TRADING WATER FOR SOIL FERTILITY IN RICE SYSTEMS UNDER CLIMATE CHANGE

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Background information

- As human population increases and more land is sought for increased crop production, important ecosystems such as flood plains and valleys are tilled, drained, eroded and /or compacted.

- Climatic Changes are further reducing water availability and reliability for rice farming

- A number of options to counter these challenges have been proposed or already adopted
  - Alternative Wetting and Drying(AWD)
  - System of Rice Intensification

- However, the link between the proposed rice farming practices, SOC stocks build-up and climate change is poorly understood.

- The present study employs a field based & modeling approach to evaluate long term effects of adopted rice farming practices and climate change on SOC stocks the Kilombero Valley, in Tanzania

Aim and Objectives

Aim: The general aim of this project is to understand the soil-water dynamics into evaluations of sustainability of rice systems in a changing climate.

Objective1:
Establishment of research sites in Kilombero, for local-scale monitoring of SOC and water level in rice paddies.

Objective2:
Assessment of SOC stocks and rice yields in relation to water consumption rates at spatial scale.

Objective3:
Using climate change projections to assess sustainability of rice systems under future climate conditions and provide indications for adaptation strategies

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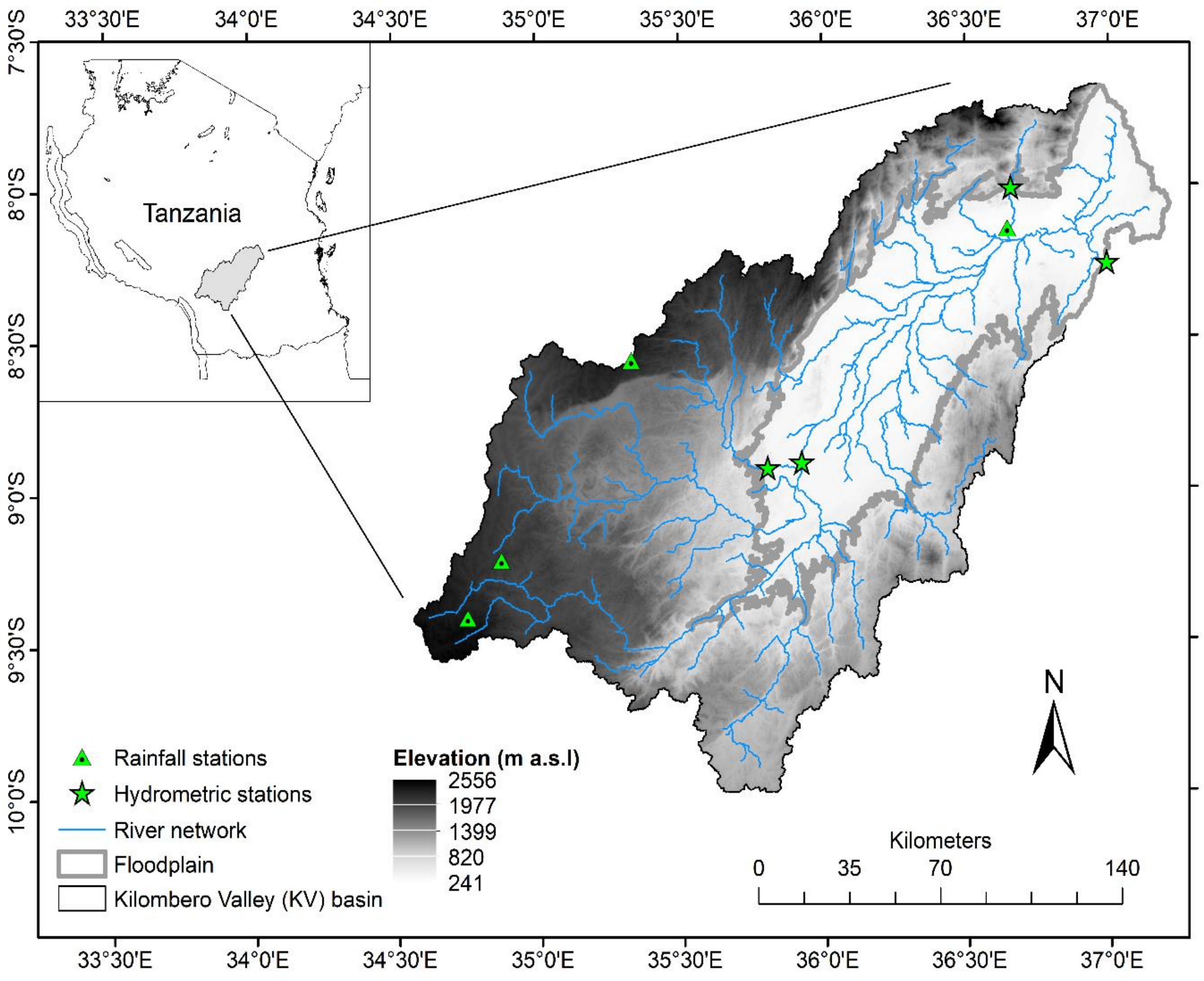
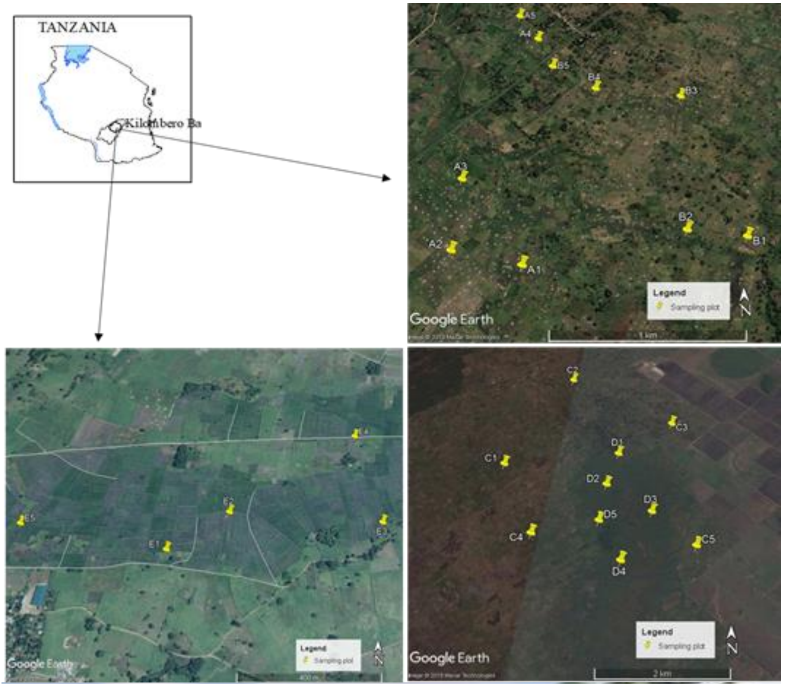
Study Area



