, E. (2014). Osmo-and hydropriming enhance germination rate and reduce thermal time requirement of pea (Pisum sativum L. cv. Winner) seeds. *Akademik Ziraat Dergisi*, *3*(1), 1–12.Retrieved from http://azd. odu.edu.tr

Ellis, R. H., Covell, S., Roberts, E. H., & Summerfield, R. J. (1986). The Influence of Temperature on Seed Germination Rate in Grain Legumes. *Journal of Experimental Botany*, *37*(10), 1503–1515. http://doi.org/10.1093/jxb/37.10.1503

Elzaki, H. (2015). Evaluation of the Nutritive Value of New Sorghum (*Sorghum bicolor* L. Monech) Lines. Retrieved from http://41.67.2 0.41/handle/123456789/17934

EM-DAT. (2016). EM-DAT The International Disaster Database. Retrieved July 3, 2016, from http://www.emdat.be/

FAO. (2003). Global potential soil erosion with reference to land use and climate changes. *Hydrological Processes*, *17*(14), 2913–2928. http://doi.org/10.1002/hyp.1441

FAO. (2015). Food and Agriculture Organization of the United Nations Statistics Division. Retrieved December 20, 2015, from http://faostat 3.fao.org/home/E

FAOSTAT. (2016). Agriculture Organization of the United Nations Statistics Division (2014).

Farahani, H. A., Moaveni, P., & Maroufi, K. (2011). Effect of thermopriming on germination of cowpea (Vigna sinensis L.). *Advances in Environmental Biology*, 1668–1674.

Farooq, M., Aziz, T., ur Rehman, H., ur Rehman, A., Cheema, S. A., & Aziz, T. (2011). Evaluating surface drying and re-drying for wheat seed priming with polyamines: effects on emergence, early seedling growth and starch metabolism. *Acta Physiologiae Plantarum*, *33*(5), 1707–1713. http://doi.org/10.1007/s11738-010-0707-3

Farooq, M., Aziz, T., Wahid, A., & Lee, D. (2009). Chilling tolerance in maize: agronomic and physiological approaches. *Crop and Pasture*. Retrieved from http://www.publish.csiro.au/?paper=CP08427

Farooq, M., Basra, S., & Hafeez, K. (2006). Seed invigoration by osmohardening in coarse and fine rice. *Seed Science and*. Retrieved from http://www.ingentaconnect.com/content/ista/sst/2006/00000034/00000001/art00019

Farré, I., & Faci, J. M. (2006). Comparative response of maize (Zea mays L.) and sorghum (Sorghum bicolor L. Moench) to deficit irrigation in a Mediterranean environment. *Agricultural Water Management*, *83*(1), 135–143. http://doi.org/10.1016/j.agwat.2005.11.001

Fatondji, D., Martius, C., Zougmore, R., Vlek, P. L. G., Bielders, C. L., & Koala, S. (2009). Decomposition of organic amendment and nutrient release under the zai technique in the Sahel. *Nutrient Cycling in Agroecosystems*, *85*(3), 225–239. http://doi.org/10.1007/s10705-009-9261-z

Fereres, E., Acevedo, E., Henderson, D. W., & Hsiao, T. C. (1978). Seasonal Changes in Water Potential and Turgor Maintenance in Sorghum and Maize under Water Stress. *Physiologia Plantarum*, *44*(3), 261–267. http://doi.org/10.1111/j.1399-3054.1978.tb08629.x

Feyen, L., & Dankers, R. (2009). Impact of global warming on streamflow drought in Europe. *Journal of Geophysical Research*, *114*(D17), D17116. http://doi.org/10.1029/2008JD011438

Finch-Savage, W. E., & Leubner-Metzger, G. (2006). Seed dormancy and the control of germination. *New Phytologist*, *171*(3), 501–523. http://doi.org/10.1111/j.1469-8137.2006.01787.x

Fritz, C., Pancotto, V. A., Elzenga, J. T. M., Visser, E. J. W., Grootjans, A. P., Pol, A., … Smolders, A. J. P. (2011). Zero methane emission bogs: extreme rhizosphere oxygenation by cushion plants in Patagonia. *New Phytologist*, *190*(2), 398–408. http://doi.org/10.1111/j.1469-8137.2010.03604.x

G D Farquhar, J R Ehleringer, and, & Hubick, K. T. (2003). Carbon Isotope Discrimination and Photosynthesis. *http://dx.doi.org/10.1146/annurev.pp.40.060189.002443*.

Gerrano, A., Labuschagne, M., & Biljon, A. van. (2016). Quantification of mineral composition and total protein content in sorghum genotypes. *Cereal Research*. Retrieved from http://www.akademiai.com/doi/abs/10.1556/0806.43.2015.046

Ghassemi-golezani, K., Chadordooz-jeddi, A., & Zafarani-moattar, P. (2011). Influence of salt-priming on mucilage yield of Isabgol (Plantago ovata Forsk) under salinity stress, *5*(14), 3236–3241.

Ghassemi-Golezani, K., Jabbarpour, S., & Zehtab-Salmasi, S. (2013). Influence of seed priming on ground cover and grain yield of spring and winter rapeseed cultivars. *Int. J. Biosci*.http://doi.org/10.12692/ijb/3.2.54-61

Ghassemi-Golezani, K., & Mazloomi-Oskooyi, R. (2012). Effect of water supply on seed quality development in common bean (Phaseolus vulgaris var.). *International Journal of Plant Production*, *2*(2), 117–124.

