Maize and sorghum as non-irrigated crops

Ecophysiological
responses to water stress
in changing climate

Why maize and sorghum ?

Maize

World's most grown cereal crop: 1.16 billion tons (FAOSTAT, 2024).

Important food source, struggles with water scarcity (Lamm et al., 1994)

Sorghum

Fifth most cultivated cereal crop : 57.62 million metric tons in 2022-2023 (USDA,2024)

Better drought survivor : 89% area increase from 2023 to 2024 in France (Agreste, 2024).

How do they handle drought stress ?

Maize

More productive in optimal conditions
(Parra G. et al., 2022)

Drought induce yield losses especially in reproductive stages
(Yasin et al., 2024)

Sorghum

Drought tolerance attributed to deeper root systems (Blum A et al., 1984), more adapted osmotic regulation (Girma and Krieg, 1992)

Can delay reproductive development (Wright et al., 1983) and has a shorter growth cycle
(Farré and Faci, 2006)

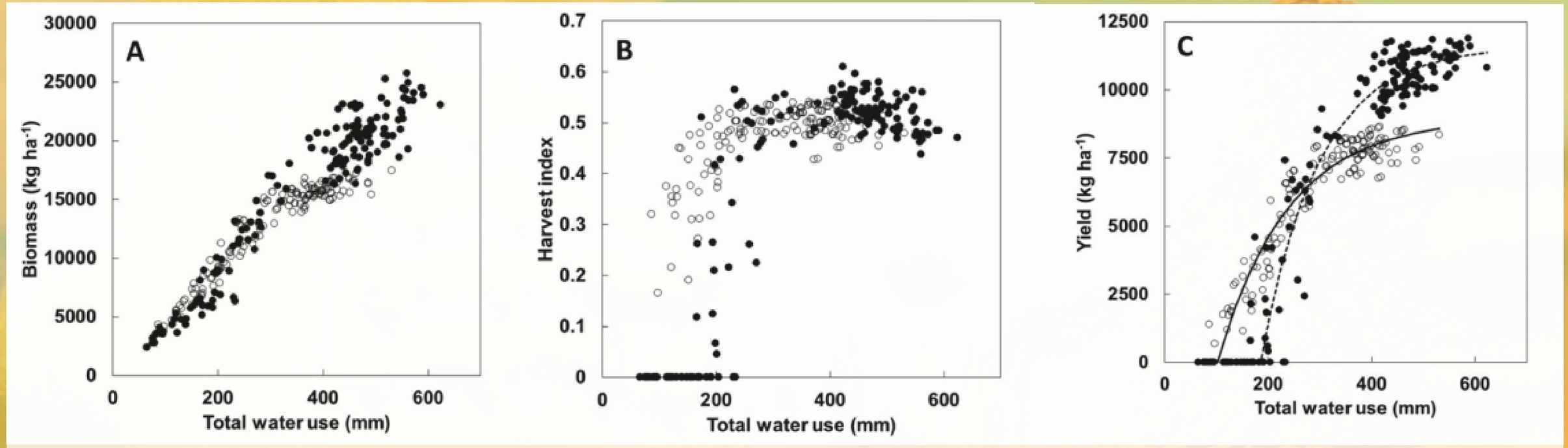


Figure 3. Simulated shoot dry mass (A), harvest index (B) and grain yield (C) of standard maize (●) and sorghum (◌) hybrids versus total crop water use for simulations at Dalby and the Liverpool Plains.

Van Oosterom EJ, Kulathunga MRDL, Deifel KS, McLean GB, Barrasso C, Wu A, et al. *Dissecting and modelling the comparative adaptation to water limitation of sorghum and maize: role of transpiration efficiency, transpiration rate and height.* Vadez V, Long SP, editors. in silico Plants. 2021

Different methodological approaches

01

Field experiments

Sorghum : lower decrease of biomass under stress, better transpiration efficiency and roots architecture.

Mediterranean US Great Plains

Agricultural practices

02

Lab experiments

Sorghum : higher WUE, deeper roots, lower TGLA.
Maize : decrease of height, leaf area and root lenght.
Breeding advancements improving drough tolerance.

03 Data analysis

Long-term data x environmental conditions
Significance of hybrid selection and water management.