- The Kilombero basin belongs to the sub-humid tropical climate,
- Long-term (1998–2010) average annual precipitation between 969 mm and 1,446 mm of which 85% to 90% falls during the wet season from December to April annually
- There are 14 primary land cover classes in the study area , among which the forest occupies more than 80% of the total area.
- Cropland covers around 13% of the study area with rice, sugarcane and maize being the main crops grown in the area

Influence water management practices on soil organic carbon and nutrients in rice farming. A case for Kilombero Valley, Tanzania.



- The objective of this study was to examine on-farm potential response of soil organic-carbon (SOC), total nitrogen (TN) and total phosphorous (TP) and bulk density (BD) to water management practices in rice farming within Kilombero Valley, Tanzania.
- Soil samples were collected from three villages in the study area at four depths as follows: 0-20; 20-30, 30-40; 40-50 cm.
- Four water management regimes namely;
  - A= continuous flooding (rainfed) without intensification of rice farming,
  - B= traditional flooding (rainfed) involving system of rice intensification (SRI),
  - C= alternative wetting and drying (AWD) involving SRI for one cropping season,
  - D= abandoned fields (fallow) and AWD involving SRI for two seasons were investigated as regards their impact on SOC, TN, TP and BD.

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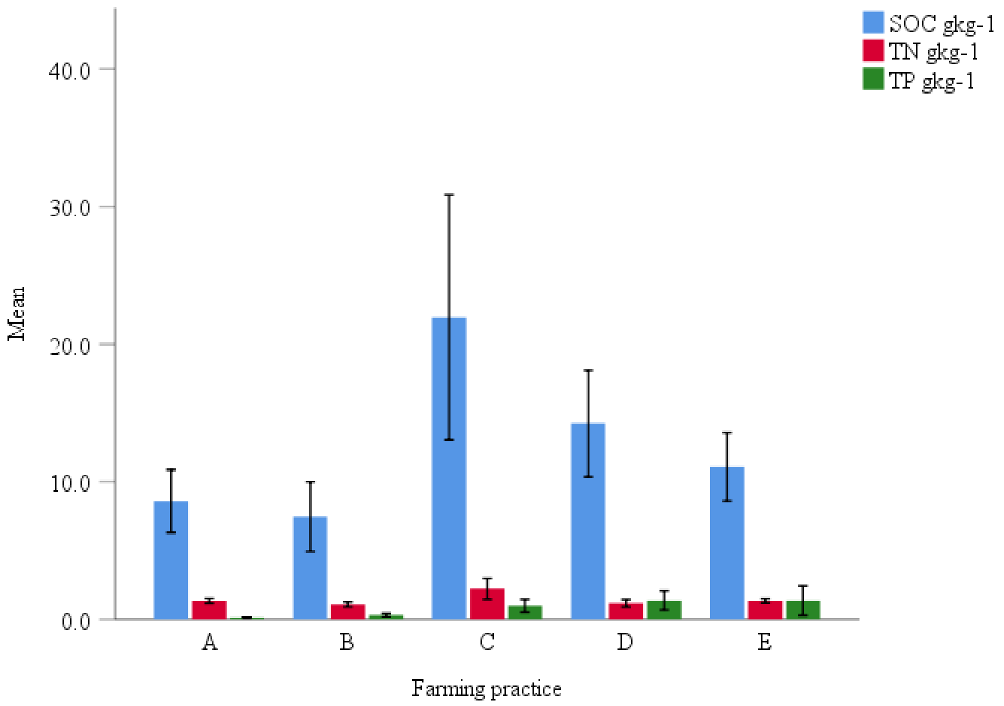
Variation of SOC and nutrient across farming practices

- Alternative wetting and drying with one farming season found to have higher mean concentration of SOC (21.94 ± 4.45 g kg-1), TN (2.21 ± 0.37 g kg-1).
- Lower concentrations of SOC and TN were 7.45 ± 1.26 g kg-1 and 1.08 ± 0.90 g kg-1 respectively found in traditional rice flooding irrigation with intensification.
- AWD farming practice involving SRI with one farming season had significant higher SOC compared to traditional flooded with (P = 0.000) and without (P = 0.001) intensification.
- TN were significant higher in AWD farming practice involving SRI with one farming season flooded irrigation farming practices.



Mean concentration of SOC, TN and TP among different farming practices in Kilombero valley. Where A=traditional flood irrigation (rainfed) without intensification of rice farming, B= traditional flooding (rainfed) with rice intensification (SRI), C=AWD farming practice involving SRI with one farming season, E=AWD farming practice involving SRI with two seasons, D= abandoned fields

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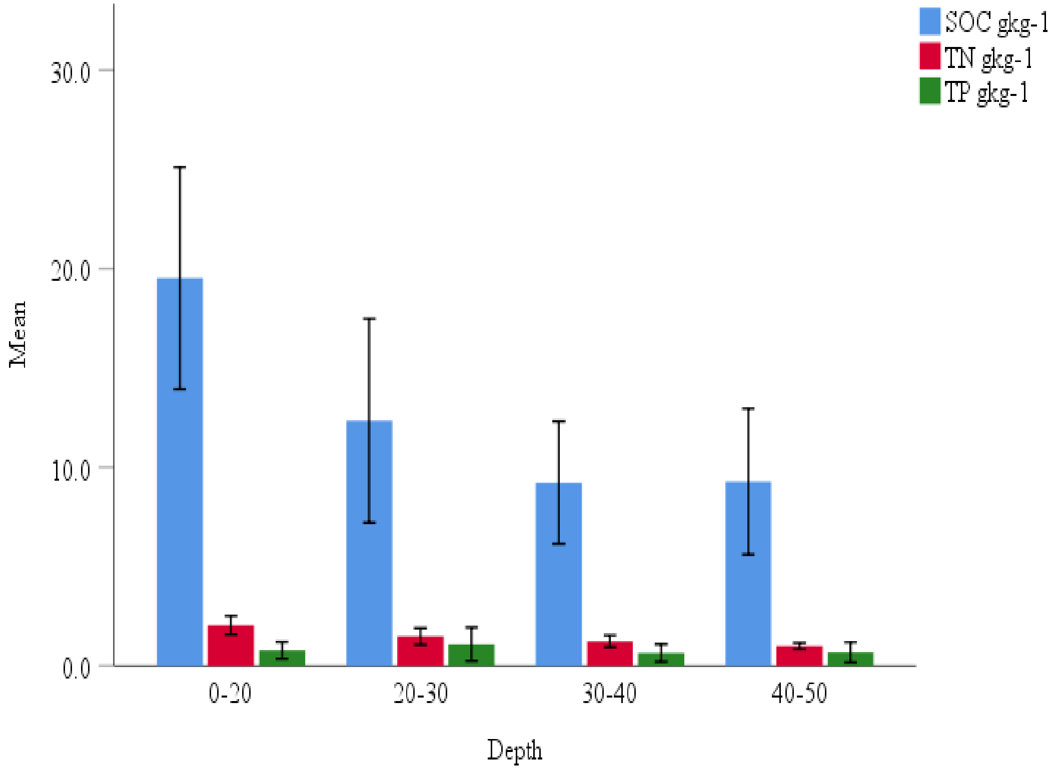
Variation of SOC and nutrient with depth