Giri, G., & Schillinger, W. (2003). Seed priming winter wheat for germination, emergence, and yield. *Crop Science*. Retrieved from https://dl.sciencesocieties.org/publications/cs/abstracts/43/6/2135

Grabs, W., Tyagi, A. C., & Hyodo, M. (2007). Integrated flood management. *Water Science & Technology*, *56*(4), 97. http://doi.org/10.2166/wst.2007.541

Hamaker, B., & Bugusu, B. (2003). Overview: sorghum proteins and food quality. *Workshop on the Proteins of Sorghum and*. Retrieved from http://www.afripro.org.uk/PAPERS/PAPER08Hamaker.PDF

Hameed, A., Goher, M., & Iqbal, N. (2010). Evaluation of seedling survivability and growth response as selection criteria for breeding drought tolerance in wheat. *Cereal Research Communications*. Retrieved from http://www.akademiai.com/doi/abs/10.1556/CRC.38.2010.2.5

Harris, D. (2006). Development and Testing of “On-Farm” Seed Priming. *Advances in Agronomy*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0065211306900042

Harris, D., Breese, W., & Rao, J. (2005). The improvement of crop yield in marginal environments using’on-farm’seed priming: nodulation, nitrogen fixation and disease resisitance. *Crop and Pasture Science*. Retrieved from http://www.publish.csiro.au/?paper=AR05079

Harris, D., Hamdi, Q. A., & Terry, A. C. (1987). Germination and emergence of Sorghum bicolor. genotypic and environmentally induced variation in the response to temperature and depth of sowing. *Plant, Cell and Environment*, *10*(6), 501–508. http://doi.org/10.1111/j.1365-3040.1987.tb01828.x

Harris, D., Raghuwanshi, B. S., Gangwar, J. S., Singh, S. C., Joshi, K. D., Rashid, A., & Hollington, P. A. (2001). Participatory Evaluation by Farmers of on-farm Seed Priming in Wheat in India, Nepal and Pakistan. *Experimental Agriculture*, *37*(3), 403–415. http://doi.org/10.1017/S0014479701003106

Hertel, T. W. (2011). The Global Supply and Demand for Agricultural Land in 2050: A Perfect Storm in the Making? *American Journal of Agricultural Economics*, *93*(2), 259–275. http://doi.org/10.1093/ajae/aaq189

Heydecker, W., Higgins, J., & Gulliver, R. L. (1973). Accelerated Germination by Osmotic Seed Treatment. *Nature*, *246*(5427), 42–44. http://doi.org/10.1038/246042a0

Hoad, S. P., Russell, G., Lucas, M. E., & Bingham, I. J. (2001). The management of wheat, barley, and oat root systems. *Advances in Agronomy*, *74*, 193–246. http://doi.org/10.1016/S0065-2113(01)74034-5

Howden, S. M., Soussana, J.-F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19691–19696. http://doi.org/10.1073/pnas.0701890104

Hsiao, T. C., Acevedo, E., Fereres, E., & Henderson, D. W. (1976). Water Stress, Growth, and Osmotic Adjustment. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *273*(927), 479–500. http://doi.org/10.1098/rstb.1976.0026

Hussain, M., Farooq, M., Basra, S. M. A., & Ahmad, N. (2006). Influence of Seed Priming Techniques on the Seedling Establishment , Yield and Quality of Hybrid Sunflower. *International Journal of Agriculture and Biology*, *8*(1), 14–18.

ICRISAT and ICARDA. (2012). *CGIAR Research Program on Dryland Cereals - CGIAR. Aglobal alliance for improving food security, nutrition and economic growth for the world's most vulnerable poor*.

Ignaciuk, A. (2015). *Adapting Agriculture to Climate Change*. OECD Publishing.

Imtiaz Sudozai, M., Tunio, S., & Rajpar, I. (2013). Seedling Establishment and Yield of Maize under Different Seed Priming Periods and Available Soil Moisture, *29*(4).

IPCC. (2007). *Changements Climatiques 2007 R a pp ort de s y n t h è se*. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_fr.pdf

Jaleel, C. A., Manivannan, P., Wahid, A., Farooq, M., Al-Juburi, J., Somasundaram, R., & Panneerselvam, R. (2009). Drought Stress in Plants: A Review on Morphological Characteristics and Pigments Composition. *Int. J. Agric. Biol*, *11*, 1560–8530. Retrieved from http://www.fspublishers.org

Joshi-Saha, A., & Reddy, K. (2015). Repeat length variation in the 5′UTR of myo-inositol monophosphatase gene is related to phytic acid content and contributes to drought tolerance in chickpea (Cicer. *Journal of Experimental Botany*. Retrieved from http://jxb.oxfordjournals.org/content/early/2015/04/16/jxb.erv156.short

Juo. (1987). Soil and Crop Science Society of Florida. Florida. Retrieved from https://books.google.fr/books?id=raEdAQAAMAAJ&q=The+Alfisols,+according+to+Juo+(1980)&dq=The+Alfisols,+according+to+Juo+(1980)&hl=fr&sa=X&ved=0ahUKEwj24I76j-nNAhWB5RoKHRpwDL04ChDoAQhKMAY

Kabore, D. and Reij, C. (2004). *The Emergence and Spreading of an Improved Traditional and Water Conservation practice in Burkina Faso*.

Kabore, V., & Guenat, C. (1999). Zaï Practice: A West African Traditional Rehabilitation System for Semiarid Degraded Lands, a Case Study in Burkina Faso Fonds Documentaire ORSTOM.

