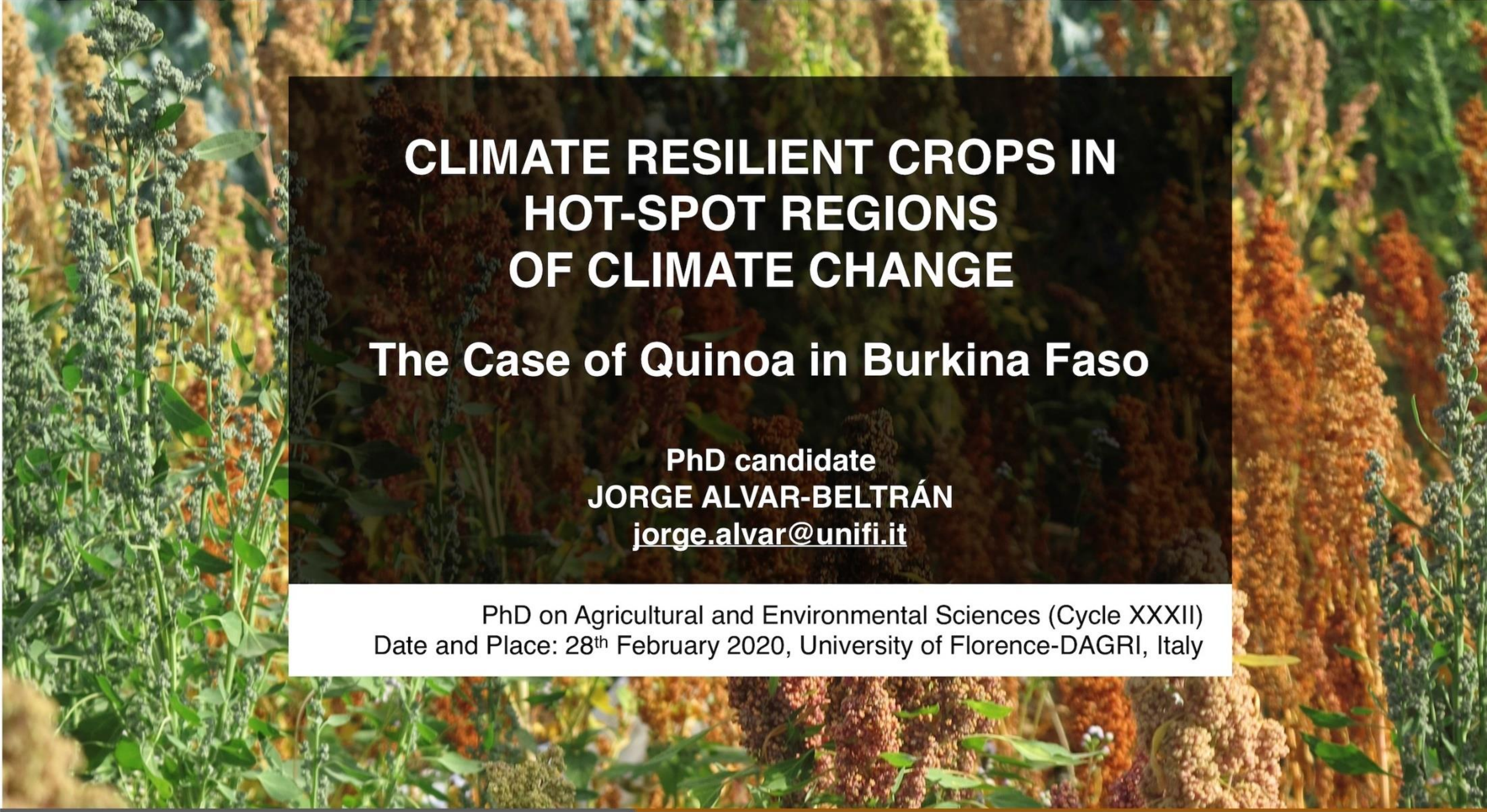

CLIMATE RESILIENT CROPS IN HOT-SPOT REGIONS OF CLIMATE CHANGE

The Case of Quinoa in Burkina Faso

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Table of Contents

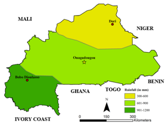
1. Background Information

- Similar to the size of Italy
- Landlocked (6 countries)

- 62 years life expectancy
- 16% undernourished children

- 21m people (Δ 3% year)
- 70 languages

- 1700€ year^{-1} GDP capita^{-1}
- 31% agriculture GDP
- 90% workforce in agriculture



- Very warm (28.3°C)
- Rainfall season (May-Oct)
- 300, 600 & 900mm year^{-1}
- Land degradation (9m ha year^{-1})

- Maize, millet, rice, sorghum, sesame
- Maize: 2t ha^{-1} (BF) vs. 11t ha^{-1} (USA)
- Rice: 2t ha^{-1} (BF) vs. 8t ha^{-1} (USA)
- Sorghum: 1t ha^{-1} (BF) vs. 5t ha^{-1}(USA)
- Yield reduction by 2050 (>15% rice, maize & sorghum)

Source: Salack, 2006; Schlenker & Lobell, 2010; CIA Factbook, 2020

2. Problem Identification & Justification

MULTI-FACTORIAL PROBLEM


Population growth


Changing climate


Landlocked country


Food insecurity


Conflict

- Warmest country on earth (1/195)
- High undernourishment rates (157/195)
- High vulnerability to climate related hazards (162/181)
- High exposure to climate related hazards (172/192)
- Low adaptive capacity (155/180)

JUSTIFICATION

National Adaptation Plan for agriculture (4/10 objectives)

1. Short cycle and drought resistant varieties (short term)
2. Soil and water conservation strategies (short term)
3. Apply water saving irrigation techniques (short term)
4. Improve access to climate information services (medium term)

Source: FAO, 1965; CRU, 2011; NAP, 2015; CIA, 2017

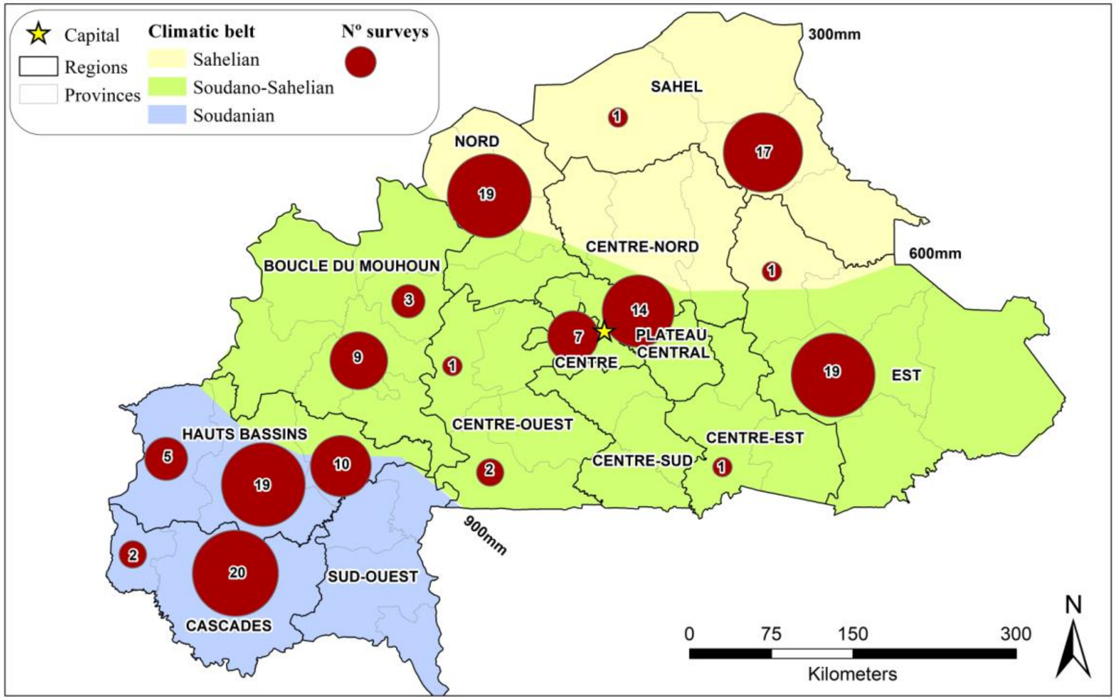
3. Understanding Agriculture & Climate Change