- Soil Organic Carbon (SOC), total nitrogen (TN), and total phosphorus (TP) concentrations decreased with soil depth

- The average carbon concentration was higher in the 0 - 20 cm topsoil, 19.52 ± 2.7 g kg-1, 2.04 ± 0.2 g kg-1 and 0.78 ± 0.12 g kg-1 of SOC, TN and TP respectively.

- The lower concentrations of were 9.28 ±1.84 g kg-1 for SOC, 1.0 ± 0.08 g kg-1 for TN, and 0.68 ± 0.25 g kg-1 for TP at 40- 50 cm soil layer.

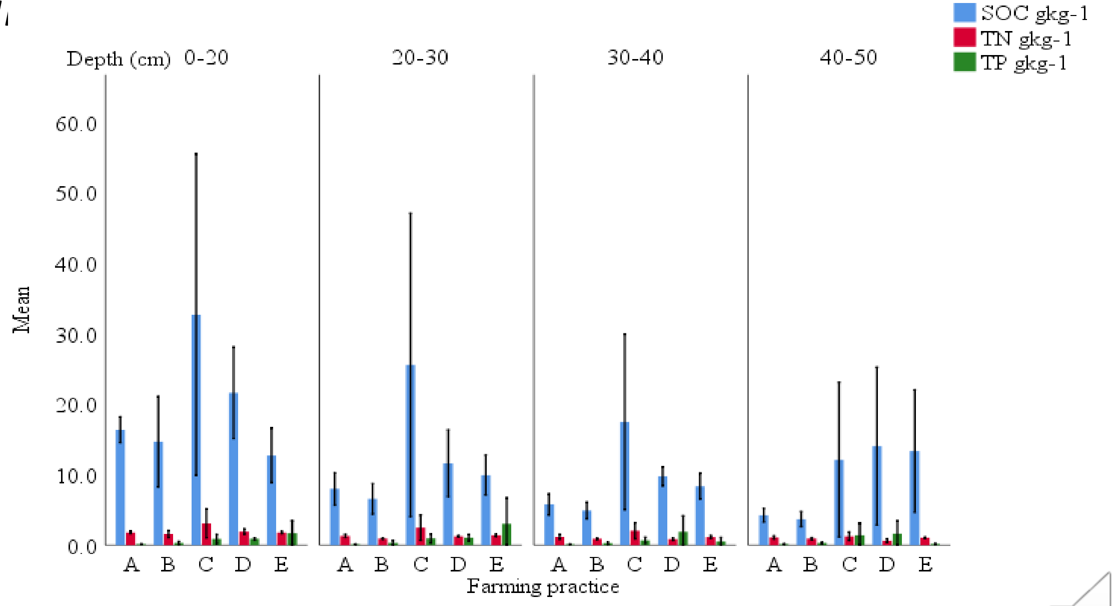


Mean concentration of SOC, TN and TP in a vertical profile of soil.

Farming practices and variation of nutrients with depth

- In all farming management, higher mean concentrations of SOC, TN and TP were found in the upper soil layers.
- SOC concentration (g kg−1) decreased with depth in all farming practices except in abandoned field, which were relatively constant
- SOC were higher at AWD farming practice-involving SRI with one seasons in all soil depth.

- *Mean concentration of SOC, TN, TP at farming practices A, B, C, D and E wit depth at Kilombero valley. Where A=traditional flood irrigation (rainfed) without intensification of rice farming, B= traditional flooding (rainfed) with rice intensification (SRI), C=AWD farming practice involving SRI with one farming season, E=AWD farming practice involving SRI with two seasons, D= aba*



Relationship among SOC, nutrients and physical chemical characteristics

- After examining the effect farming practices with depth, we find a relationship of environmental variables with SOC, TN and TP.
- Pearson correlation indicated BD had significant negative correlation with SOC, TN and TP concentrations.
- Porosity were positively correlated with mean SOC, TN and TP.
- Meaning increasing in pore spaces increased accumulation of nutrient, and lower bulk density.