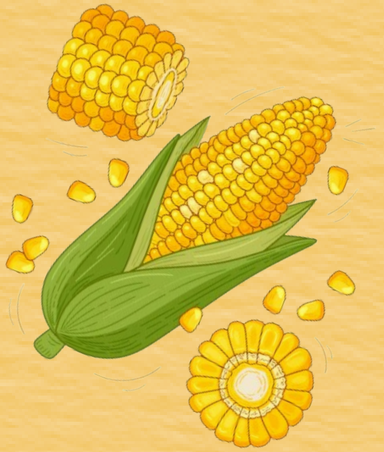
- 221 kg per hectare yield increase for every additional 1 cm increase in the ASWP;
- Maize (ca. 110 kg ha-1 year-1) had higher yield gains than sorghum (ca. 62 kg ha-1 year-1)

04 Predictive modeling

Understand the impact of environmental stressors on crop and to guide crop breeding

- The most crucial preciptation period is just prior to tasseling through the middle of grain filling;
- Maize yield increased 20.5 kg ha per mm of precipitation.

Some Research gaps to adress



- Large number of varieties to test;
- Lack of direct comparisons: Maize and sorghum have different growth cycles;
- Limited environmental studies;
- Overemphasis on reproductive stage: stage development and root structure;
- Roots and early stages.

The Questions

- How do environmental conditions (soil type, temperature, rainfall) in regions where maize and sorghum are frequently grown influence their comparative performance under water stress?

- Does sorghum invest more into roots compared to maize in early growth stages, and is this a plastic response to drought ?

Experimental design

Root system and biomass allocation comparative experiment on maize and sorghum in response to drought

Context

- Sorghum genotypes showed some leads to drought tolerance linked traits such as deeper root systems and more effective root system structure *(Blum and Arkin 1984)*

- Biomass allocation study showed that sweet sorghum higher productivity, under water stress, is likely attributable to a deeper and more important root penetration (*Schittenhelm and Schroet 2014*)

Research questions

Reputation of sorghum is to invest more into roots compared to maize

- Is it confirmed by a direct comparative study between the species in early growth stages ?

- Is this behavior a constitutive difference between maize and sorghum, or is it the consequence of different responses to drought ?

Hypothesis

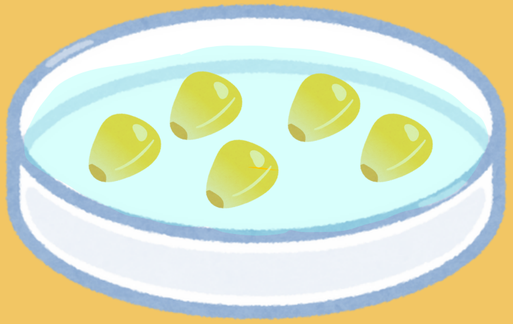
	Well-watered condition	Water stress condition
Maize	Invests more in above ground biomass	Is more affected in its biomass production
Sorghum	Invests more in under ground biomass	Is more efficient in maintaining its productivity

Hypothesis

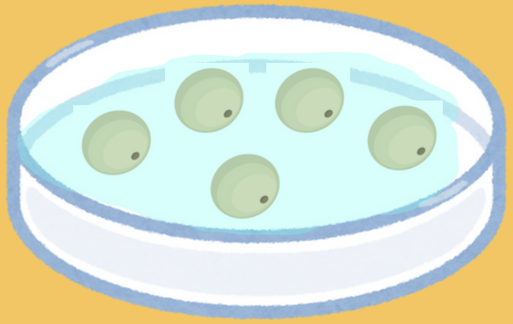
	Well-watered condition	Water stress condition
Maize	Higher leaf biomass Faster leaf expansion Greater WUE	Higher decrease of root and shoot biomass
Sorghum	Higher root/shoot ratio	Increase on root/shoot ratio, daily root growth and better WUE