AIM

- To evaluate the risks of agriculture to climate change

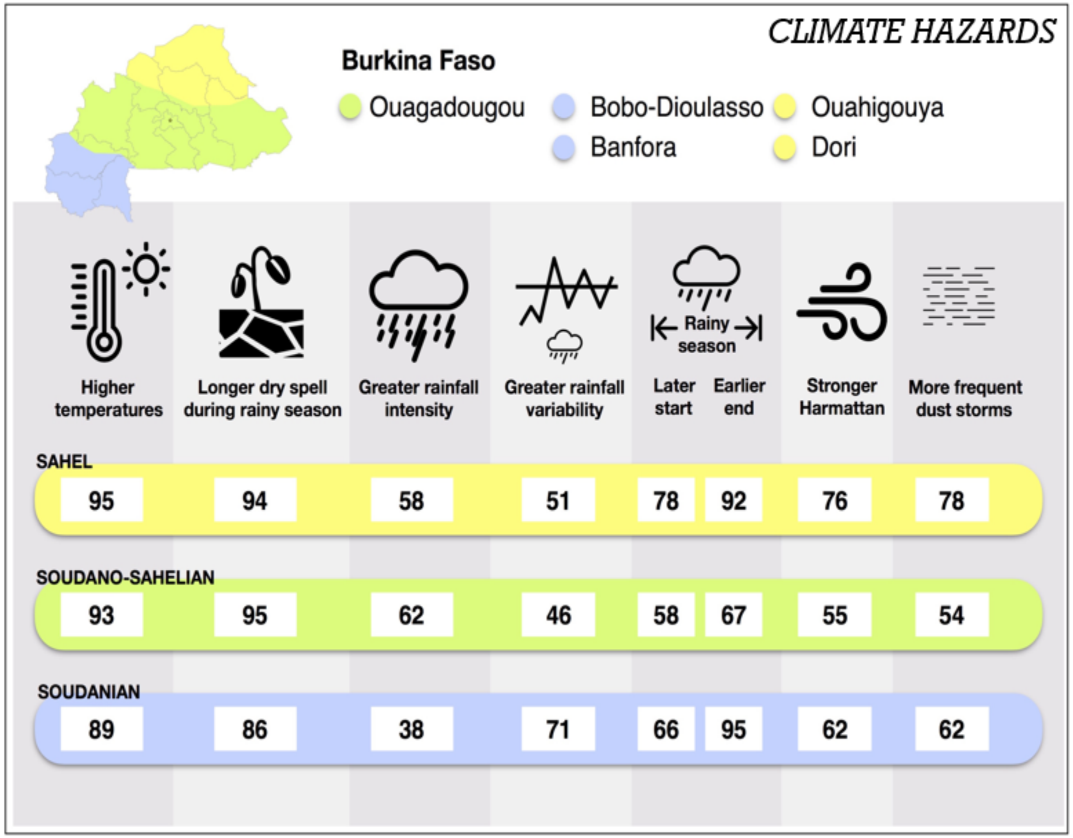
METHODS

- 150 surveys in 3 agro-ecological zones
- 17 question surveys
  - Climate hazards
  - Adaptation to climate change
  - Vulnerability & climate services



3. Understanding Agriculture & Climate Change

RESULTS



CLIMATE HAZARDS

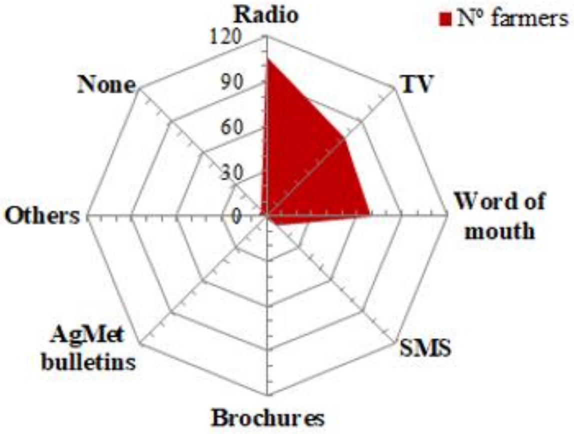
Burkina Faso

● Ouagadougou ● Bobo-Dioulasso ● Ouahigouya
● Banfora ● Dori

	Higher temperatures	Longer dry spell during rainy season	Greater rainfall intensity	Greater rainfall variability	Rainy season: Later start	Rainy season: Earlier end	Stronger Harmattan	More frequent dust storms
SAHEL	95	94	58	51	78	92	76	78
SOUDANO-SAHELIAN	93	95	62	46	58	67	55	54
SOUDANIAN	89	86	38	71	66	95	62	62

AGRICULTURAL ADAPTATION

CLIMATE SERVICES



4. Research Approach: Quinoa

- *Chenopodium quinoa* Willd. Herbaceous, C3 crop

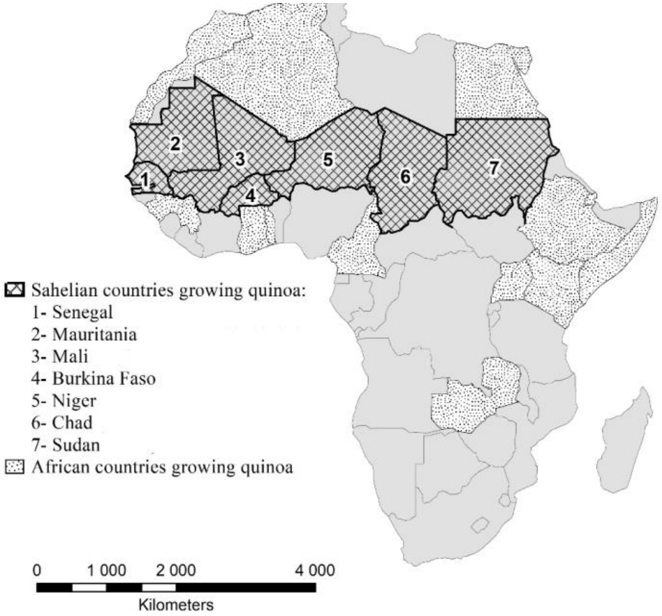
- Traditionally grown in the Andes (7000 years)

- Thrive in a wide range of ecosystems:
  Altiplano, Inter-valleys, Salares, Coastal and Yunga

- Genetic diversity (over 16 thousand accessions)

- Abiotic stress resilience:
  a) Drought (200-400 mm)
  b) Halophyte (sea water of 600 mM NaCl)
  c) Frost (-14°C seedling & -4°C milky grains)
  d) Heat (+40°C)
  e) pH versatile & poor soils (sandy & low nutrient)