Conclusion and recommendations

- Water use management in farming practices is a very important aspect as demand for water increase with an increase in rainfall variability and extreme events.
- Irrigation and fertilization strategies are part of approaches for improving agricultural productivity
- AWD in SRI can save water with little or low weed pressure and efficient use of N, because of nutrient accumulation.
- Both approaches have impacts on nutrients and microbial activities where;
    - The water-saving irrigation by controlling limiting values of soil water potential related to specific growth stages not only reduced water input, but also increased production, therefore enhancing water nutrient-productivity.
- Farming practices with AWD involving system of rice intensification can be among the best conservation farming as it retain SOC, which limit emission of CO2 and TN which is important limiting nutrient in agriculture as well as save water.

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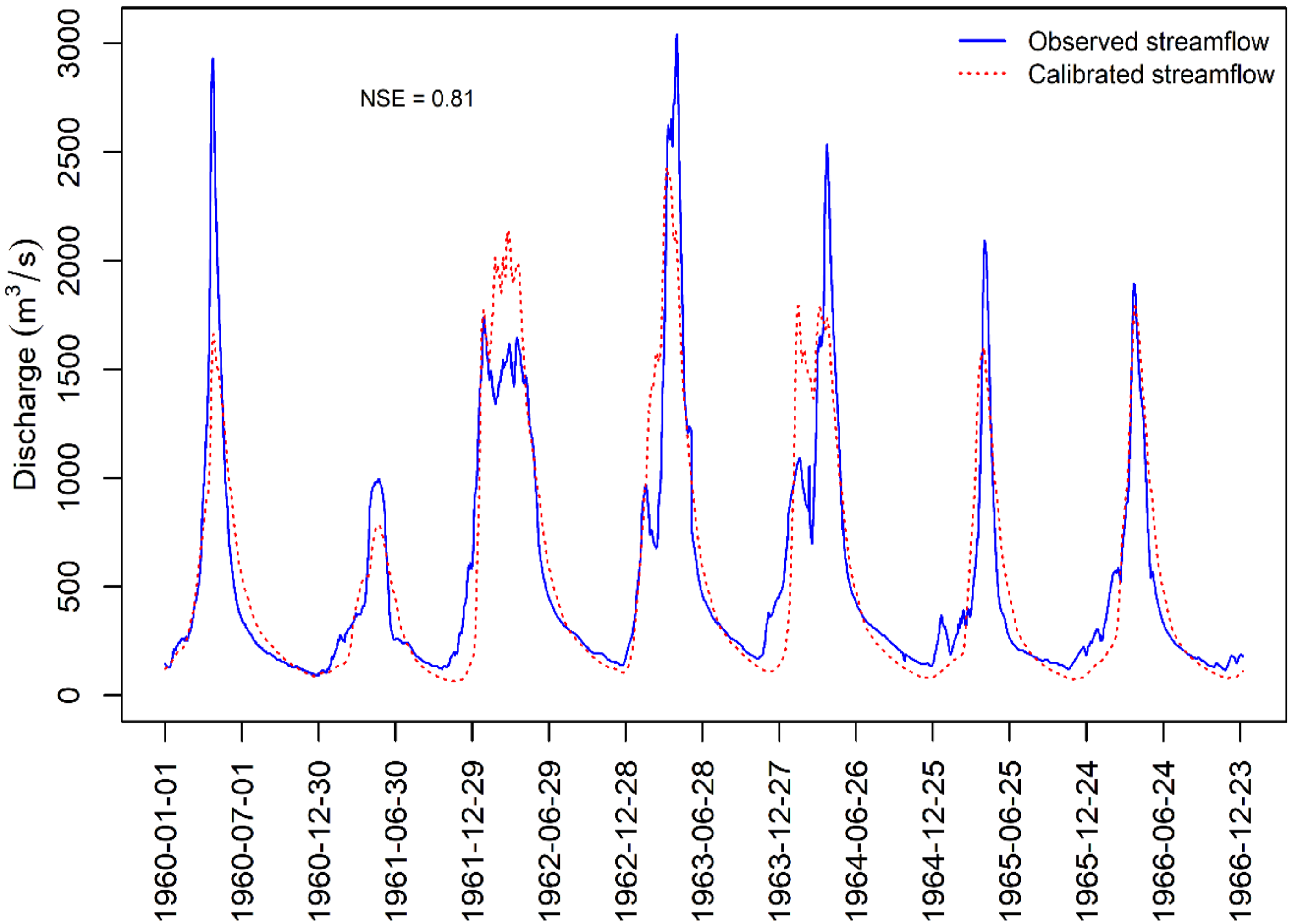
2. Uncertainties Associated with Climate Change projections on Future Water Resources in Kilombero Basin, Tanzania