Kadhimi, A., Alhasnawi, A., & Isahak, A. (2014). Use of biotechnology to improve the tolerance in rice (Oryza sativa) to drought stress. *Journal of Pure and*. Retrieved from https://www.researchgate.net/profile/Febri_Doni/publication/267630038_Use_of_Biotechnology_to_Improve_the_Tolerance_in_Rice_(Oryza_sativa)_to_Drought_Stress/links/545491cc0cf2bccc490b3532.pdf

Kaya, M. D. (2009). The role of hull in germination and salinity tolerance in some sunflower (Helianthus annuus L.) cultivars. *African Journal of Biotechnology*, *8*(4), 597–600. Retrieved from http://www.academicjournals.org/AJB

Kaydan, D., & Yagmur, M. (2008). Germination, seedling growth and relative water content of shoot in different seed sizes of triticale under osmotic stress of water and NaCl. *African Journal of Biotechnology*. Retrieved from http://search.proquest.com/openview/98e9c771e837a5bbc791b59cfe30058c/1?pq-origsite=gscholar

Keyantash, John; Dracup, J. A. (2002). The quantification of drought: An evaluation of drought indices. *Bulletin of the American Meteorological Society*, (83.8), 1167–1180. Retrieved from http://search.proquest.com/openview/afc945fd4c4b7afc7f3d820dbf95d82a/1?pq-origsite=gscholar

Khalil, S. K., Khan, S., Rahman, A., Khan, A. Z., Khalil, I. H., Amanullah, … Khan, A. (2010). Seed Priming and Phosphorus Application Enhance Phenology and Dry Matter Production of Wheat. *Pakistan Journal of Botany*, *42*(3), 1849–1856.

Khan, A. A., Peck, N. H., & Samimy, C. (2013). Seed Osmoconditioning: Physiological and Biochemical Changes. *Israel Journal of Botany*.

Khan, A., Khalil, S. K., Khan, A. Z., Marwat, K. B., & Afzal, A. (2008). The role of seed priming in semi-arid area for mung bean phenology and yield. *Pakistan Journal of Botany*, *40*(6), 2471–2480.

Kibite, S., & Harker, K. N. (2011). Effects of seed hydration on agronomic performance of wheat, barley and oats in central Alberta. *http://dx.doi.org/10.4141/cjps91-072*.

kobayashi, y., murata, m., minami, h., yamamoto, s., kagaya, y., hobo, t., … hattori, t. (2005). abscisic acid-activated snrk2 protein kinases function in the gene-regulation pathway of aba signal transduction by phosphorylating aba response element-binding factors. *the plant journal*, *44*(6), 939–949. http://doi.org/10.1111/j.1365-313x.2005.02583.x

Koller, D., & Hadas, A. (1982). Water Relations in the Germination of Seeds. In *Physiological Plant Ecology II* (pp. 401–431). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-642-68150-9_13

Kouyate, Z., & Wendt, G. W. (1991). Gestion de l’eau et de la fertilité du sol au Mali, (199).

Krishnamurthy, L., Zaman-Allah, M., Purushothaman, R., Irshad Ahmed, M., & Vadez, V. (2011). 3 Plant Biomass Productivity Under Abiotic Stresses in SAT Agriculture, 1–18. Retrieved from http://oar.icrisat.org/1312/1/lk1.pdf

Law, D. R., Crafts-Brandner, S. J., & Salvucci, M. E. (2001). Heat stress induces the synthesis of a new form of ribulose-1,5-bisphosphate carboxylase/oxygenase activase in cotton leaves. *Planta*, *214*(1), 117–125. http://doi.org/10.1007/s004250100592

Leegood, R. (2002). C4 photosynthesis: principles of CO2 concentration and prospects for its introduction into C3 plants. *Journal of Experimental Botany*. Retrieved from http://jxb.oxfordjournals.org/content/53 /369/581.short

Lemrasky, M. G., & Hosseini, S. Z. (2012). Effect of seed priming on the germination behavior of wheat. *International Journal of Agriculture and Crop Sciences*, *4*(9), 564–567.

Liu, Q., Liu, H., Wen, J., Peterson, P. M., Garber, E., Lazarides, M., Moritz, C. (2014). Infrageneric Phylogeny and Temporal Divergence of Sorghum (Andropogoneae, Poaceae) Based on Low-Copy Nuclear and Plastid Sequences. *PLoS ONE*, *9*(8), e104933. http://doi.org/10.1371/journal. pone.0104933

Lontchi Josine, T., Ji, J., Wang, G., & Guan, C. F. (2011). Advances in genetic engineering for plants abiotic stress control. *African Journal of Biotechn ology*, *10*(28), 5402–5413. Retrieved from http://www.academicjournals. org/AJB

Loon, A. Van, & Lanen, H. Van. (2012). A process-based typology of hydro logical drought. *Hydrology and Earth*. Retrieved fromhttp://www.hydrol-earth-syst-sci.net/16/1915/2012/hess-16-1915-2012.pdf

Loon, A. Van, Lanen, H. Van, & Hisdal, H. (2010). Understanding hydrological winter drought in Europe. *Change: Facing Risks …*. Retrieved from http://www.academia.edu/download/41207366/

VanLoon_etal_2010_Hydrological_winter_drought_IAHS.pdf20160115-19908-cl5h1o.pdf

M.N. Danjuma and S. Mohammed. (2015). Zai Pits System: A Catalyst for Restoration in the Dry Lands\n. *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS), 8*(2), 01–04. http://doi.org/10.9790/2380-08210104

Macar, T. K., Turan, Ö., & Ekmekçi, Y. (2009). Effects of Water Deficit Induced by PEG and NaCl on Chickpea (Cicer arietinum L.) Cultivars and Lines at Early Seedling Stages.