- High nutritional properties
  - Essential amino-acids & high protein content
  - Rich in Ca, Fe & Mg; vitamins A, B2 & E
  - Gluten free



Source: Vacher, 1998; Jacobsen et al., 2003; Mamedi et al., 2007; Jacobsen et al., 2010; Steduto et al., 2012; Fuentes, 2015

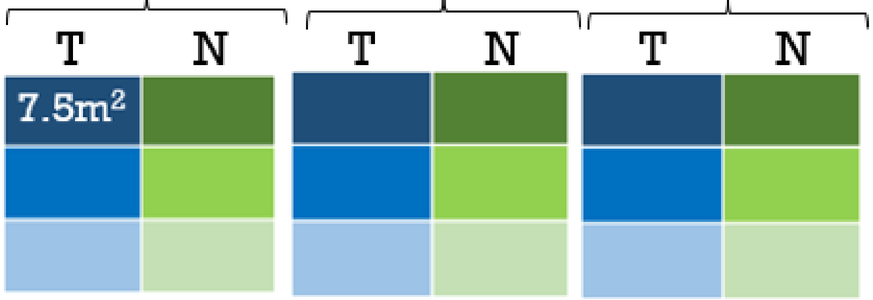
5. Tackling Problem: Quinoa Field Experiments

AIM

- Evaluate the adaptability of quinoa in the Sahel

EXPERIMENTAL DESIGN

2017-2018
4/11 & 8/12

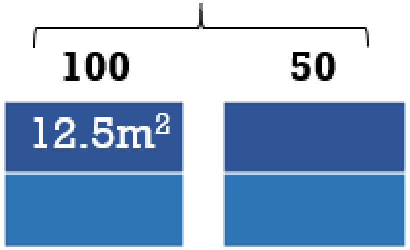


		100		80		60	% PETc
		T	N	T	N	T	N
	100	7.5m²					
Kg N ha⁻¹	50						
	25						

T: Titicaca
N: Negra Collana

x 3 replicates (405m²)

2018-2019
25/10 & 19/11



		Titicaca		
		100	50	% PETc
	100	12.5m²		
Kg N ha⁻¹	0			

x 4 replicates (200m²)

5. Tackling Problem: Overcoming Research Barriers

EXPERIMENTAL DESIGN

2017-2018

Randomized Split-Split-Block design

- Block: irrigation (100, 80 & 60% PETc)
- Split: genotype (Titicaca & Negra Collana)
- Split: fertilization (100, 50 & 25 kg N ha^{-1})

18 treatments x 3 rep. (54 exp. plots)

2018-2019

Randomized Split-Block design

- Block: irrigation (100 & 50% PETc)
- Split: fertilization (100 & 0 kg N ha^{-1})

4 treatments x 4 rep. (16 exp. plots)

DATA ANALYSIS

Analysis of Variance (Two way ANOVA)

- Analyse the differences among groups of means

Post-hoc Tukey HSD test (p-value <0.05)(pairwise comparison groups of means)

- Test factor interaction (irrigation vs. N-fertilization)
- Test main factor effect (irrigation & N-fertilization)
- More sensitive to SD than Fisher LSD test
- Can be used for both equal/unequal sample sizes per group

5. Tackling Problem: Overcoming Research Barriers

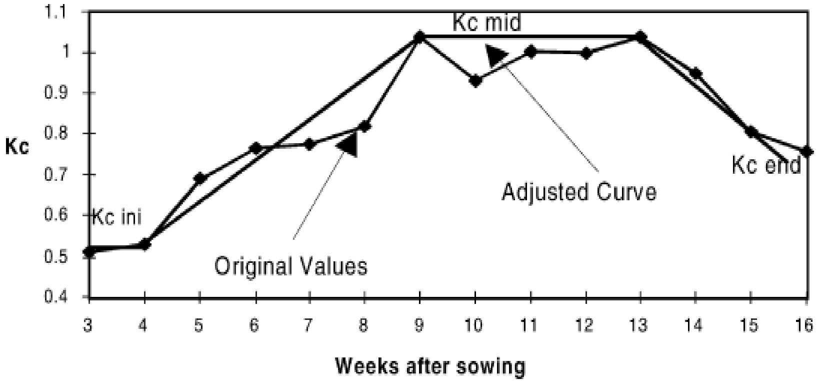
IRRIGATION SCHEDULING

Evapotranspiration (ETo in mm)

$ETo = 0.0023\ (Tmean + 17.78) * Ro * (Tmax - Tmin)\ \hat{}\ 0.5$

Ro is the solar radiation (1 mm day^{-1} = 2.45 MJ m^{-2} day^{-1}).

Ro monthly adjusted during the growing season



Potential Crop ET (PETc in mm)

$PETc = ETo\ * Kc$

Kc is the crop coefficient.

Kc weekly adjusted as follows:

Kc at E, 2L, 4L, 8L, PF, F, MG, PG, PM

Kc values: 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 0.9, 0.8, 0.7

Total Irrigation (TI in l m^{-2} or mm)

$$TI = \left(\left(\frac{m^3}{1000}\right) \div m^2\right) - 70$$

70 liters of water to attain drip-irrigation working pressure

Source: Hargreaves & Samani, 1985; Allen et al. 1998; García et al. 2003

5. Tackling Problem: Quinoa Field Experiments

FIELD & LAB MEASUREMENTS

Irrigation

- Amount, frequency & timing

Agro-meteorology

- Tmax, Tmin, T mean, precipitation, RH & PETc
- Soil temperature
- Solar radiation & photoperiodicity

Plant phenology and physiology

- Time E, 2L, 4L, 8L, PF, F, LS, MG, PG, PM
- Plant height, panicle length & width, root architecture, n° of branches & stem diameter
- Kernel weight, biomass/yield production & canopy cover

Soil characteristics

- pH, soil texture, org. matter, N, C, P, K content & bulk density

5. Tackling Problem: Quinoa Field Experiments

RESULTS

TITICACA VS. NEGRA COLLANA

Crop variety	Titicaca	Negra Collana
Seed yield (kg ha^{-1})	686 **a**	102 **b**
Biomass (kg ha^{-1})	1686 **a**	1725 **a**

⚠ *Average of all treatments (irrigation & N-fertilization) & sowing dates (4-Nov and 8-Dec). Experiment 2017-2018*

<u>TITICACA</u> (Two year experiment 4-sowing dates)

- Main effect N-fertilization ($p>0.05$).
- Main effect Irrigation ($p<0.05$). 100 & 80 vs. 60 & 50 PETc
- Sowing dates ($p<0.05$). 25-Oct vs. 8-Dec

Sowing date	25-Oct	4-Nov	19-Nov	8-Dec
Seed yield (kg ha^{-1})	1128**a**	898**ab**	659**ab**	540**b**

⚠ *Titicaca: best irrigation schedules (FI & PD) & all N-fertilization levels (100, 50, 25 & 0 kg N ha^{-1}).*