- While there have been efforts in improving climate change impact uncertainty using ensembles of climate models,
  - there has been less focus on the combined effect of climate models and hydrological model uncertainty.
- Soil and Water Assessment Tool (SWAT) was forced with climate data and calibrated against river discharge using automatic calibration routine within the SWAT calibration and uncertainty program (SWAT-CUP).
- Satisfactory model performance result, with daily NSE value of 0.82 was obtained.
- The results from the hydrological models are utilized to project the effect of climate change on river discharge and other water balance components as given by ensemble mean from RCMs models given (CORDEX-Africa) for the two representative concentration paths (RCPs), namely RCP4.5 and RCP8.5 emission scenarios.
- The RCM projections of change in monthly precipitation, temperature, potential evapotranspiration, actual evapotranspiration, and total water yield were estimated by comparing the two future time slices (near future [2031-2060] far future [2071-2100]) climate conditions to the reference (historical) period (1957-2005).

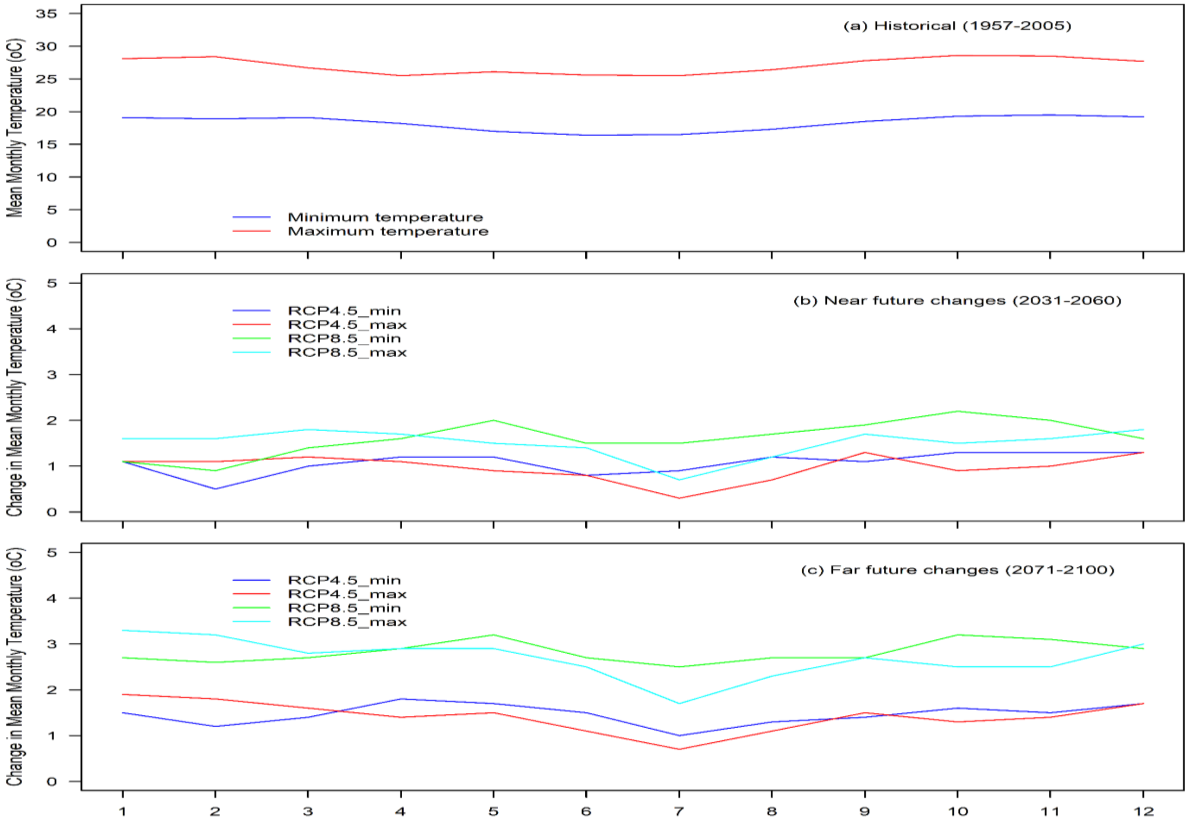
Model Performance



- Streamflow hydrograph showing the observed and the calibrated streamflow for the Kilombero River at Swero gauging station.
- Statistical metric is shown within the graph and refer to the Nash-Sutcliffe Efficiency (NSE)

What can we expect in the future for the Kilombero Basin?

