Understanding genotype-environment interaction by characterizing drought stress patterns in the Malian sorghum production belt using crop modeling

Photos: Rik Schuiling/TropCrop -TCS

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ICRISAT
INTERNATIONAL CROPS RESEARCH
INSTITUTE FOR THE SEMI-ARID TROPICS

Outline:

Chapter I: MODELING

- **1. Introduction**
- **2. Material and methods**

✓ **Parameterize sorghum types specific to:**

✓ **Run water stress EC**

✓ **Clustering analysis**

- **3. Results**

1. Introduction:

- Drought is as a major factor limiting crops production

- But when, where, how much and how often drought stress reduces yield remains largely an unanswered question

- In West Africa G×M×E remain a limitation for targeting genotypes to their appropriate environments

- Assessing the extent and nature of the complexity of such interactions over time and space remains a challenge that this study tackles using crop simulation modelling

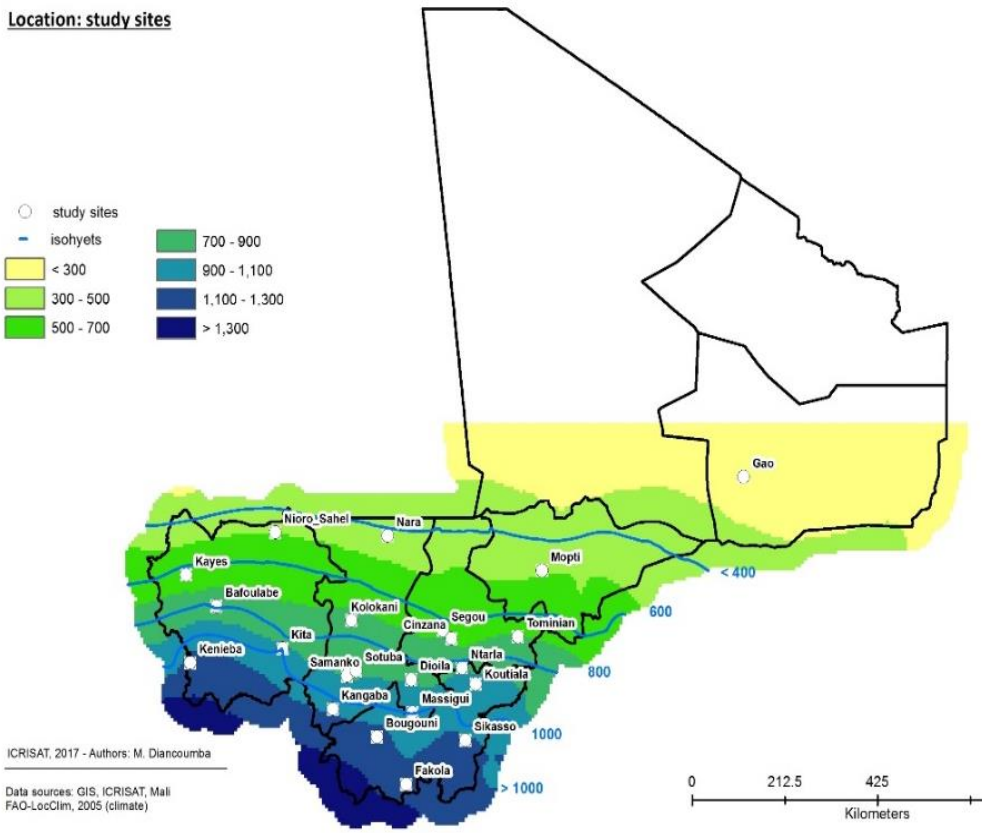
Objectives

- i) parameterize the representative genotypes of sorghum grown in the main production regions of Mali in the APSIM model

- ii) identify the type and frequency of water deficit patterns experienced by these genotypes during their life cycle across the sorghum production belt in Mali

- iii) evaluate the effect of each major stress type identified on grain yield.

2. Materials and methods: Sites description



Parameterize 3 sorghum types specific to 3 agro-ecological zones:

- **Sahelian zone; CSM63E/Jakumbe**
- **Sudan-sahelian zone; CSM335/Tieble**
- **Sudanian zone; IS15401/Sumalemba**

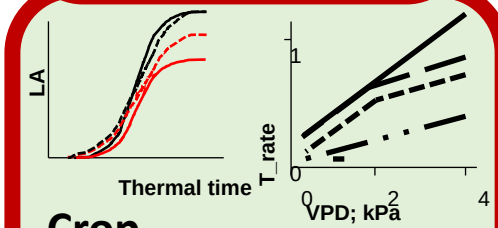
=> 22 study sites have been selected across country

2. Materials and methods: Model APSIM description

INPUT

Climate

Tmin
Tmax
Rainfall
Radiation



Crop

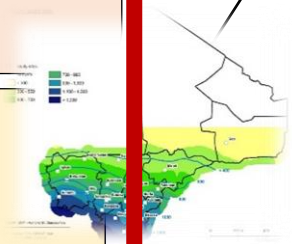
MEASURABLE parameters

Soil

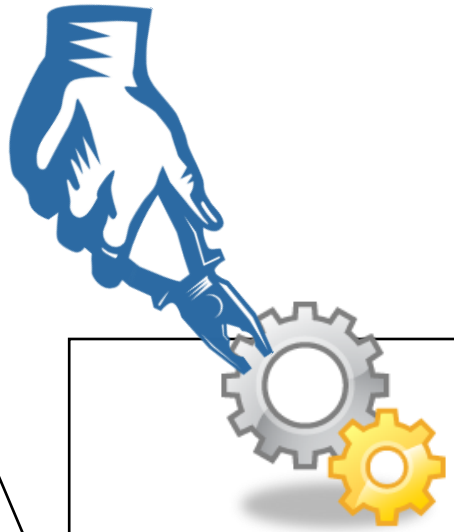
Depth, WHC
Hydraulic properties
water content