6. Tackling Problem: Climatic Chamber

AIM

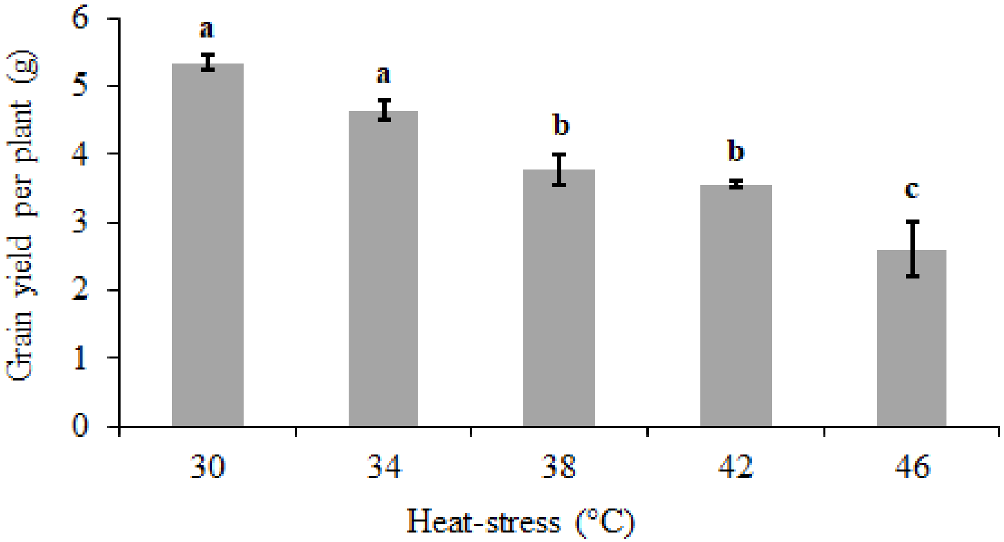
- To study the effect of heat-stress on seed-germination & flowering
- To identify the most suitable sowing dates (crop calendars)

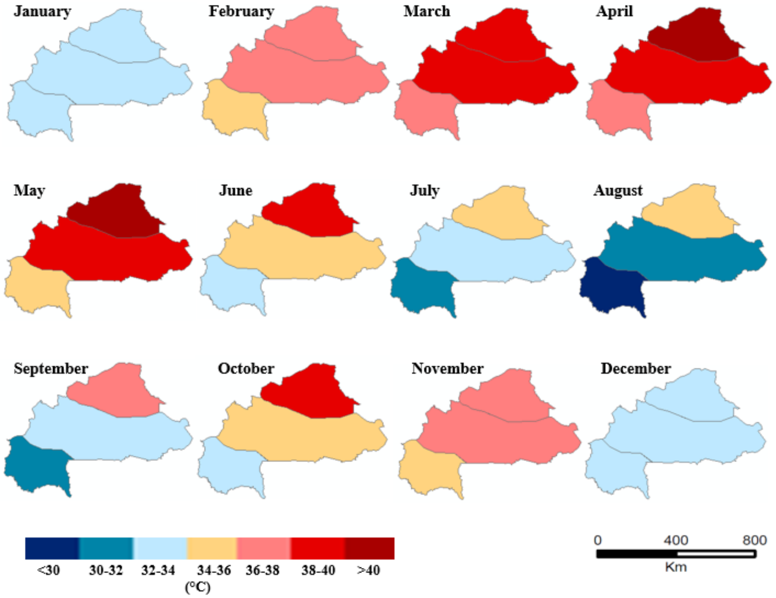
EXPERIMENTAL DESIGN

- Cv. Titicaca (the most extended variety in the Sahel)
- Factor levels: 30, 34, 38, 42, 46°C (6h day^{-1} for 10 days)
- One way ANOVA

RESULTS

- Relationship between heat-stress at flowering & seed yield at harvest





7. Tackling Problem: Crop Modelling

AIM

- Calibrate & validate quinoa in AquaCrop for a new environment under different irrigation schedules

EXPERIMENTAL DESIGN

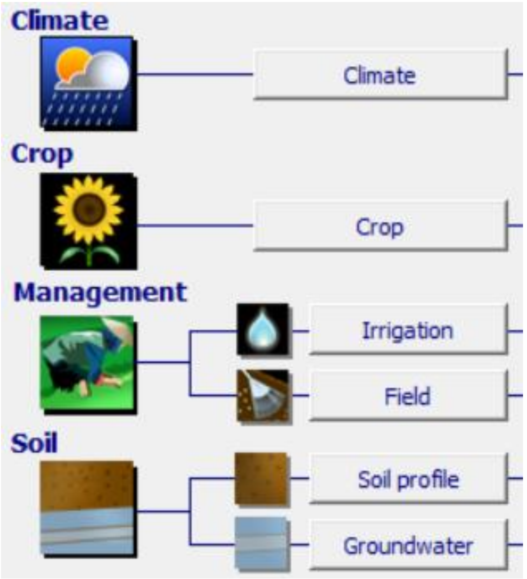
- T_1 , T_3 (Full irrigation-FI) 100% PETc
- T_5 , T_6 , T_8 (Progressive drought-PD) 70-90% PETc
- T_4 , T_7 , T_9 (Deficit irrigation-DI) 50% PETc
- T_2 , T_{10} (Extreme deficit irrigation-EDI) <50% PETc

MODEL CALIBRATION

- Climate: Tmax, Tmin, PETc, precipitation & RH
- Crop: development, production & response to stress
- Management: irrigation method & field practices
- Soil: texture, permanent wilting point & field capacity