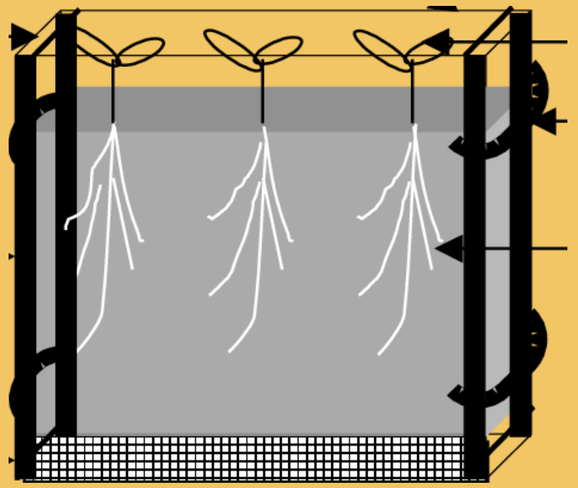
=> Sorghum is more efficient in developing its roots under water stress during early growth stages

Seedling and germination



room T
2 days





Chiunxa Wang. (2004). *Colonization and persistence of a plant growth-promoting bacterium Pseudomonas fluorescens strain CS85, on roots of cotton seedlings.* Research Gate

Design

16 rhizotrons

8 Maize

ZM4560 Maxxis
RAGT-R2N (2005)
FAO370 G3

4 water stress

4 no water stress

8 Sorghum

ARMAX (2018)
reddish grain
semi-early

4 water stress

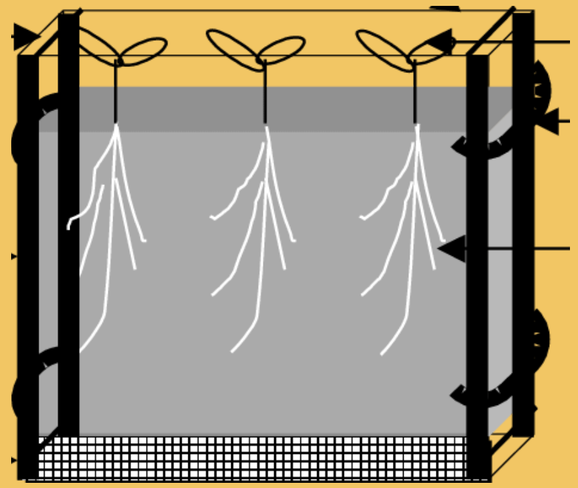
4 no water stress

2 plants/rhizotrons
(considered as 1)