Management

Sowing date
Sowing density
Fertilizers



APSIM

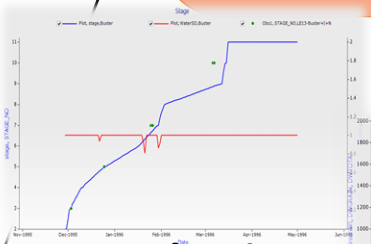


Process driven algorithms

OUTPUT

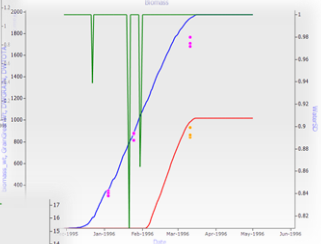
Crop dynamics

- Dynamics of growth & development
- Dynamics of resources uptake

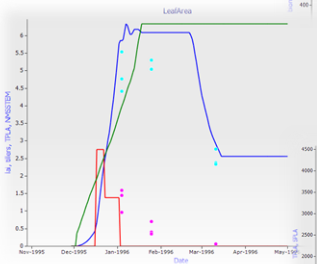


phenology

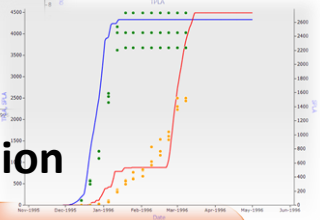
production



canopy



Water depletion



Soil dynamics

- Dynamics of soil resources content

Adapted from Marrou et al, 2014
IFLRC VI & ICLGGV II

2. Materials and methods: WaterSD

APSIM model: 7.6.v.milletP

A water status index (water supply/demand ratio) output by the model, which provides a daily calculation of the ratio of how much water is available to the crop to how much water is needed by the crop for each location-year combination.

A	B	C	D	E	F	G	H	I	J	K
ApsimVersion = 7.6										
Title = Gao Daily										
season	SowYear	SowDay	DaysAfter	stage	ftn	DeltaLeafl	DeltaGree	TT	InCropRai	WaterSD
()	()	()	(days)	()	()	(lvs/d)	(g/m^2)	()	()	()
1950	1950	181	1	1.999	0	0	0	0	0	1
1950	1950	181	2	2	0	0	0	0	0	1
1950	1950	181	3	2	0	0	0	0	0	1
1950	1950	181	4	2	0	0	0	0	0	1
1950	1950	181	5	2	0	0	0	0	0	1
1950	1950	181	6	2	0	0	0	0	0	1
1950	1950	181	7	2.145	0	0	0	0	11	1
1950	1950	181	8	2.145	0	0	0	6.547	11	1
1950	1950	181	9	2.145	0	0	0	6.547	14.7	1
1950	1950	181	10	2.145	0	0	0	6.547	14.7	1
					0	0	0	6.547	14.7	1
					0	0	0	6.547	15.2	1
					0	0	0	6.547	15.2	1

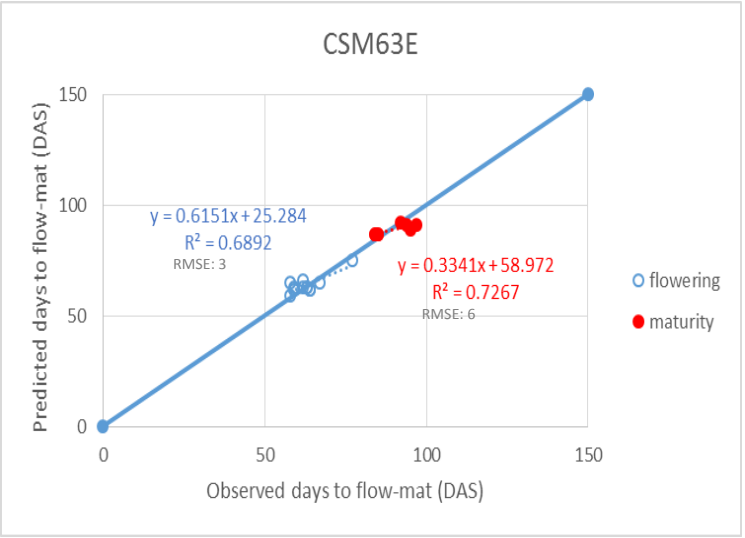
This daily water stress index is averaged every 100Cd and centered at flowering (400Cd before and after flowering)

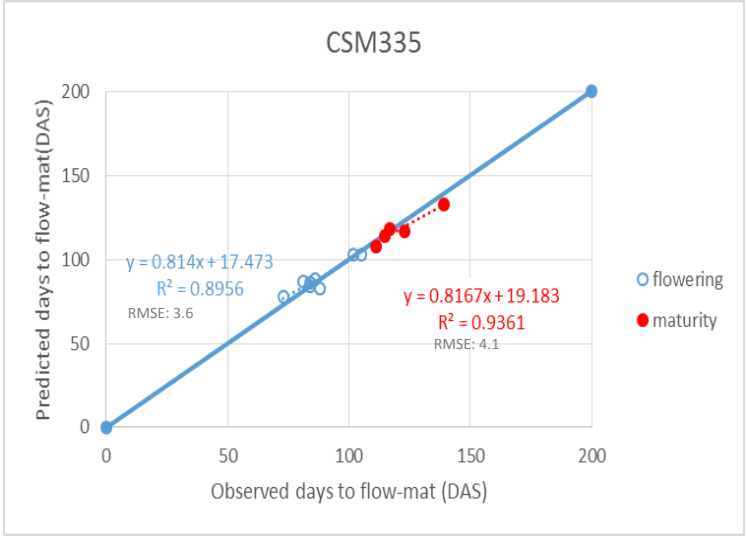
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Season	Yield	Wate	Wate	Rainf	Rainf	EClass	-400	-300	-200	-100	0	100	200	300	400
1971	679.6	48	31	613	29	1	1	1	1	1	1	1	1	1	1
1972	748.2	59	36	231	50	1	1	1	1	1	1	1	1	1	1
1973	683.8	51	30	455	14	1	1	1	1	1	1	1	1	1	1
1974	694.5	49	34	614	30	1	1	1	1	1	1	1	1	1	1
1975	725.9	54	33	692	30	1	1	1	1	1	1	1	1	1	1
									1	1	1				
									1	1	1				
									1	1	1				
									1	1	1				
									1	1	1				
									1	1	1				
									1	1	1				