Maguire, J. D. (1962). Speed of Germination—Aid In Selection And Evaluation for Seedling Emergence And Vigor1. *Crop Science*, *2*(2), 176. http://doi.org/10.2135/cropsci1962.0011183X000200020033x

Malleshi, N., & Desikachar, H. (1988). Reducing the paste viscosity (dietary bulk) of roller dried weaning foods using malt flour or fungal amylase. *Journal of Food Science and Technology*. Retrieved from http://cat.inist.fr/?aModele=afficheN&cpsidt=7735238

Manzungu, E., Senzanje, A., & Zaag, P. van der. (1999). Water for agriculture in Zimbabwe: policy and management options for the smallholder sector.

Masendeke, S., & Shoko, K. (2014). Drought Coping Strategies and Their Effectiveness: The Case of Ward 12 in Mberengwa District Zimbabwe. *International Journal of Social Science Studies*, *2*(1). http://doi.org/10.11 114 /ijsss.v2i1.299

Masih, I., Maskey, S., Muss??, F. E. F., & Trambauer, P. (2014). A review of droughts on the African continent: A geospatial and long-term perspective. *Hydrology and Earth System Sciences*, *18*(9), 3635–3649. http://doi.org/10.5194/hess-18-3635-2014

Matsushima, Ken-Ichi; Sakagami, J.-I. (2013). Effects of Seed Hydropriming on Germination and Seedling Vigor during Emergence of Rice under Different Soil Moisture Conditions. *American Journal of Plant Sciences*, 1584–1593. Retrieved from http://search.proquest.com/openview/09fdd

5b9f3eddceecc35afe8533e7491/1?pq-origsite=gscholar

Meyers, S. P., Nelson, C. J., & Horrocks, R. D. (1984). Temperature effects on imbibition, germination and respiration of grain sorghum seeds. *Field Crops Research*, *8*, 135–142. http://doi.org/10.1016/0378-4290(84)9

0057-1

Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, *391*(1), 202–216. http://doi.org/10.1016/j.jhydrol.2010. 07.012

Mohammadi, H., Soltani, A., Sadeghipour, H. R., & Zeinali, E. (2011). Effects of seed aging on subsequent seed reserve utilization and seedling growth in soybean. *International Journal of Plant Production*. Retrieved from www.ijpp.info

Mortlock, M. Y., & Vanderlip, R. L. (1989). Germination and establishment of pearl millet and sorghum of different seed qualities under controlled high-temperature environments. *Field Crops Research*, *22*(3), 195–209. http://doi.org/10.1016/0378-4290(89)90092-0

Moussa, I., Maiga, O., Ambouta, J., & Sarr, B. (2009). Les conséquences géomorphologiques de l’occupation du sol et des changements climatiques dans un bassin-versant rural sahélien. *Science et Changements*. Retrieved from http://www.jle.com/fr/revues/sec/e-docs/les_consequences_geomorphologiques_de_loccupation_du_sol_et_des_changements_climatiques_dans_un_bassin_versant_rural_sahelien_281044/article.phtml

Murungu, F., & Chiduza, C. (2004). Effect of on-farm seed priming on emergence, growth and yield of cotton and maize in a semi-arid area of Zimbabwe. *Experimental*. Retrieved from http://journals.cambridge .org/abstract_S0014479703001509

Murungu, F., Chiduza, C., Nyamugafata, P., & Clark, L. (2004). Effects of “on-farm seed priming”on consecutive daily sowing occasions on the emergence and growth of maize in semi-arid Zimbabwe. *Field Crops*. Retrieved from http://www.sciencedirect.com/science/article/pii /S0378429004000607

Murungu, F., Nyamugafata, P., & Chiduza, C. (2003). Effects of seed priming, aggregate size and soil matric potential on emergence of cotton (Gossypium hirsutum L.) and maize (Zea mays L.). *Soil and Tillage*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0167198703001697

Murungu, F. S., Nyamugafata, P., Chiduza, C., Clark, L. J., & Whalley, W. R. (2013). Effects of seed priming and water potential on germination of cotton (Gossypium hirsutum L.) and maize (Zea mays L.) in laboratory assays. *http://dx.doi.org/10.1080/02571862.2005.10634683*.

Myers, O., Yopp, J. H., & Krishnamani, M. R. S. (2011). Breeding Soybeans for Drought Resistance. In *Plant Breeding Reviews* (pp. 203–243). Hoboken, NJ, USA: John Wiley & Sons, Inc. http://doi.org/10.1002/9781118061015.ch7

Nabhan, H., Mashali, A. M., & Mermut, A. R. (1997). Integrated Soil Management for Sustainable Agriculture and Food security in Southern and East Africa. In *... Management for Sustainable Agriculture and Food ...* (pp. 1–415). Retrieved from Les plus visités

Nakaune, M., Tsukazawa, K., Uga, H., Asamizu, E., Imanishi, S., Matsukura, C., & Ezura, H. (2012). Low sodium chloride priming increases seedling vigor and stress tolerance to Ralstonia solanacearum in tomato. *Plant Biotechnology*, *29*(1), 9–18. http://doi.org/10.5511/plantbiotechnology.11.1122a

Nellemann, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A. and Kaltenborn, B. (eds.). (2009). *The Environmental Food Crisis. The environment's role in averting future food crises. A UNEP rapid response assessment. Arendal, UNDP*. Retrieved from https://books. google. fr/books?hl=fr&lr=&id=BO6d5mBc42cC&oi= fnd&pg=PA9&dq =Nellemann+et+al.,+2009&ots=_ANe6OexJA&sig=zYf3zK2qiYcaMKL xaauDTyLnOLc#v=onepage&q=Nellemann et al.%252C 2009&f=false

Nelson, L. R., & HSU, K. H. (1985). Effects of Leachate Accumulation During Hydration in a Thermalscrew Blancher on the Water Absorption and Cooked Texture of Navy Beans. *Journal of Food Science*, *50*(3), 782–788. http://doi.org/10.1111/j.1365-2621.1985.tb13796.x

Ng'uni, D. (2011). Phylogenetics of the genus sorghum, genetic diversity and nutritional value of its cultivated species.