Low power

Global conditions

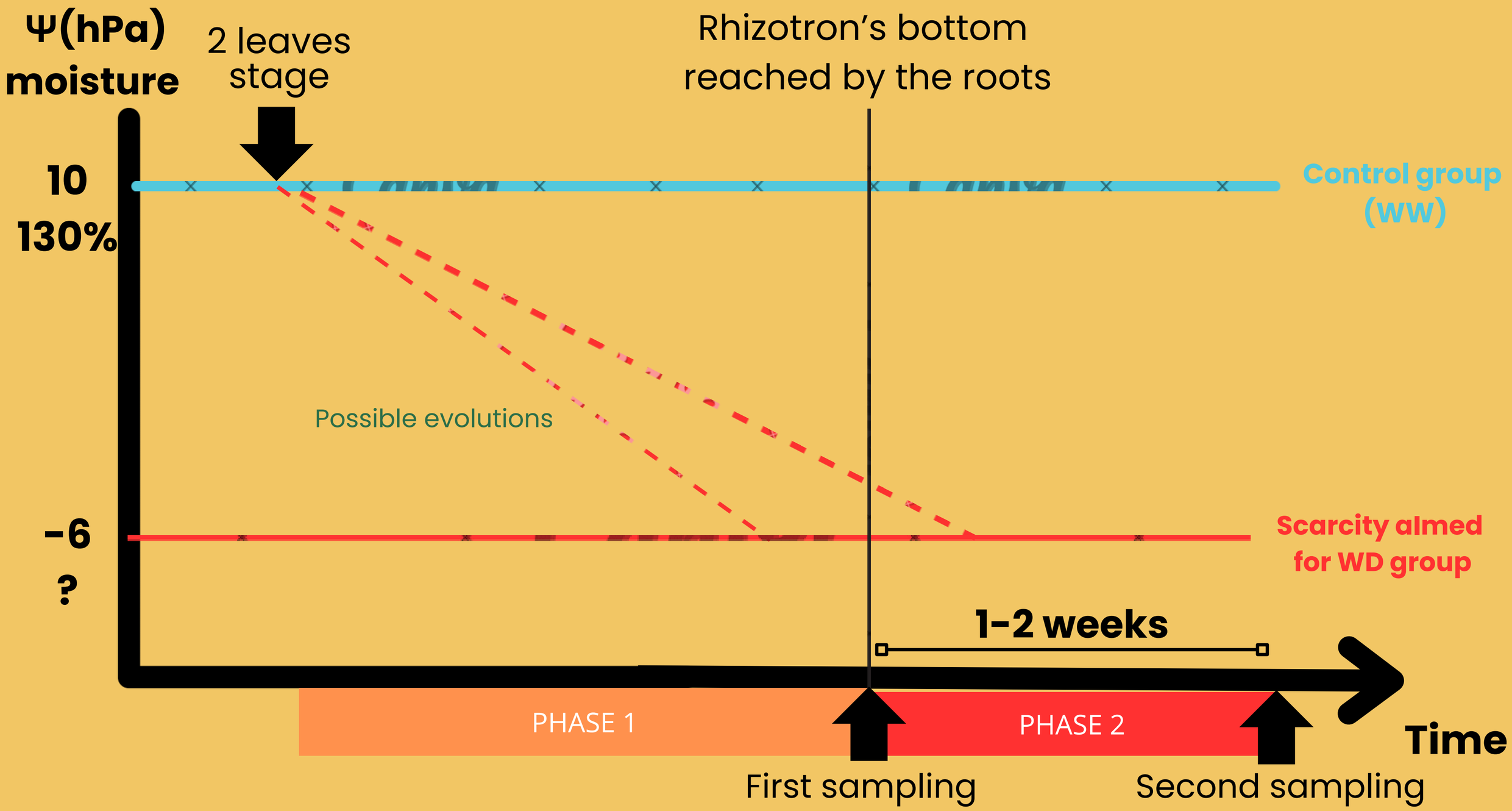
- Controlled chamber (a May day conditions)
  -> temperature : 16-26°C
  -> light time : 16 hours



- Rhizotrons
  -> dimensions : ~11 liters
  -> soil : 70% of clay

- Irrigation : every 2 days on average

Chiunxa Wang. (2004). *Colonization and persistence of a plant growth-promoting bacterium Pseudomonas fluorescens strain CS85, on roots of cotton seedlings.* Research Gate


Ψ(hPa)
moisture
2 leaves
stage
Rhizotron's bottom
reached by the roots
10
130%
Control group
(WW)
Possible evolutions
-6
?
Scarcity aimed
for WD group
1-2 weeks
PHASE 1
PHASE 2
Time
First sampling
Second sampling

What we are going to measure

PHASE 1

PHASE 2

First sampling

- Weight total dry biomass
- Weight **root and shoot biomass**

Second sampling

- Weight total dry biomass
- Weight **root and shoot biomass**

On mondays, wednesdays, fridays

- Scans of **roots length**
- **Leaves** mesurements
- Weighting the rhizotrons -> **transpiration**
- Water the plants

On mondays, wednesdays, fridays

- **Leaves** mesurements
- Weighting the rhizotrons -> **transpiration**
- Water the WW plants