MODEL VALIDATION

- Seed yield, biomass & canopy cover

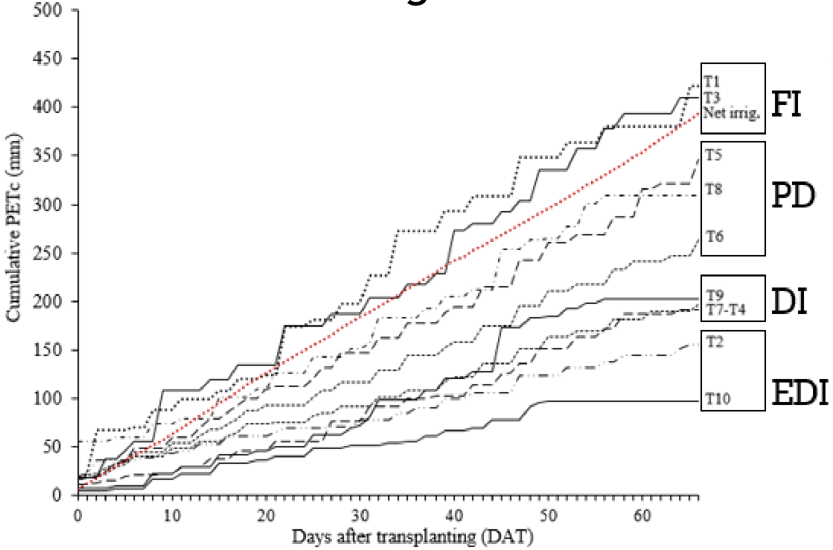


7. Tackling Problem: Crop Modelling

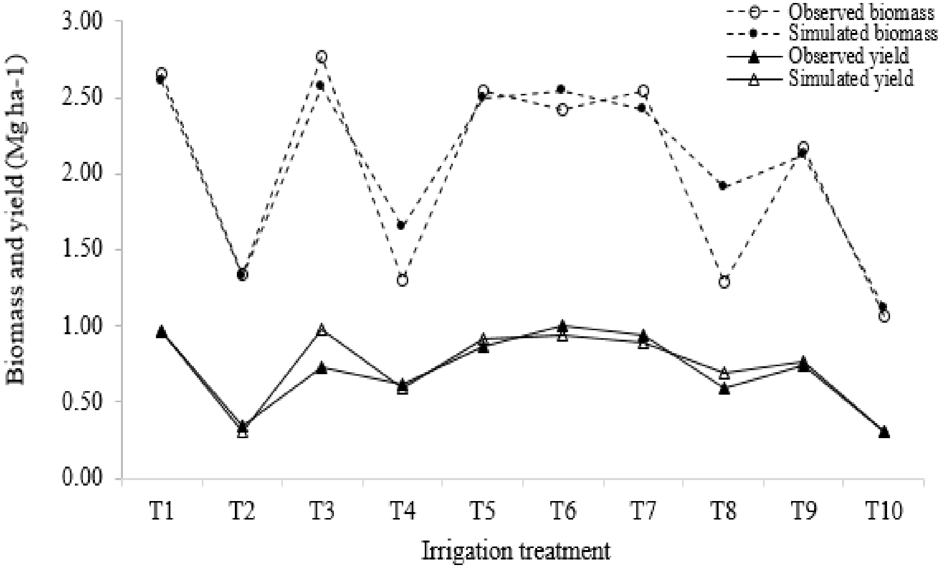
RESULTS

- PD vs. FI (13% yield reduction but 25% water savings)
- Yield & Biomass calibration (NRMSE = 11 & 18%)
- Yield & Biomass validation (NRMSE =15 & 9%)

Different irrigation schedules



Simulated & observed yield & biomass



<u>Normalised Root Mean Square Error (NRMS)</u>

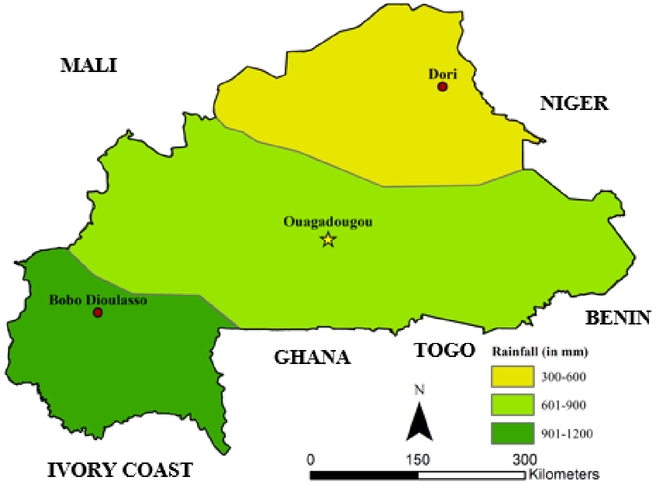
$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Pi - Oi)^2}\ ; NRMSE = \frac{RMSE}{\hat{P}} \times\ 100$$

O_i is the observed value, P_i is the simulated value and $\hat{P}$ is the simulated mean.

8. Tackling Problem: Climate Modelling

AIM

- To estimate temperature rise & evaluate its impact on crop yield



EXPERIMENTAL DESIGN

PAST CLIMATE

- 3 weather stations
- 45 years Tmax & Tmin daily data (1973 – 2017)

FUTURE CLIMATE SIMULATIONS

- 3 weather stations
- 43 GCMs
- 2 climate scenarios (RCP 4.5 & RCP 8.5)
- 95 years Tmax & Tmin daily data simulations (2006 – 2100)

CROP GROWTH SIMULATIONS

- 3 agro-ecological zones (Sahel, Soudano-Sahelian & Soudanian)
- 4 sowing dates (October, November, December & January)
- 4 time horizons (2020, 2025, 2050 & 2075)
- 3 soil textures per agro-ecological zone
- 2 climate scenarios (RCP 4.5 & RCP 8.5)

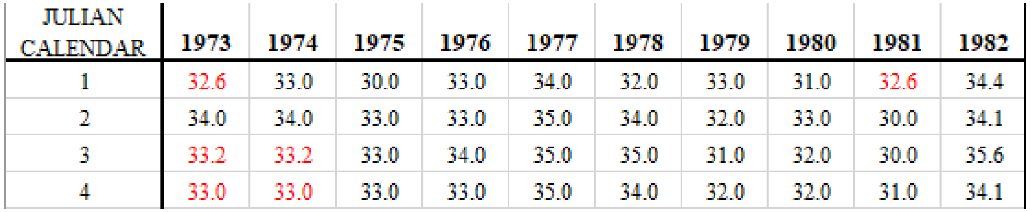
8. Tackling Problem: Overcoming Research Barriers

CLIMATE MODELLING

Past climatic data (Tmax & Tmin)

Daily gaps for 3 weather stations (1973-2017)

$$T\,max/min = \frac{\Sigma\,Tdaily_{\,1973\ to\ 1982}}{10}$$



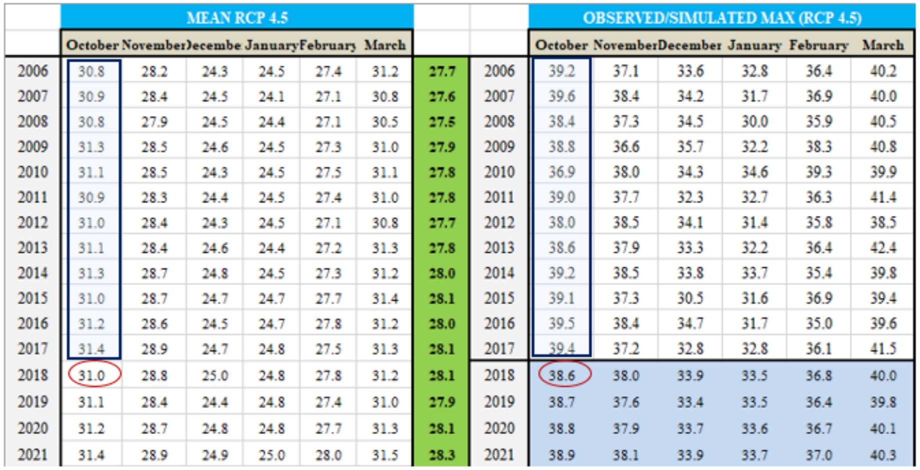
JULIAN CALENDAR	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
1	32.6	33.0	30.0	33.0	34.0	32.0	33.0	31.0	32.6	34.4
2	34.0	34.0	33.0	33.0	35.0	34.0	32.0	33.0	30.0	34.1
3	33.2	33.2	33.0	34.0	35.0	35.0	31.0	32.0	30.0	35.6
4	33.0	33.0	33.0	33.0	35.0	34.0	32.0	32.0	31.0	34.1

Future climate data

Delta method for monthly mean T, (2018-2100, RCP 4.5 & 8.5, 3 weather stations)

$$T\,mean = \Big(\overset{Observed}{\frac{\Sigma\,Tmax\ 2006_{\ to\ 2017}}{12}} - \overset{Simulated}{\frac{\Sigma\,Tmean\ 2006_{\ to\ 2017}}{12}}\Big) + \overset{Simulated}{Tmean_{\ 2018\ to\ 2100}}$$