Nicol, A., Langan, S., Victor, M., J. (2015). *Water-Smart Agriculture in Easr Africa*. CGIAR Research Program on Water, Land and Ecosystems (WLE). Retrieved from https://books.google.fr/books?id=BhHPBw

AAQBAJ&pg=PA134&dq=improved+yields+of+millet+when+grown+u sing+the+Zaï+pits+system+in+West+Africa&hl=fr&sa=X&ved=0ahUK EwjyptWAmOnNAhWCyhoKHQ9zDh4Q6AEIQjAF#v=onepage&q=im proved yields of millet when grown using th

Nikanorov, A. M., & Brazhnikova, L. V. (1989). Water Chemical Composition of Rivers, Lakes and Wetlands, II, 42–69.

Nivedita, M. (1992). Effect of moisture status and bulk density on germination and emergence of pearl millet, sorghum and groundnut on an Alfisol. Retrieved from http://oar.icrisat.org/656/

Nyamadzawo, G., Wuta, M., Nyamangara, J., & Gumbo, D. (2013). Opportunities for optimization of in-field water harvesting to cope with changing climate in semi-arid smallholder farming areas of Zimbabwe. *SpringerPlus*, *2*(1), 100. http://doi.org/10.1186/2193-1801-2-100

Obayelu, A., & Afolami, C. (2013). Comparative Analysis of Resource Use Efficiency among Various Production Scale Operators in Cassava-Based Mixed Cropping Systems of Ogun and Oyo. *2013 AAAE Fourth*. Retrieved from http://ageconsearch.umn.edu/bitstream/160123/2/

Comparaitve Analysis of Resource Use.pdf

Önemli, F. (2004). The effects of soil organic matter on seedling emergence in sunflower (Helianthus annuus L .), *2004*(11), 494–499.

Ougham, H. J., & Stoddart, J. L. (1986). Synthesis of heat-shock protein and acquisition of thermotolerance in high-temperature tolerant and high-temperature susceptible lines of Sorghum. *Plant Science*, *44*(3), 163–167. http://doi.org/10.1016/0168-9452(86)90087-7

Parera, C. A., & Cantliffe, D. J. (1994). Dehydration Rate after Solid Matrix Priming Alters Seed Performance of Shrunken-2 Corn. *Journal of the American Society for Horticultural Science*, *119*(3), 629–635.

Parry, M., & Rosenzweig, C. (2005). Climate change, global food supply and risk of hunger. *Of the Royal*. Retrieved from http://rstb.royalsociety publishing.org/content/360/1463/2125.short

Passam, H. C., & Kakouriotis, D. (1994). The effects of osmoconditioning on the germination, emergence and early plant growth of cucumber under saline conditions. *Scientia Horticulturae*, *57*(3), 233–240. http://doi.org/ 10.1016/0304-4238(94)90143-0

Peacock. (1982). Agrometeorology of Sorghum and Millet In the Semi-Arid Tropics International Crops Research Institute for the Semi-Arid Tropics. *Proceeding of the International Sympossium*, 1–328.

Prasad, P., & Staggenborg, S. (2008). Impacts of drought and/or heat stress on physiological, developmental, growth, and yield processes of crop plants. *Response of Crops to*. Retrieved fromhttps://dl.sciencesocieties .org/publications/books/abstracts/advancesinagric/responseofcrops/301

Prasad, P., & Staggenborg, S. (2009). Growth and production of sorghum and millets. *Soils, Plant Growth and Crop*. Retrieved from https://www. researchgate.net/profile/P_V_Vara_Prasad/publication/260392531_Growth_and_Production_of_Sorghum_and_Millets/links/0c9605311770e75b1b000000.pdf

Prasad, P. V. V., Staggenborg, S. a., & Ristic, Z. (2008). Impacts of Drought and/or Heat Stress on Physiological, Developmental, Growth, and Yield Processes of Crop Plants. *Response of Crops to Limited Water: Understanding and Modeling Water Stress Effects on Plant Growth Processes. Advances in Agricultural Systems Modeling Series 1.*, (December 2015), 301–356. http://doi.org/10.2134/advagricsyst model1.c11

Prasad, P. V. V., Pisipati, S. R., Momčilović, I., & Ristic, Z. (2011). Independent and Combined Effects of High Temperature and Drought Stress During Grain Filling on Plant Yield and Chloroplast EF-Tu Expression in Spring Wheat. *Journal of Agronomy and Crop Science, 197*(6), 430–441. http://doi.org/10.1111/j.1439-037X.2011.00477.x

Prein, M., & Ahmed, M. (2000). Integration of Aquaculture into Smallholder Farming Systems for Improved Food Security and Household Nutrition. *Food and Nutrition Bulletin*, *21*(4), 466–471. http://doi.org/10.1177/15 6482650002100424