Clustering analysis is done to identify the major drought patterns

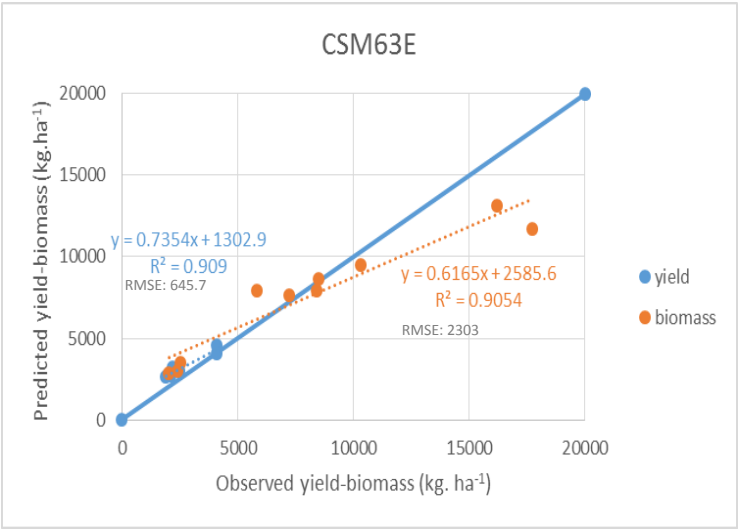
Values of the S/D ratio equal or above 1 indicate the crop experiences no stress whereas values below 1 indicate some stress

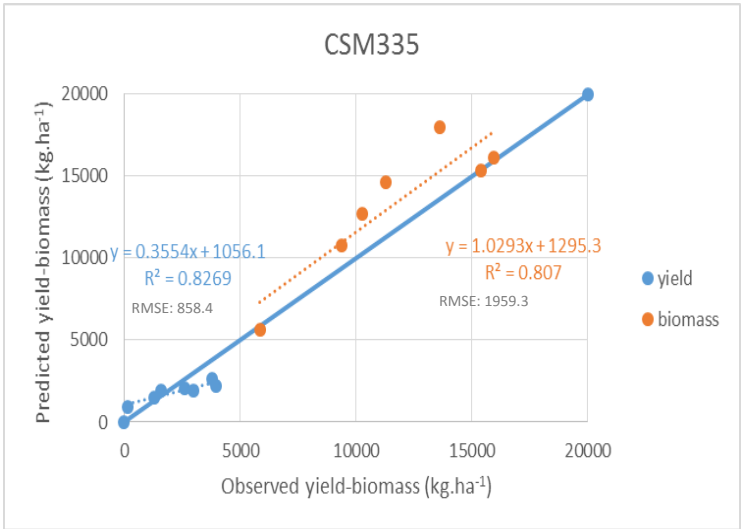
3. Results: parameterization CSM63E, CSM335