Every day : water the WD plants

Explanatory Variables

Species

Maize (*Zea mays* L.)
ZM4560 Maxxis RAGT-R2N
(2005) FAO370 G3

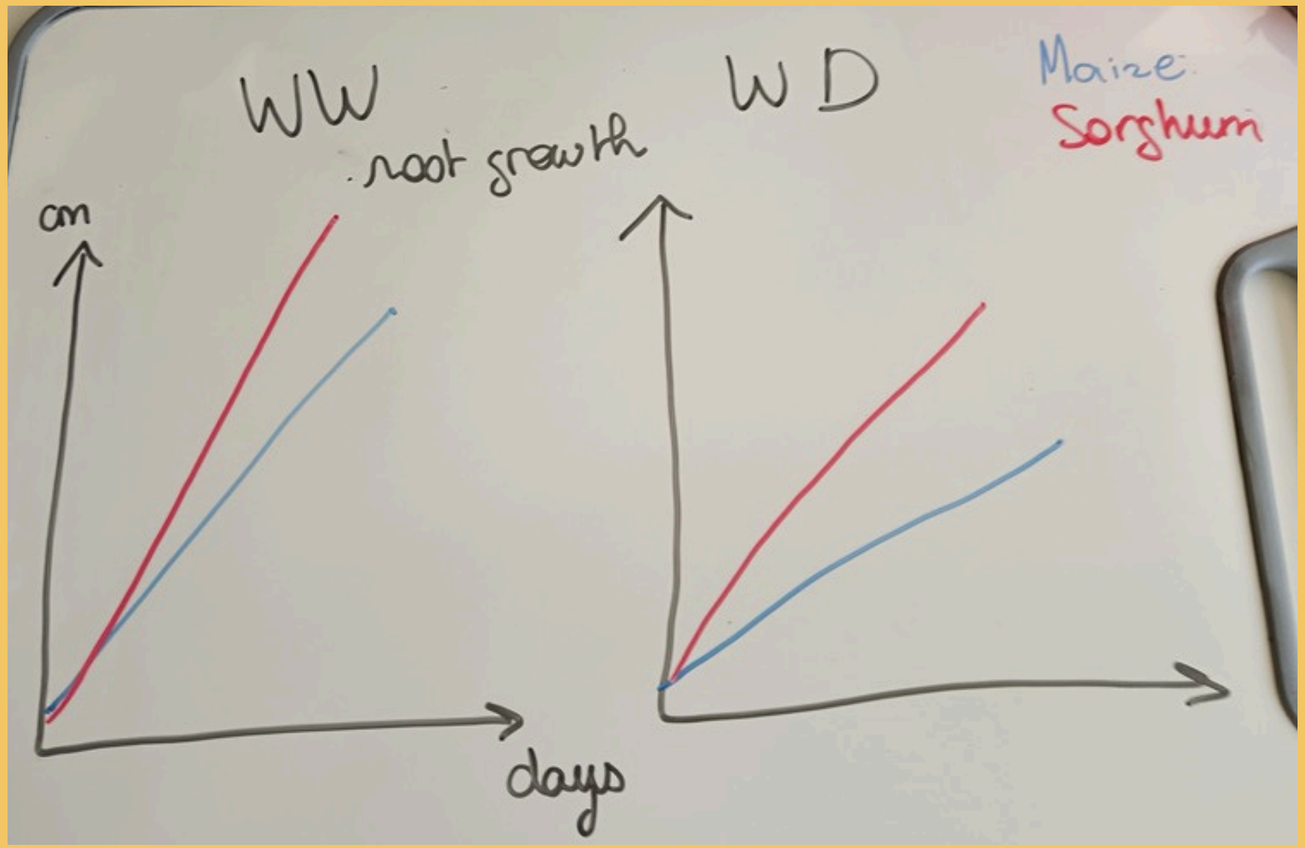
Sorghum (*Sorghum bicolor)*
ARMAX (2018) reddish grain
semi-early

Treatment

Well watered = 130% humdity

Water deficit = -6 Ψ(hPa)