Temperature



Bias-corrected historical (1957-2005) mean monthly temperature (a), near future (2031-2060) temperature change signal for scenarios RCP4.5 and RCP8.5 (b), and far future (2071-2100) temperature change signal for scenarios RCP4.5 and RCP8.5 (c) in the Kilombero River Basin. All values represent basin-wide average.

- The future of the basin is very uncertain as the projected changes in basin-wide mean monthly temperatures for both RCP4.5 and RCP8.5 show the wide ranges [0.3 to 1.9 ºC for RCP4.5 and 0.7 to 3.3 ºC for RCP8.5] (Figure b and c).
- The changes in both minimum and maximum monthly temperatures are expected to rise above 1.7 ºC under the RCP8.5 in all Months in the far future (2071 to 2100).
- Overall, the temperature signal shows a vivid trend of rising under both near (2031-2060 and far (2071-2100) future across both scenarios which implies the hotter future.

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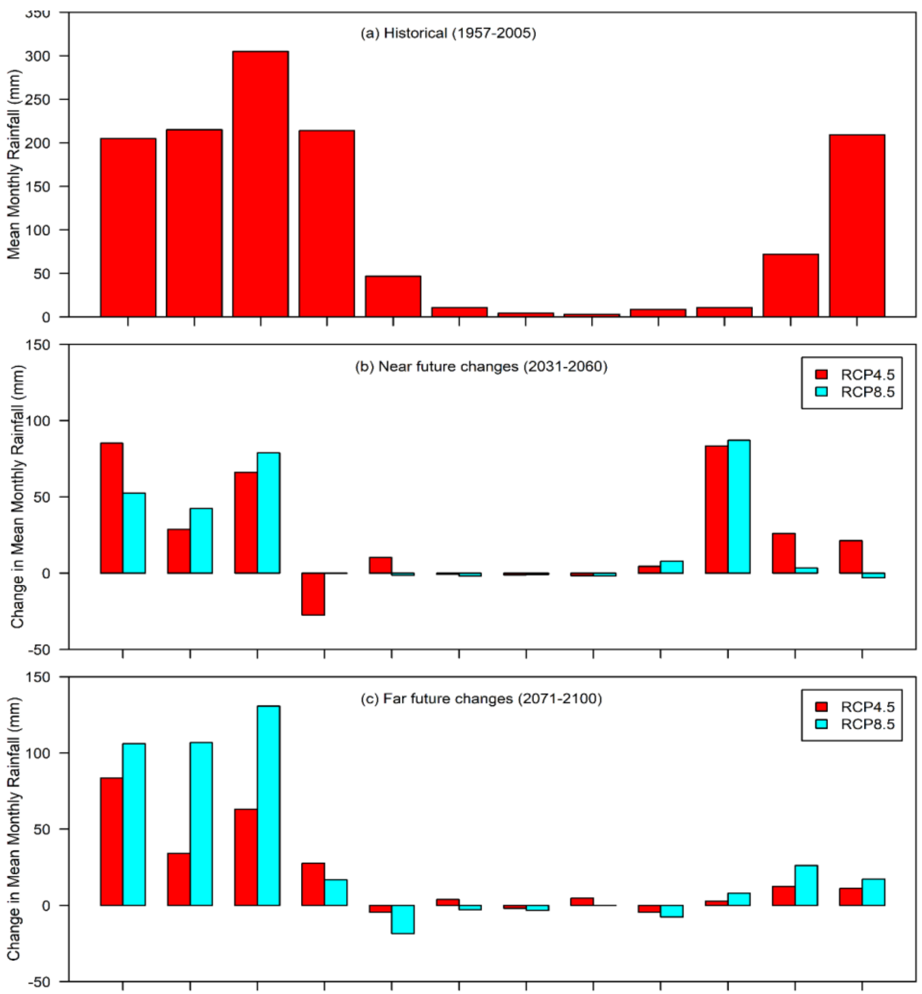
What can we expect in the future for the Kilombero Basin?

Precipitation



Bias-corrected historical (1957-2005) monthly precipitation (a), near future (2031-2060) precipitation change signal for scenarios RCP4.5 and RCP8.5 (b), and far future (2071-2100) precipitation change signal for scenarios RCP4.5 and RCP8.5 (c) in the Kilombero River Basin. All values represent basin-wide long-term average monthly precipitation for the given periods.