Monthly-year mean for 43 GCMs



	MEAN RCP 4.5								OBSERVED/SIMULATED MAX (RCP 4.5)					
	October	November	December	January	February	March			October	November	December	January	February	March
2006	30.8	28.2	24.3	24.5	27.4	31.2	**27.7**	2006	39.2	37.1	33.6	32.8	36.4	40.2
2007	30.9	28.4	24.5	24.1	27.1	30.8	**27.6**	2007	39.6	38.4	34.2	31.7	36.9	40.0
2008	30.8	27.9	24.5	24.4	27.1	30.5	**27.5**	2008	38.4	37.3	34.5	30.0	35.9	40.5
2009	31.3	28.5	24.6	24.5	27.3	31.0	**27.9**	2009	38.8	36.6	35.7	32.2	38.3	40.8
2010	31.1	28.5	24.3	24.5	27.5	31.1	**27.8**	2010	36.9	38.0	34.3	34.6	39.3	39.9
2011	30.9	28.3	24.4	24.5	27.4	31.0	**27.8**	2011	39.0	37.7	32.3	32.7	36.3	41.4
2012	31.0	28.4	24.3	24.5	27.1	30.8	**27.7**	2012	38.0	38.5	34.1	31.4	35.8	38.5
2013	31.1	28.4	24.6	24.4	27.2	31.3	**27.8**	2013	38.6	37.9	33.3	32.2	36.4	42.4
2014	31.3	28.7	24.8	24.5	27.3	31.2	**28.0**	2014	39.2	38.5	33.8	33.7	35.4	39.8
2015	31.0	28.7	24.7	24.7	27.7	31.4	**28.1**	2015	39.1	37.3	30.5	31.6	36.9	39.4
2016	31.2	28.6	24.5	24.7	27.8	31.2	**28.0**	2016	39.5	38.4	34.7	31.7	35.0	39.6
2017	31.4	28.9	24.7	24.8	27.5	31.3	**28.1**	2017	39.4	37.2	32.8	32.8	36.1	41.5
2018	31.0	28.8	25.0	24.8	27.8	31.2	**28.1**	2018	38.6	38.0	33.9	33.5	36.8	40.0
2019	31.1	28.4	24.4	24.8	27.4	31.0	**27.9**	2019	38.7	37.6	33.4	33.5	36.4	39.8
2020	31.2	28.7	24.8	24.8	27.7	31.3	**28.1**	2020	38.8	37.9	33.7	33.6	36.7	40.1
2021	31.4	28.9	24.9	25.0	28.0	31.5	**28.3**	2021	38.9	38.1	33.9	33.7	37.0	40.3

8. Tackling Problem: Climate Modelling

RESULTS

PAST TRENDS

1975-2015

Mean: 14 °C
Mean Δ = ≈0.50°C

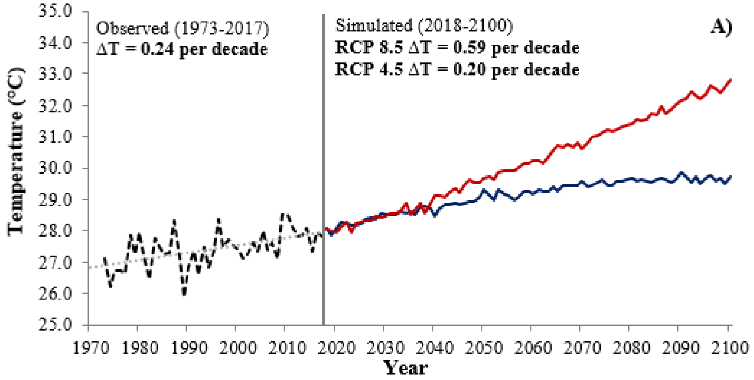
Mean: 28.3 °C (CRU,2011)
Mean Δ = 0.44-1.28°C

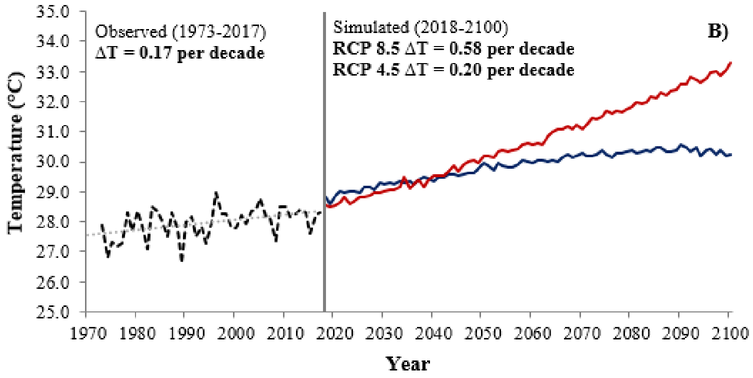
	Nº days year^{-1} T > 40°C			
	1983-92	1993-02	2003-12	2013-17
Dori (A)	98	102	94	98
Ouaga (B)	29	38	44	**60**
Bobo (C)	2	2	6	**6**

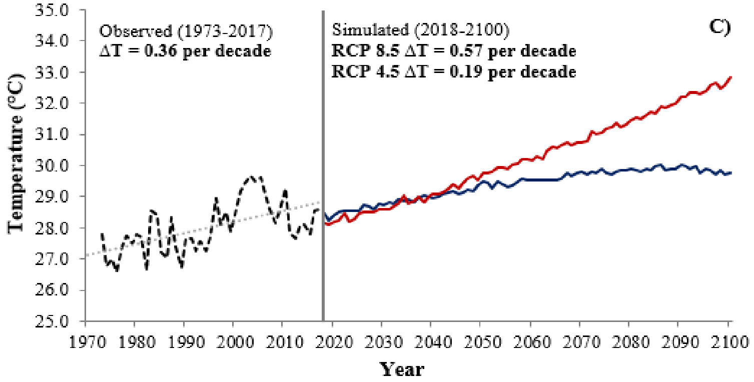
FUTURE TRENDS

- Temp. 2100: RCP 4.5 & 8.5 (+1.7°C & +4.9°C)

	Max mean Temperatures (°C) (Oct. - March) *RCP 8.5			
	2025	2050	2075	2100
Dori (A)	36.7	38.1	39.6	**41.2**
Ouaga (B)	37.2	38.5	**40.0**	**41.6**
Bobo (C)	34.7	36.1	37.6	39.2