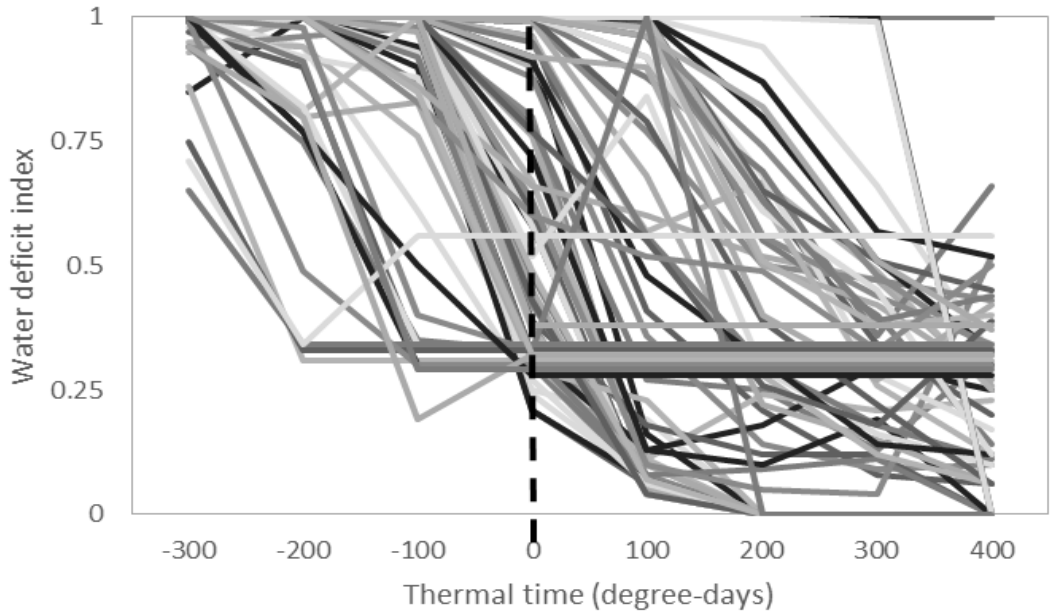


Phenological stages well captured by APSIM



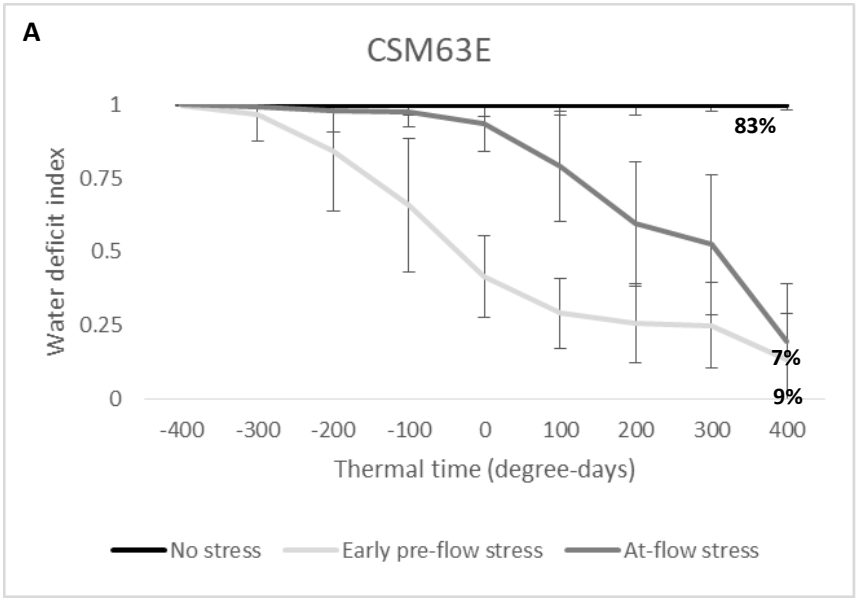


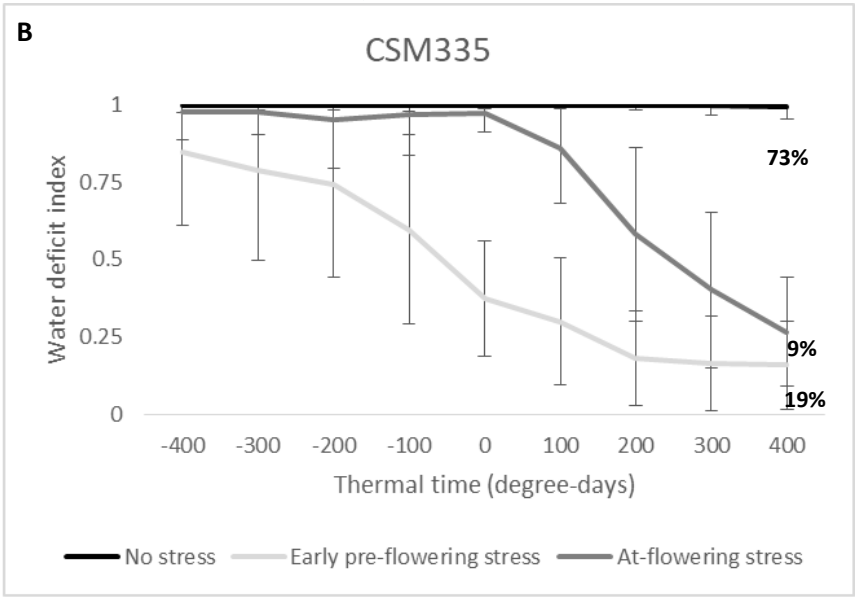
3. Results: Water EC for CSM63E, CSM335



All stress scenarios identified across years and locations. The vertical line represents the flowering time, as a reference

3 major environments types are identified as drought patterns experienced by Tieble and Jakumbe genotypes in Mali

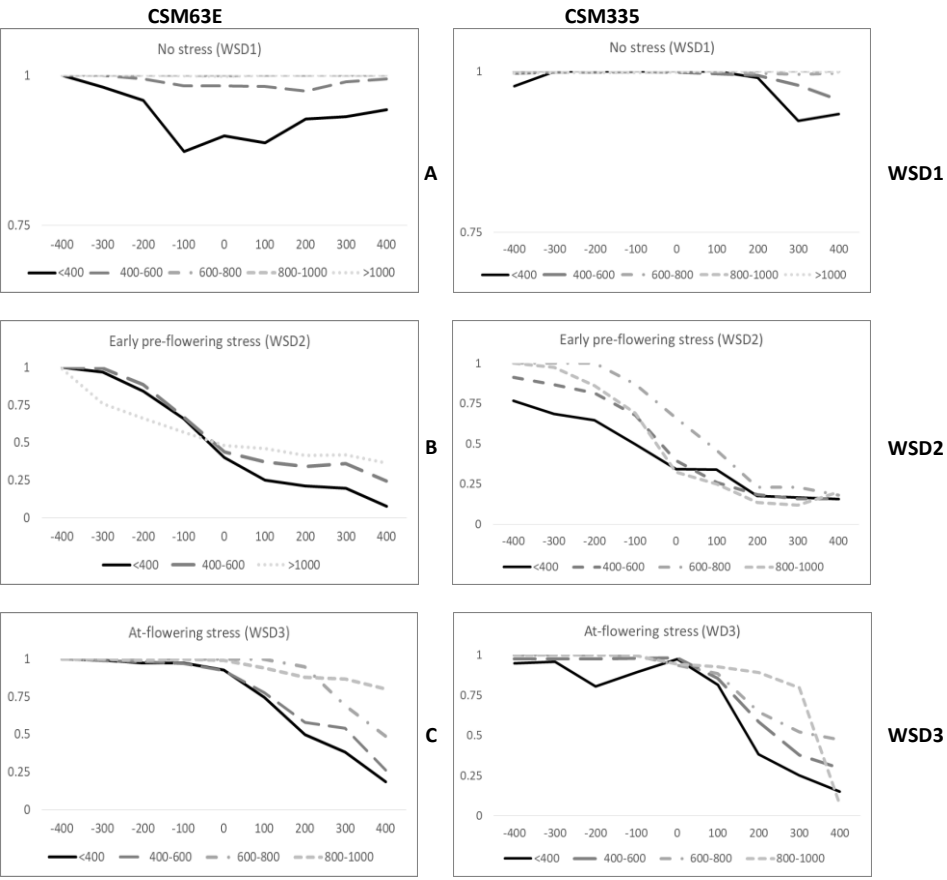




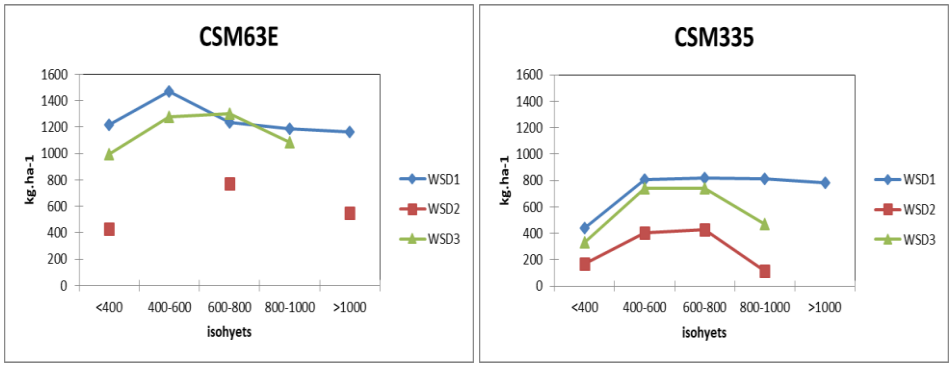
Diancoumba et al.; in prep

3. Results:

WSD1: no stress
WSD2: Early pre-flow stress
WSD3: At flow-stress



Dynamic of each drought stress scenario identified across 5 agro-ecological zones in Mali for CSM63E and CSM335. The lines represent different agro-ecological zones



Average grain yield, simulated per stress scenario and for CSM335 and CSM63E .