Root lenght -> Daily root growth



Scanner
ImageJ processing

PHASE 1 only

	WW	WD
Maize	4	4
Sorghum	4	4

2 ways ANOVA

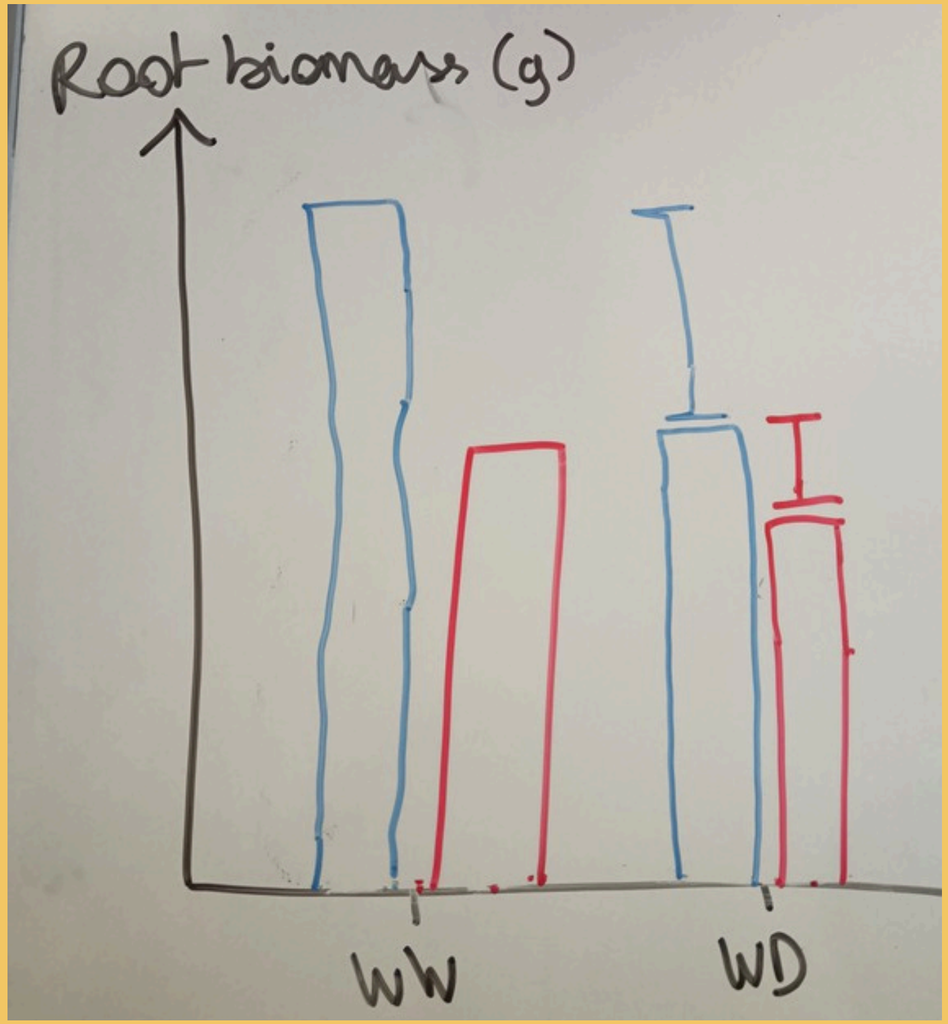
Leaf area -> Daily leaf expansion

Measuring tape
Formula???