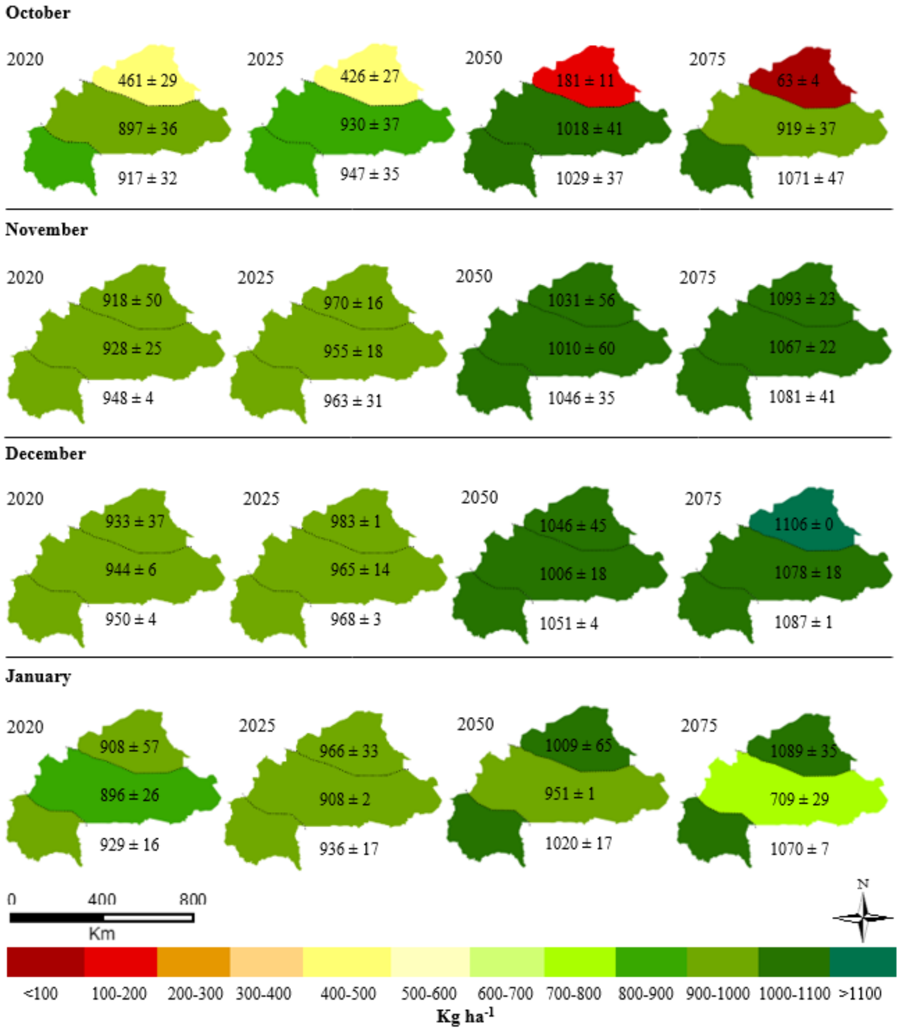


8. Tackling Problem: Climate Modelling

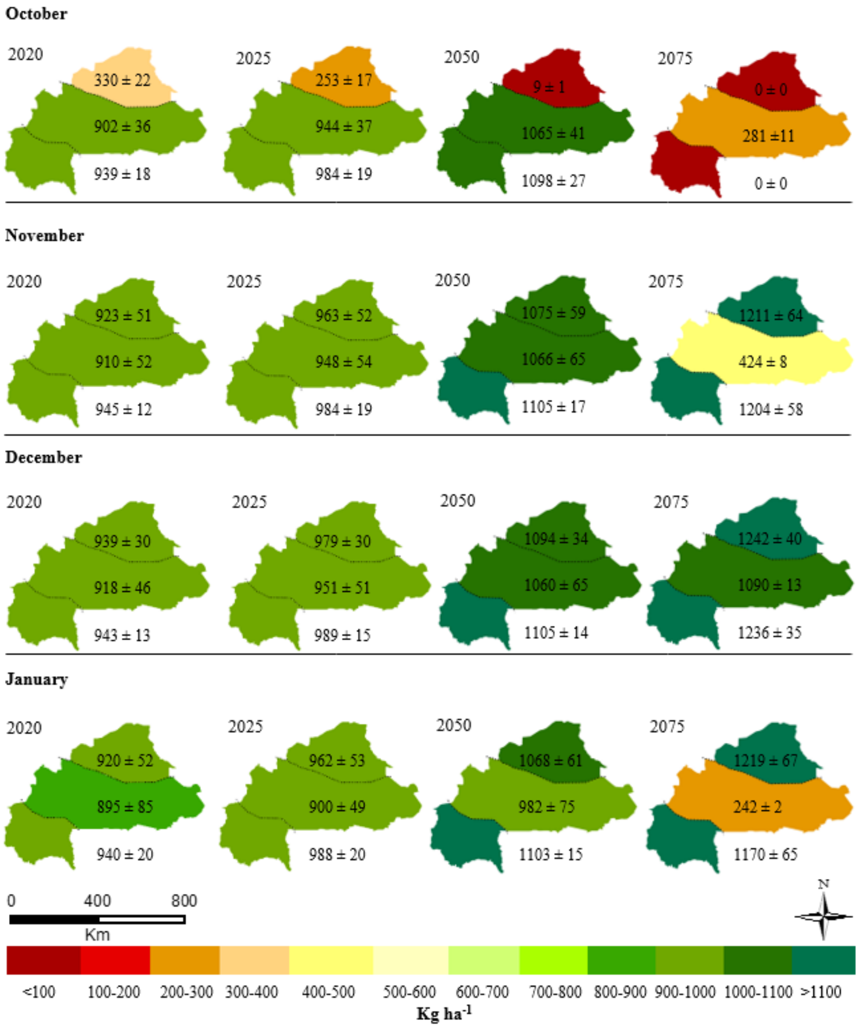
AQUACROP

RESULTS

RCP 4.5 (≈ 550 ppm CO_2)



RCP 8.5 (> 1000 ppm CO_2)



9. Conclusions, Discussion & Further Research

SURVEYS

- Farmers are aware of changing climatic patterns

- Highest vulnerability & exposure to natural hazards (Sahel)

- SWC strategies are largely widespread (Sahel)

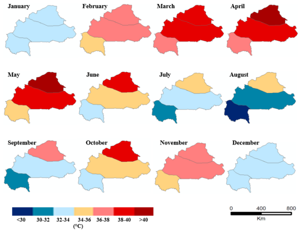
- Market-oriented & conventional agriculture (Soudanian)

CONTROLLED CONDITIONS

- 38°C is the critical temperature for quinoa pollination and seed-germination

- At 38°C there is a 30% yield loss & 50% decrease germination rates

- Optimal growing period
    - Sahel: November-February
    - Soudano-Sahelian: June-February*
    - Soudanian: all year round*



*Quinoa is highly affected by water-logging *(Dao et al., 2016)*

9. Conclusions & Discussion & Further Research

FIELD EXPERIMENTS & CROP MODELLING

- Yields ≥1t ha^{-1} under FI and PD (≈300-400mm)
- End October optimal sowing time (Soudanian zone)
- Short cycle (Titicaca-90DAS) rather than long cycle (Negra Collana-150DAS)
- N-fertilization: 25 kg N ha^{-1}
- Frequent irrigation (2/3 events week^{-1}) & little amount (≈ 8mm irrigation event^{-1})
- PD vs. FI (yield reduction of 13% but water savings of 25%)

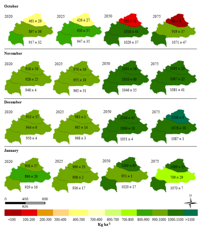
- Water requirements: sugar-cane (>1500mm); maize (800 mm); rice & cotton (>700mm); sorghum, groundnuts & millet (500mm)
- N-requirements of maize: 250-300 kg N ha^{-1}
- High-temperature tolerance at flowering: rice, maize, sorghum & tomato (34-35°C)

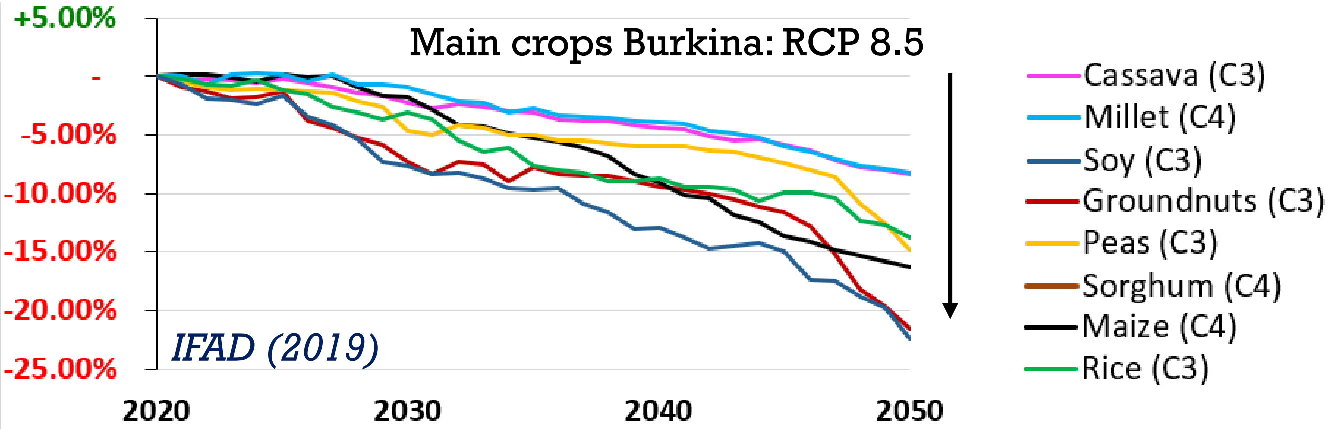
Source: FAO, 1992; FAO, 2006: Prasad et al., 2011