Summary

- (Individual leaf approach necessary to capture changes in canopy due to PP)
- 2 (CSM63E, CSM335) representing zone adaptation reliably parameterized (IS15401 parameterization is going on)
- Protocol for $EC_{drought}$ Mali standardized
- Major stress types identified
- Low yield despite high frequency of occurrence of no stress

Chapter II: Modeling

Objectives:

- Test, using sowing dates from actual farmer practices, the effects of four different levels of fertilizer on grain yield and three previously identified drought stress patterns in Mali;

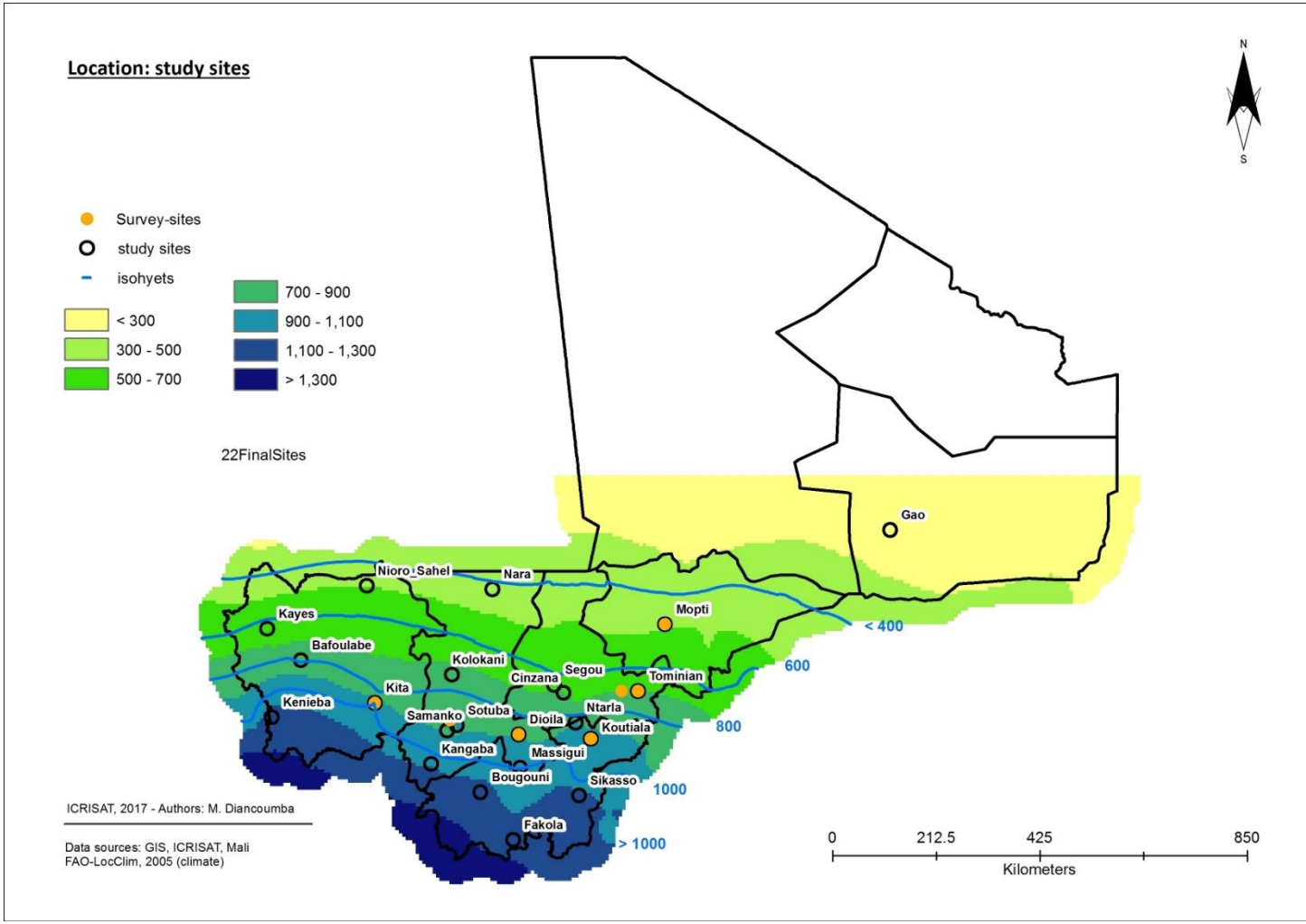
- Evaluate for each level of fertilization, the effects of three sowing densities on each of the stress pattern identified and on grain yield.

2. Chapter II: **Materials and methods:** survey sites location

Sowing dates

- Sowing dates obtained from trials data collected in 4119 farmer fields in 6 survey sites