Price, H. J., Dillon, S. L., Hodnett, G., Rooney, W. L., Ross, L., & Johnston, J. S. (2005). Genome evolution in the genus Sorghum (Poaceae). *Annals of Botany*, *95*(1), 219–27. http://doi.org/10.1093/aob/mci015

Quinby, J. R., Hesketh, J. D., & Voigt, R. L. (1973). Influence of Temperature and Photoperiod on Floral Initiation and Leaf Number in Sorghum1. *Crop Science*, *13*(2), 243. http://doi.org/10.2135/cropsci1973.001118 3X001300020028x

Rahimi, A. (2013). Seed priming improves the germination performance of cumin (Cuminum syminum L.) under temperature and water stress. *Industrial Crops and Products*, *42*, 454–460. http://doi.org/10.1016 /j.indcrop.2012.06.026

Rahmat, S. N., Jayasuriya, N., & Bhuiyan, M. A. (2016). Short-term droughts forecast using Markov chain model in Victoria, Australia. *Theoretical and Applied Climatology*, 1–13. http://doi.org/10.1007/s00704-016-1785-y

Rao, S.S., Seetharama, N., Kiran Kumar, K.A., & Vanderlip, R. . (2004). Characterization of sorghum growth stages. *NRCS Bulletin Series*, (14).

Rastin, S., Madani, H., & Shoaei, S. (2013). Effect of seed priming on red bean (Phaseolus calcaratus) growth and yield. *Scholars Research Library Annals of Biological Research*, *4*(2), 292–296. Retrieved from www.scholarsresearchlibrary.com

Reay, D., Davidson, E., Smith, K., & Smith, P. (2012). Global agriculture and nitrous oxide emissions. *Climate Change*. Retrieved from http://www.nature.com/nclimate/journal/v2/n6/full/nclimate1458.html

Reddy, A. R., Chaitanya, K. V., & Vivekanandan, M. (2004). Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *Journal of Plant Physiology*, *161*(11), 1189–1202. http://doi.org/10.1016/j.jplph.2004.01.013

Reddy, B., & Kumar, A. A. (2010). Recent advances in sorghum improvement research at ICRISAT. *Journal (Natural Science*. Retrieved from http://oar.icrisat.org/252/

Reij, C., Tappan, G., & Smale, M. (2009). Agroenvironmental Transformation in the Sahel.

Rippke, U., Ramirez-Villegas, J., Jarvis, A., Vermeulen, S. J., Parker, L., Mer, F., … Howden, M. (2016). Timescales of transformational climate change adaptation in sub-Saharan African agriculture. *Nature Climate Change*, *6*(6), 605–609. http://doi.org/10.1038/nclimate2947

Roose, E., Kabore, V., & Guenat, C. (2010). Zai Practice: A West African Traditional Rehabilitation System for Semiarid Degraded Lands, a Case Study in Burkina Faso. *http://dx.doi.org/10.1080/089030699263230*.

Rosegrant, M., Yohe, G., & Ewing, M. (2010). Climate change and Asian agriculture. *Asian Journal of*. Retrieved from http://6thasae.searca.org/ajad/files/061411173637_rosegrant_et_al..pdf

Roy, M. M., Dutta, A., Corscadden, K., & Havard, P. (2011). Co-combustion of Biosolids with Wood Pellets in a Wood Pellet Stove. *International Journal of Engineering & Technology IJET-IJENS IJENS I J E N S, 11*(3).

Sahib, M. M., Hamzah, N. A., & Hussein, H. J. (2013). Effect of Seed Priming by KH_2PO_4 and Different Temperature on Seeds Germination Behavior of Okra (*Abelmoschus esculentus* L.).

Salvucci, M. (2008). Association of Rubisco activase with chaperonin-60β: a possible mechanism for protecting photosynthesis during heat stress. *Journal of Experimental Botany*. Retrieved from http://jxb.oxfordjournals.org/content/59/7/1923.short

Schmitz, C., Meijl, H. van, Kyle, P., & Nelson, G. (2014). Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. *Agricultural*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/agec.12090/full

Sebnem Kusvuran, S. (2012). Effects of drought and salt stresses on growth, stomatal conductance, leaf water and osmotic potentials of melon genotypes (Cucumis melo L.). *African Journal of Agricultural Research*, *7*(5), 775–781. http://doi.org/10.5897/AJAR11.1783

Seetharama, N., Bidinger, F. R., Rao, K. N., Gill, K. S., & Mulgund, M. (1987). Effect of pattern and severity of moisture deficit stress on stalk rot incidence in Sorghum I. Use of line source irrigation technique, and the effect of time of inoculation. *Field Crops Research*, *15*(3–4), 289–308. http://doi.org/10.1016/0378-4290(87)90018-9

Seneviratne, S. I. (2012). Climate science: Historical drought trends revisited. *Nature*, *491*(7424), 338–339. http://doi.org/10.1038/491338a

Seyed Sharifi, R., & Khavazi, K. (2005). Effects of seed priming with Plant Growth Promoting Rhizobacteria (PGPR) on yield and yield attribute of maize (Zea mays L.) hybrids. *Journal of Food, Agriculture & Environment Journal of Food Agriculture & Environment*, *99*(4), 496–500.

Shaban, M. (2013). Effect of water and temperature on seed germination and emergence as a seed hydrothermal time model, *1*(12), 1686–1691.