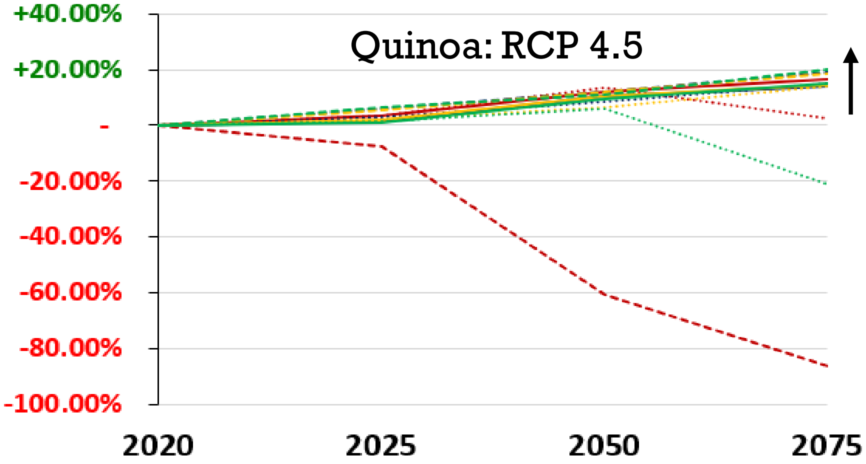
9. Conclusions & Discussion & Further Research

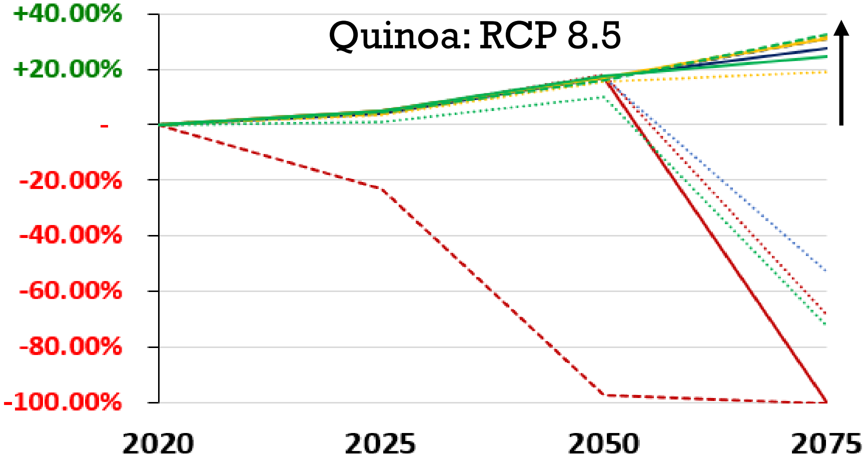
CLIMATE MODELLING

- Temperature RCP 4.5 (+1.7°C) & RCP 8.5 (+4.9°C)
- Yield loss of main crops (rice, maize, millet), but yield enhancement quinoa (33%)
- Doubling CO_2 concentrations can increase yields of C3 crops *(Ceccarelli et al., 2010)*




IFAD (2019)





9. Conclusions & Discussion, Further Research

FURTHER RESEARCH

QUINOA

- Plant breeding: higher yields (lower to other regions) *(Jarvis et al., 2017)*
- Plant breeding: heat/wind/water-logging tolerant (spatio-temporal extension)
- Social & economic: use/acceptance of quinoa & agricultural value chain

CLIMATIC TRENDS

- Precipitation patterns: false departure of the rainy season
- Impact of increasing temperatures and CO_2 concentrations in main crops

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THESIS CONCLUSION

Quinoa has a great potential in the Sahel in terms of adaptability to abiotic stresses & must be promoted as an alternative crop to alleviate food insecurity during the dry-season and under changing climatic conditions.

10. Main Outcomes & Results Dissemination

RESEARCH PAPERS

- Alvar-Beltrán, J. et al. (2019). Effect of Drought, Nitrogen Fertilization, Temperature and Photoperiodicity on Quinoa Plant Growth and Development in the Sahel. *Agronomy*, *9*(10), 607. (published)

- Alvar-Beltrán, J. et al. (2019). Effect of drought and nitrogen fertilization on quinoa (*Chenopodium quinoa* Willd.) under field conditions in Burkina Faso. *Italian Journal of Agrometeorology*, (1), 33-43 (published)

- Alvar-Beltrán, J. et al. (2019). Can global warming hinder the potential of quinoa in the Sahel? *European Journal of Agronomy* (under review)

- Alvar-Beltrán, J. et al. (2019). Heat-stress effect on quinoa (*Chenopodium quinoa* Willd.) under controlled climatic conditions: the potential of quinoa in Burkina Faso. *Agricultural Science* (accepted)

- Alvar-Beltrán, J. et al. (2019). Irrigation scheduling of drought-resistant quinoa in Burkina Faso with AquaCrop model. *Irrigation Science* (under review)

- Alvar-Beltrán, J. et al. (2019). Farmer´s awareness and agricultural adaptation to climate change in Burkina Faso´s different agro-climatological zones. *Environmental Management* (under review)

10. Main Outcomes & Results Dissemination

SEMINARS & CONFERENCES

- FAO, Rome-Italy (Feb. 2020)

- RAMAO, Granada-Spain (Oct. 2019)

- CUCS, Trento-Italy (Sep. 2019)

- WMO-RTC, Nanjing-China (July 2019)

- INERA, Bobo Dioulasso-Burkina Faso (May 2018 & Feb. 2019)

- CESAO, Bobo Dioulasso-Burkina Faso (Feb. 2019)

OTHERS

- 1 quinoa tasting, Bobo Dioulasso-Burkina Faso (Feb. 2019)

- 1 press release (https://lefaso.net/spip.php?article88127), Burkina Faso (Feb. 2019)

- 1 farmer workshop, Ouaga-Burkina Faso (April 2019)

- 3 month consultancy at WMO-Rwanda & Senegal (July-Sept. 2018)

THANK YOU !

Pics de Sindou, Banfora

Crop Perspectives

PRODUCTION & RESEARCH

- Field trials 2 agro-ecological zones
- 3 MSc and 1 PhD thesis (adaptability & practices)
- 50 farmers growing quinoa
- Production of 200 kg (scaling-up crop production)
- 0.5-1kg seeds (key stakeholders) for 500 – 1000m^2

ACCEPTANCE & USE

- 2 quinoa tasting events (INERA & UNIFI)
- Multiple workshops: benefits & adaptability to climate change (authorities, technicians, agro-business and farmers)
- High production acceptance by farmers
- Consumption acceptance & use of quinoa not yet evaluated