	WW		WD	
Maize	4	4	4	4
Sorghum	4	4	4	4

2 ways ANOVA

Root biomass

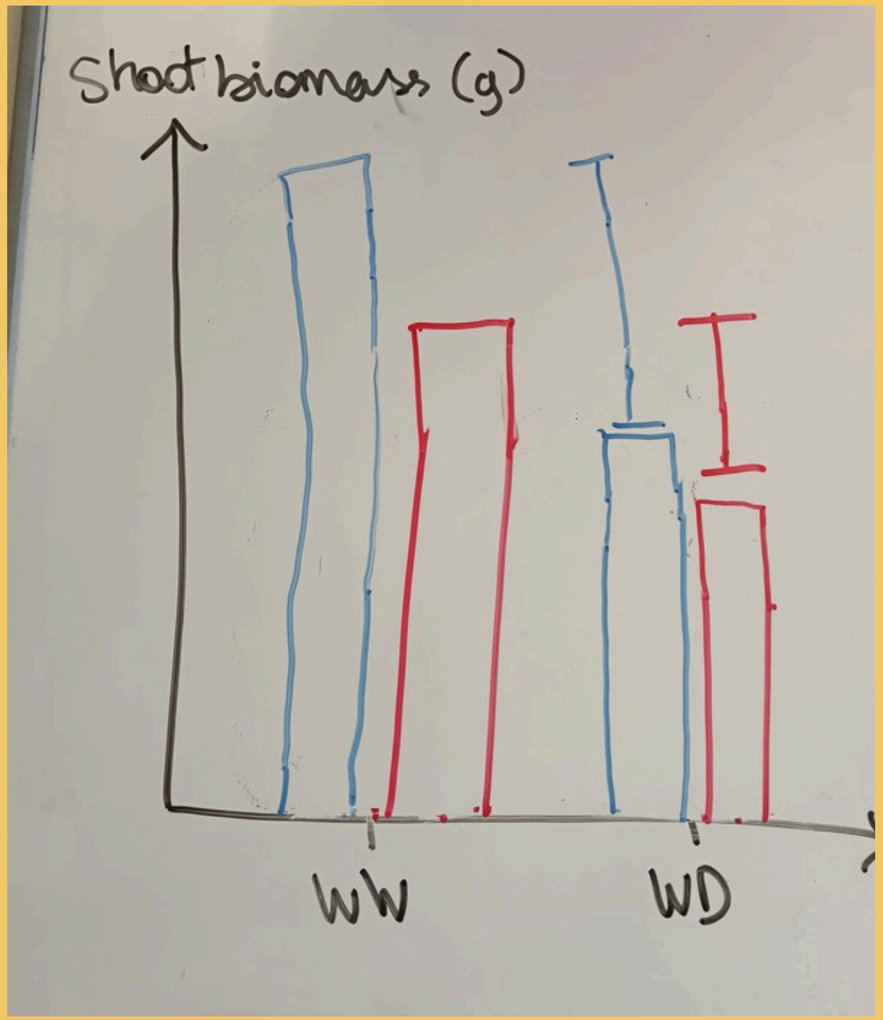


Drying in oven
Weighting

	WW		WD	
Maize	4	4	4	4
Sorghum	4	4	4	4

2 ways ANOVA

Shoot biomass

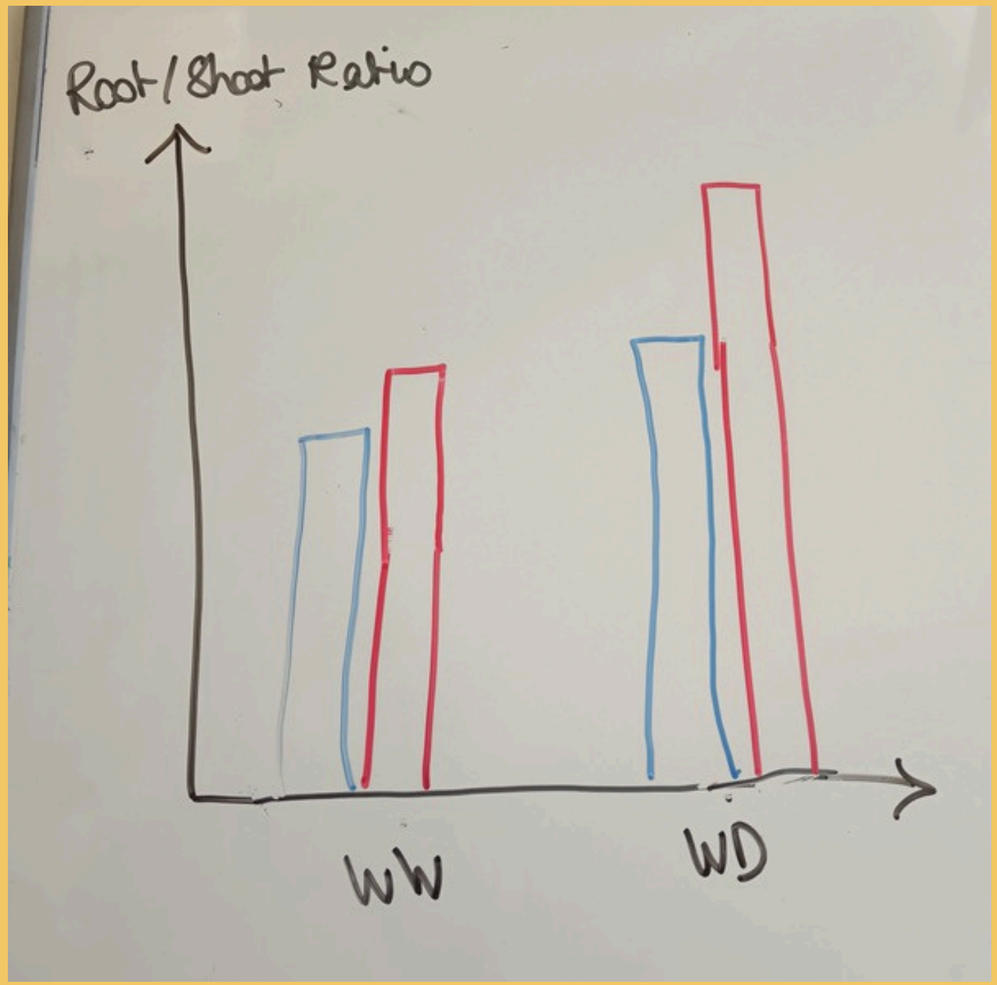


Drying in oven
Weighting

	WW		WD	
Maize	4	4	4	4
Sorghum	4	4	4	4

2 ways ANOVA

Root/Shoot Ratio