- These survey sites were mapped to our 22 study sites



2. Chapter II: **Materials and methods:** Management practices

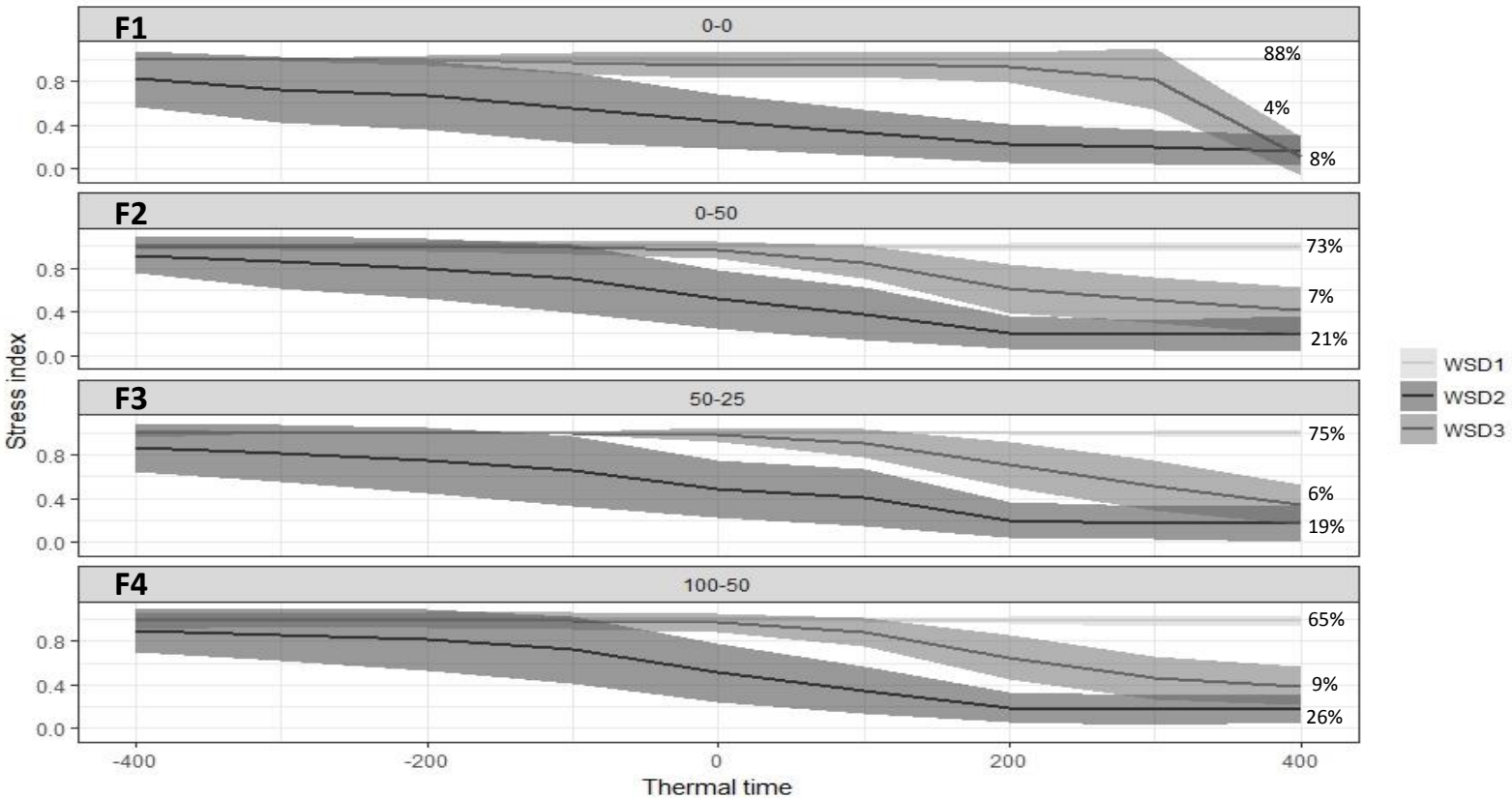
Fertilizer levels

- 0Kg.ha^{-1} of fertilizer (F1)
- 0Kg.ha^{-1} at sowing and 50Kg.ha^{-1} of urea 45days after sowing (DAS) (F2)
- 50Kg.ha^{-1} of DAP at sowing and 25 Kg.ha^{-1} of urea 45 DAS(F3)
- 100Kg.ha^{-1} of DAP at sowing and 50 Kg.ha^{-1} of urea 45 days after sowing (F4)

Sowing density

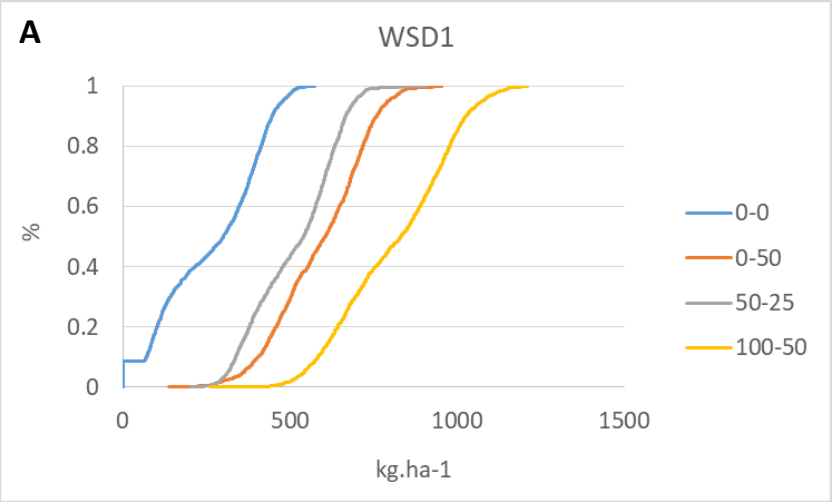
- Initial density: 5.7 plants/m2
- -50% of the initial density: 2.85 plants/m2
- +50% of the initial density: 8.55 plants/m2

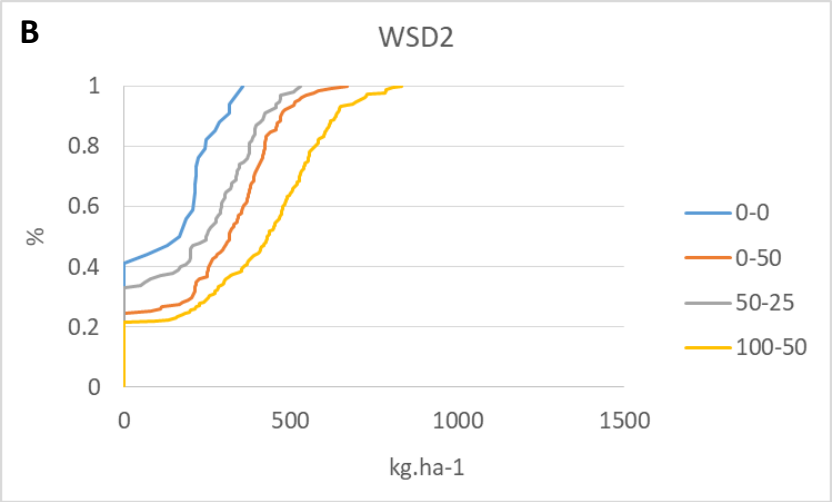
3. Chapter II: **Results: Fertilizer effects on stress patterns**

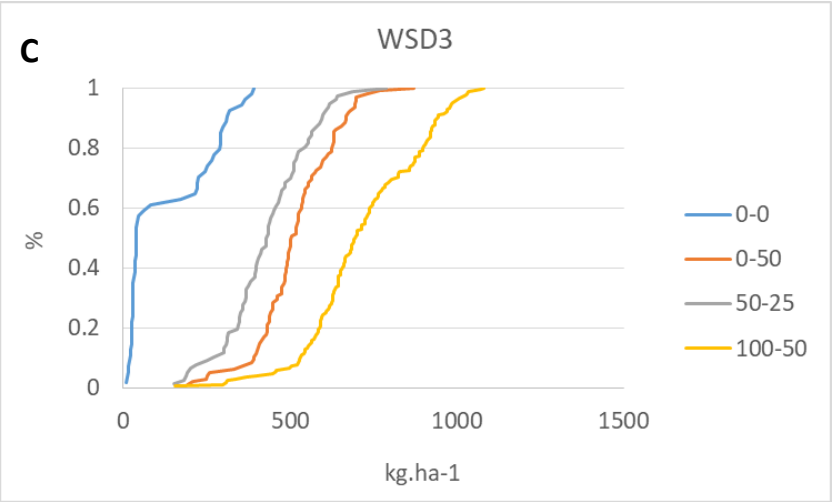


Frequency of occurrence of the 3 stress scenarios under the 4 rates of fertilizer application tested with 4owing dates observed in farmers fields.