Sharaf M. M., Atawia A. R., B. K. A., ., EL, A., -, & M, R. (2016). Effect of Pre-Sowing Seeds Soak in Different GA3 and ZnSo4 Solutions on Germination and Growth of Cleopatra Mandarin and Rangpur Lime Rootstocks. *Middle East Journal of Agriculture Research*, 233–238.

Shitole, S., & Dhumal, K. (2012). Effect of water Stress by polyethylene glycol 6000 and sodium chloride on seed germination and seedling growth of Cassia Angustifolia. *International Journal of*. Retrieved from http://search.proquest.com/openview/fcb6bafeddff7c2d05dcd3f240c67a1f/1?pq-origsite=gscholar

Simsek, M., Can, A., Denek, N., & Tonkaz, T. (2011). The effects of different irrigation regimes on yield and silage quality of corn under semi-arid conditions. *African Journal of Biotechnology*, *10*(31), 5869–5877. http://doi.org/10.5897/AJB11.259

Singh, N.P., Byjesh, K., Bantilan, C., Rao, V.U.M., Venkateswarulu, B., Niranjan, F., Jayatilaka, W., Deb, U.K., Ha, P.Q. and Suddhiyam, P. (2015). Evaluating Adaptation Options at Crop Level for Climate Change in The Tropics of South Asia and West Africa (pp. 115–232). Retrieved from https://books.google.fr/books?hl=fr&lr=&id=ziwZCwAAQBAJ&oi fnd&pg=PA115&dq=In+the+semi-arid,+tropical+regions,+changes+ in+rainfall+and+certainly+when+coupled+with+rising+temperatures,+are+likely+to+reduce+the+length+of+the+growing+season,+which+usually+is

Sivakumar, M. V. K. (1992). Empirical Analysis of Dry Spells for Agricultural Applications in West Africa. *Journal of Climate*, *5*(5), 532–539. http://doi.org/10.1175/1520-0442(1992)005<0532:EAODSF>2.0.CO;2

Sivakumar, M. V. K., & Sivakumar, M. V. K. (1992). Empirical Analysis of Dry Spells for Agricultural Applications in West Africa. *http://dx.doi.org/10.1175/1520-0442(1992)005<0532:EAODSF>2.0.CO;2*.

Sivakumar, M. V. K., & Virmani, S. M. (1984). Crop productivity in relation to interception of photosynthetically active radiation. *Agricultural and Forest Meteorology*, *31*(2), 131–141. http://doi.org/10.1016/0168-1923(84)90015-7

Six, J., Conant, R. T., Paul, E. a, & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: Implications for C-saturatin of soils. *Plant and Soil*, *241*, 155–176. http://doi.org/10.1023/A:1016125726789

Smit, B., & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development*. Retrieved from http://www.start.org/Program/advanced_institute3_web/download/Smit_etal_IPCCwg2_ch18.pdf

Smith-Eskridge, E. (2014). Assessing the Effects of Soil Moisture on Germination of Winter Wheat. Retrieved from http://digitalcommons.unl.edu/envstudtheses

Smith, C. W., & Frederiksen, R. A. (2000). *Sorghum : origin, history, technology, and production*. Wiley.

Smith, P., Martino, D., Cai, Z., Gwary, D., & Janzen, H. (2007). Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0167880906002544

Snape, J., Butterworth, K., Whitechurch, E., & Worland, A. (2001). Waiting for fine times: genetics of flowering time in wheat. *Euphytica*. Retrieved from http://link.springer.com/article/10.1023/A:1017594422176

Soltani, A., Waismoradi, A., Heidari, M., & Rahmati, H. (2013). Effect of Water Deficit Stress and Nitrogen on Yield and Compatibility Metabolites on Two Medium Maturity Corn Cultivars. *International Journal of Agriculture and Crop Sciences*, *5*(7), 637–740. Retrieved from www.ijagcs.com

Soni, R., Chadha, B., & Saini, H. S. (2008). Novel Sources of Fungal Cellulases of Thermophilic/Thermotolerant for Efficient Deinking of Composite Paper Waste. *BioResources*, *3*(1), 234–246. http://doi.org/10.15376/BIORES.3.1.234-246

Soreng, R. J., Peterson, P. M., Romaschenko, K., Davidse, G., Zuloaga, F. O., Judziewicz, E. J., Morrone, O. (2015). A worldwide phylogenetic classification of the Poaceae (Gramineae). *Journal of Systematics and Evolution*, *53*(2), 117–137. http://doi.org/10.1111/jse.12150

SOUZA, F. H. D. DE, & Marcos-filho, J. (2001). The seed coat as a modulator of seed-environment relationships in Fabaceae. *Revista Brasileira de Botânica*, *24*(4), 365–375. http://doi.org/10.1590/S0100-84042001000400002

Suleiman, A. A., & Ritchie, J. T. (2003). Modeling Soil Water Redistribution during Second-Stage Evaporation. *Soil Science Society of America Journal*, *67*(2), 377. http://doi.org/10.2136/sssaj2003.3770

Sullivan, C. Y., Norcio, N. V., & Eastin, J. D. (1977). Plant Responses to High Temperatures. In *Genetic Diversity in Plants* (pp. 301–317). Boston, MA: Springer US. http://doi.org/10.1007/978-1-4684-2886-5_28

Taylor, A. (1997). Seed storage, germination and quality. *The Physiological of Vegetable Crops. New York*. Retrieved from http://dspace.utalca.cl:8888/bibliotecas/primo_digital/47990-1-2.pdf

Tekle, A. T., & Alemu, M. A. (2016). Drought Tolerance Mechanisms in Field Crop s. *World J. Biol. Med. Science*, *3*(2), 15–39.