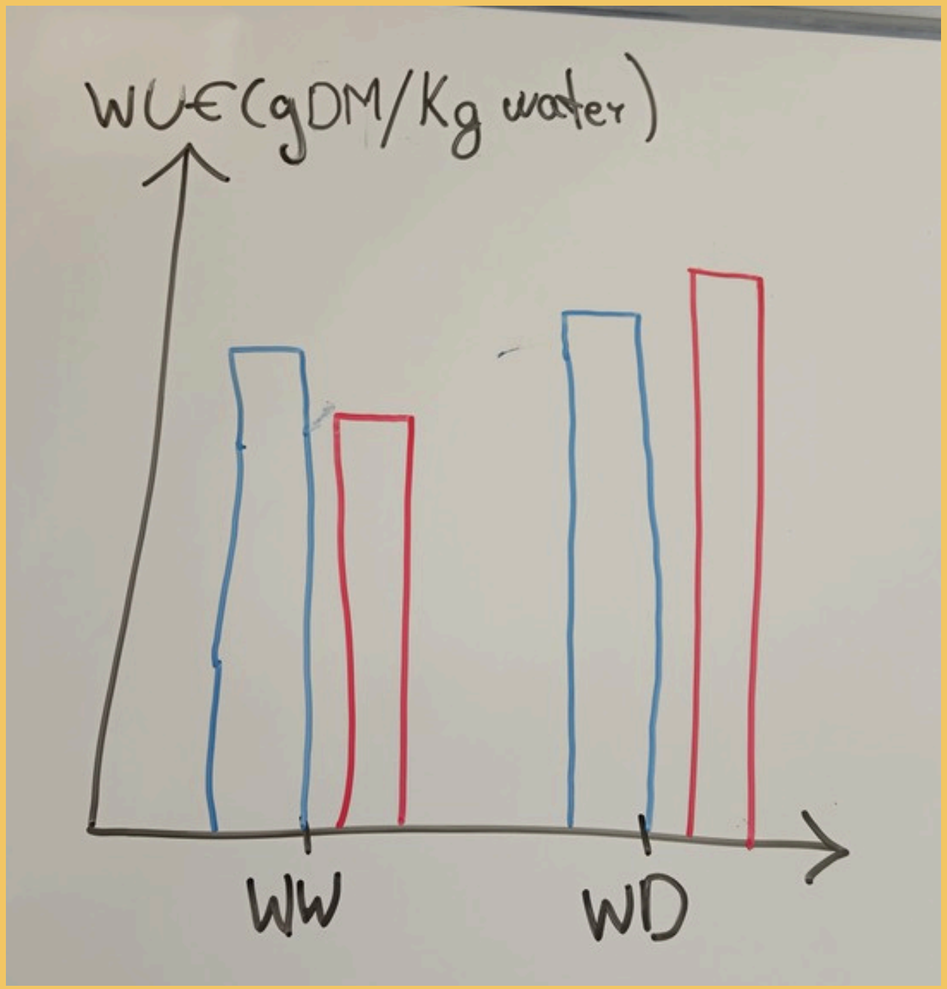


Root biomass /
Shoot biomass

	WW		WD	
Maize	4	4	4	4
Sorghum	4	4	4	4

2 ways ANOVA

Transpiration -> Water Use Efficiency



Weighting difference
2 days after watering

Total dry biomass / used water (transpiration)

	WW		WD	
Maize	4	4	4	4
Sorghum	4	4	4	4

2 ways ANOVA
Multiple linear regression with other traits