3. Chapter II: Results: Fertilizer effects on grain yield



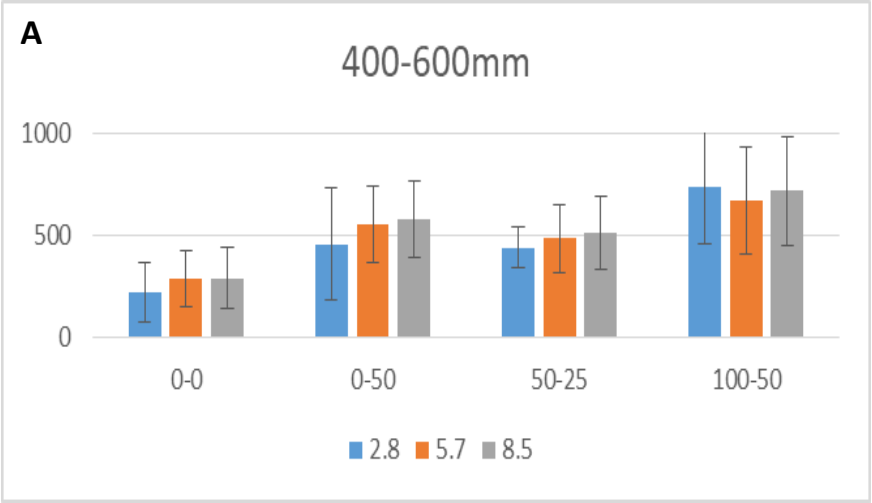


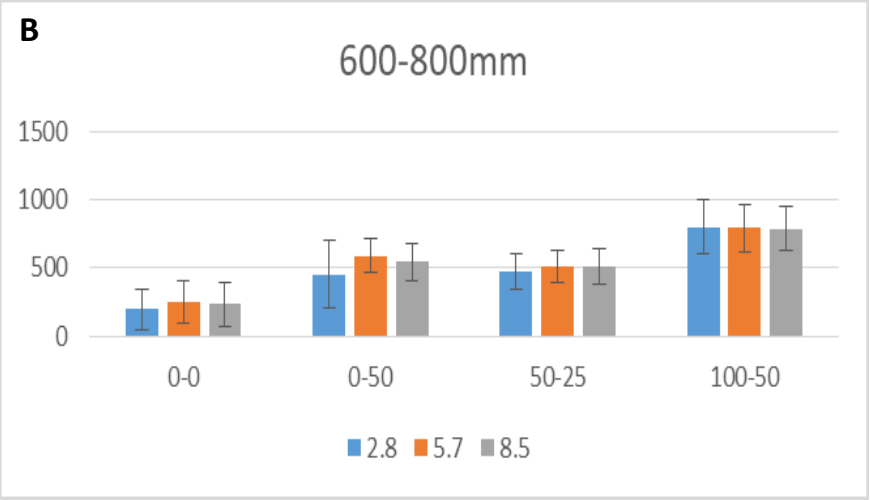


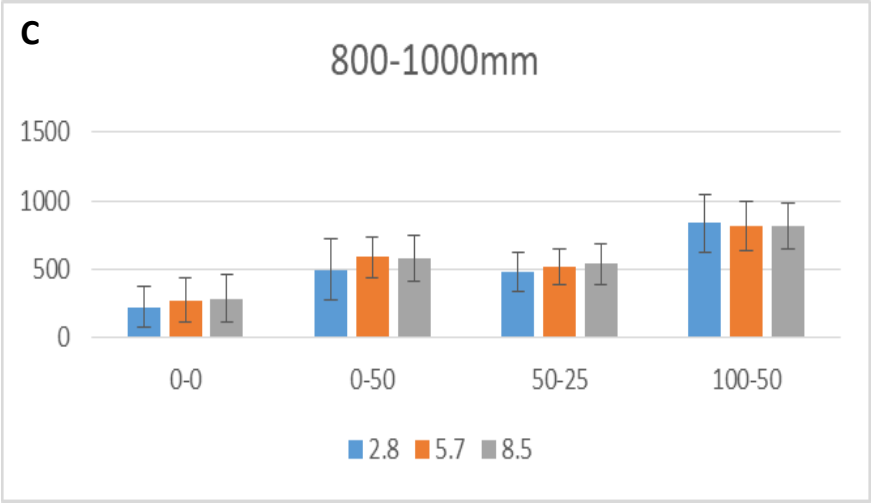
Under no fertilization, if you experience a water stress (WSD2 and 3) you have about 40 to 60% of crop failure

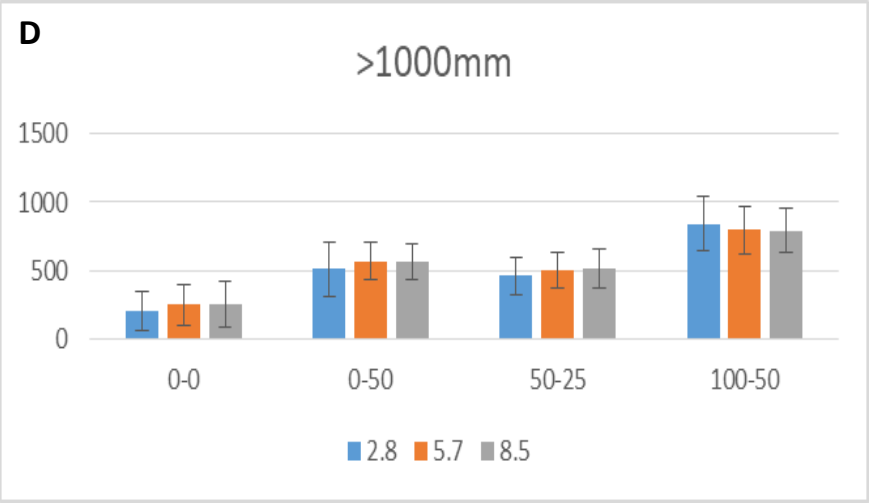
If you fertilize you increase the risk for water stress, but you decrease the risk of crop failure!