Thomson, I. (2006). E. Chakauya, P. Tongoona, EA Matibiri and M. Grum. *International Journal of Botany*. Retrieved from http://scialert.net/abstract/?doi=ijb.2006.29.35

Tian, Y., Guan, B., Zhou, D., Yu, J., Li, G., & Lou, Y. (2014a). Responses of Seed Germination, Seedling Growth, and Seed Yield Traits to Seed Pretreatment in Maize (*Zea mays* L.). *The Scientific World Journal*, *2014*, 1–8. http://doi.org/10.1155/2014/834630

Tian, Y., Guan, B., Zhou, D., Yu, J., Li, G., & Lou, Y. (2014b). Responses of Seed Germination, Seedling Growth, and Seed Yield Traits to Seed Pretreatment in Maize (*Zea mays* L.). *The Scientific World Journal*, *2014*, 1–8. http://doi.org/10.1155/2014/834630

Toklu, F., Baloch, F. S., Karaköy, T., & Özkan, H. (2015). Effects of different priming applications on seed germination and some agromorphological characteristics of bread wheat (Triticum aestivum L.). *Turkish Journal OF Agriculture And Forestry*, *39*, 1005–1013. http://doi.org/10.3906/tar-1404-41

Toklu, F., Baloch, F. S., Karaköy, T., & Özkan, H. (2015). Effects of different priming applications on seed germination and some agromorphological characteristics of bread wheat (Triticum aestivum L.). *Turkish Journal of Agriculture and Forestry*, *39*(6), 1005–1013.

Tøttrup, A. P., Klaassen, R. H. G., Kristensen, M. W., Strandberg, R., Vardanis, Y., Lindström, Å., … Pedersen, P. (2012). Drought in Africa caused delayed arrival of European songbirds. *Science (New York, N.Y.)*, *338*(6112), 1307. http://doi.org/10.1126/science.1227548

Tubiello, F. N., Salvatore, M., Golec, R. D. C., Ferrara, A., Rossi, S., Biancalani, R., … Flammini, A. (1990). Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks.

UNDP. (2013). United Nations Development Programme United Nations Development Programme, (January), 1–17.

USDA. (2016). World Sorghum Production 2016/2017. Retrieved April 25, 2016, from https://www.worldsorghumproduction.com/

Van Loon, A. F. (2015). Hydrological drought explained. *Wiley Interdisciplinary Reviews: Water*, *2*(4), 359–392. http://doi.org/10.1002/wat2.1085

Vanderlip, R. L., & Reeves, H. E. (1972). Growth Stages of Sorghum [Sorghum bicolor, (L.) Moench.]1. *Agronomy Journal*, *64*(1), 13. http://doi.org/10.2134/agronj1972.00021962006400010005x

Vinocur, B., & Altman, A. (2005). Recent advances in engineering plant tolerance to abiotic stress: achievements and limitations. *Current Opinion in Biotechnology*, *16*(2), 123–132. http://doi.org/10.1016/j.copbio.2005.02.001

Vogel, J. P., Garvin, D. F., Mockler, T. C., Schmutz, J., Rokhsar, D., Bevan, M. W., Baxter, I. (2010). Genome sequencing and analysis of the model grass Brachypodium distachyon. *Nature*, *463*(7282), 763–768. http://doi.org/10.1038/nature08747

Wani, S., Albrizio, R., & Rao, V. N. (2012). Sorghum. Retrieved from http://oar.icrisat.org/6113/

Williams, A. P., Funk, C., Michaelsen, J., Rauscher, S. A., Robertson, I., Wils, T. H. G., … Loader, N. J. (2012). Recent summer precipitation trends in the Greater Horn of Africa and the emerging role of Indian Ocean sea surface temperature. *Climate Dynamics*, *39*(9–10), 2307–2328. http://doi.org/10.1007/s00382-011-1222-y

Wilson, G., & Eastin, J. (1982). The plant and its environment. *Sorghum in the Eighties*. Retrieved from http://agropedia.iitk.ac.in/sites/default/files/RA00045.pdf#page=110

WMO. (2006). *Scientific Assessment of Ozone Depletion: 2006*. Retrieved from http://www.wmo.int/pages/prog/arep/gaw/ozone_2006/ozone_asst_report.html

WMO. (2011). WMO statement on the status of the global climate in 2011.

Woodstock, L. (1988). Seed imbibition: a critical period for successful germination. *Journal of Seed Technology*. Retrieved from http://www.jstor.org/stable/23432691

Wright, I., & Westoby, M. (1999). Differences in seedling growth behaviour among species: trait correlations across species, and trait shifts along nutrient compared to rainfall gradients. *Journal of Ecology*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2745.1999.00330.x/full

Yamoah, C. F., Clegg, M. D., & Francis, C. A. (1998). Rotation effect on sorghum response to nitrogen fertilizer under different rainfall and temperature environments. *Agriculture, Ecosystems & Environment*, *68*(3), 233–243. http://doi.org/10.1016/S0167-8809(97)00152-7

Yanrong, W., Jianquan, Z., Huixia, L., & Xiaowen, H. (2003). Physiological and ecological responses of alfalfa and milkvetch seed to PEG priming. *Acta Ecologica Sinica*, *24*(3), 402–408.

Yari, L., Khazaei, F., Sadeghi, H., & Sheidaei, S. (2011). Effect of Seed Priming on Grain Yield and Yield Components of Bread WheatT (Triticum aestivum L.), *6*(6).