3. Chapter II: **Results:** Yield response to different densities









Challenges

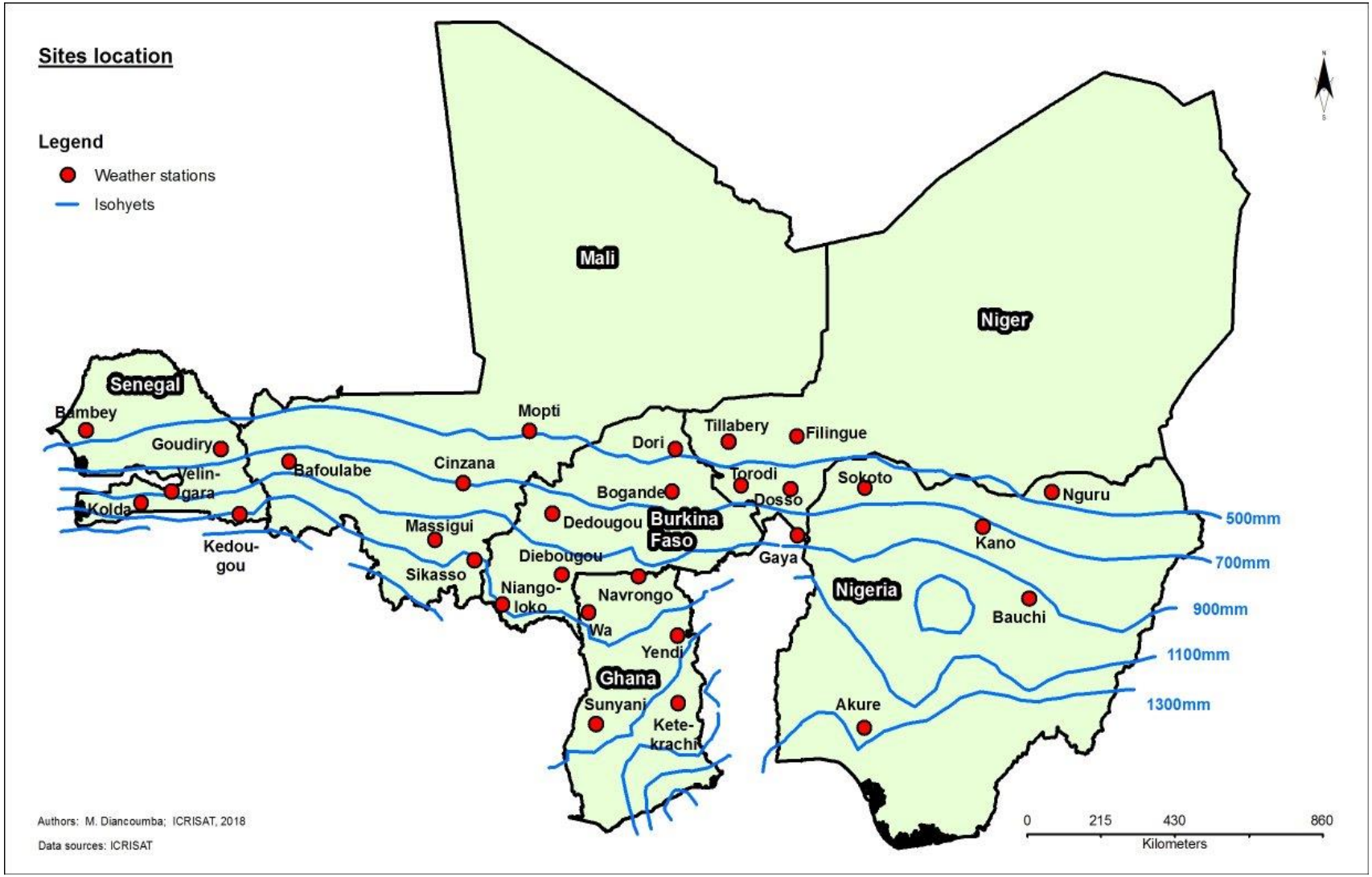
Genotypes parameterization was a challenge

- **Phenology & Photoperiod sensitivity :** Extremely long guineas phenology collapses in released 7.6 v.

- **Canopy size & development:** LA function cannot reliably support genotypes with >27 leaves

Major support from UQ; Hammer, McLean

Perspectives



Thank you
ICRISAT

Definitions

- APSIM: is a crop growth and development model that combines, individual module (crops, soils, N, carbone) to simulate biophysical processes in a cropping system context
- Calibration: is adjusting certain model parameters to make the model match the measured values at the given location.
- Parameterization
- Crop model: is a simulation model that describes processes of crop growth and development as a function of weather conditions, soil conditions, and crop management
- Plant water stress: has been defined as being when plant water status is reduced sufficiently to affect normal plant functioning
- Water deficit scenario
- Water deficit index:
- Clustering analysis: is used to find groups of similar objects in a dataset
- Crop demand: Potential transpiration depending on the climate and plant status
- Water supply: resource supply available to the roots on the considered date
- CSM: Malian sorghum Collection

2. Materials and methods: Genotypes parameterization

- **Growth**

➢ **Duration emergence to panicle initiation:** **daily thermal time ΔTT from endjuv. to floral ini. was cumulated and plotted against the average PP of that same period.**

➢ **Duration flowering to maturity:**

- **Canopy simulation :** **maximum leaf size plotted against leaf number maximum**

- **Yield:** **dm_per_seed & Max-Gf-rate coefficients have been calculated using approach proposed by J.Kholova et al. (in prep) or kept as APSIM default values**

Chapter I: Genotypes for parameterization

Genotype	Race/type	origin	Height (m)	Cycle duration	Photoperiod sensitivity	Specific characteristic	Isohyet (mm)
CSM63E	Guinea	Mali	2.1	90	Low	Good grain quality	400-700
CSM335	Guinea	Mali	4.6	120	Moderate	Resistant to on-farm water stagnation	800-1000
IS15401	Guinea	Cameroun	4.4	145	High	Very resistant to Striga and midge	900-1200