- Results of projected changes in precipitation under both near (Figure b) and far (Figure c) futures across both scenarios, show no significant signal towards shortening or an extension of the wet or dry seasons.
- In the far future, under the RCP8.5 (Figure b), precipitation amounts seem to increase (between around 17 mm [in December] and around 130 mm [in March]) within the rainy season, which implies the wetter future.
- In contrast, the precipitation amounts primarily decrease (between around -18 mm [in May] and around 0.0 mm [in August] within the dry season, which implies the drier future. These two antagonistic results (i.e. wetter future during the wet season and drier future during the dry season) to some extent, show uncertainty in the projected precipitation signals based on the RCMs provided by the CORDEX-Africa.

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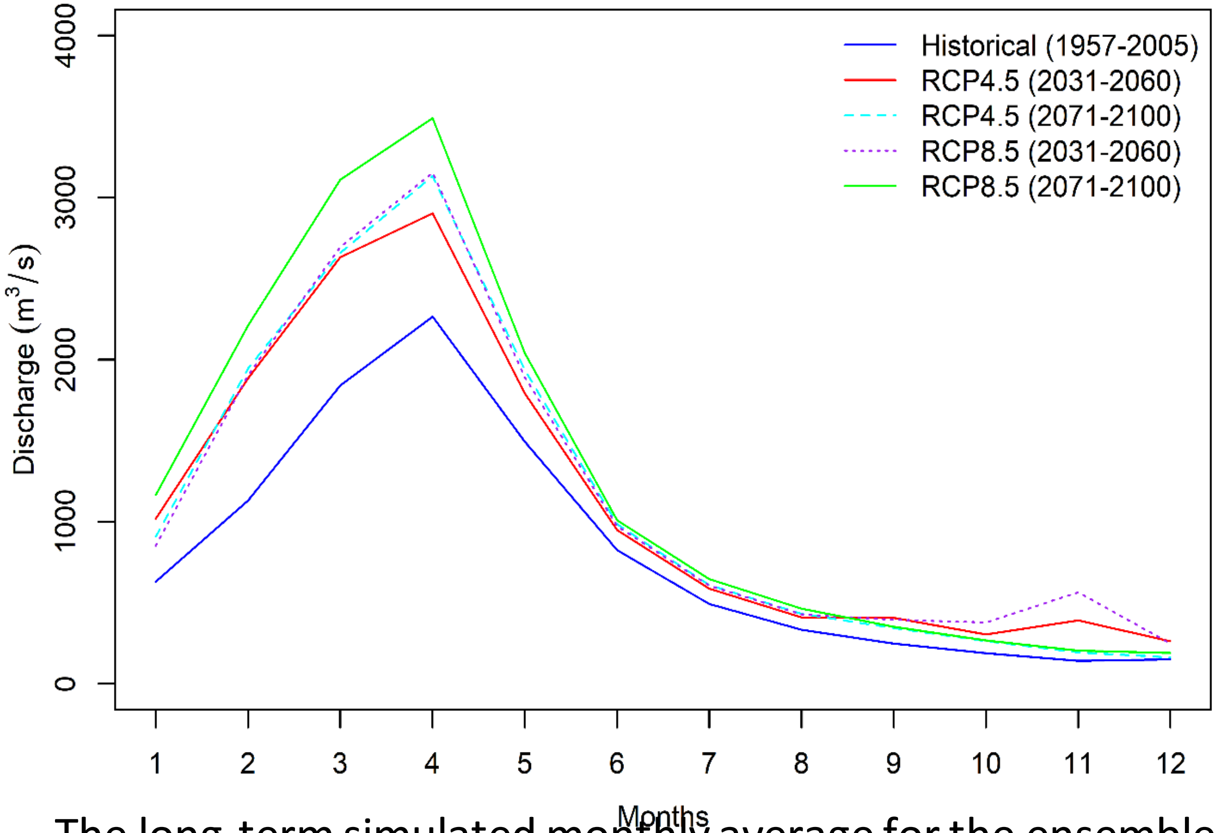
What can we expect in the future for the Kilombero Basin?

Water resources



The long-term simulated monthly average for the ensemble mean of RCMs historical (1957-2005) climate data, and the long-term simulated monthly average discharges for the near future (2031-2060) and far future (2071-2100) based on the RCP4.5 and RCP8.5 scenarios.

- The projected streamflow discharge shows consistent increasing across all scenarios with a clear increase during the wet season and little increase during the dry season

- . Our findings are similar to the findings reported by other researchers who study climate changes across the regions (e.g. Adhikari et al., 2017; Getachew et al., 2021).

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What can we expect in the future for the Kilombero Basin?

Water Resources

Scenario/Variable	RCP4.5 (near)	RCP4.5 (far)	RCP8.5 (near)	RC8.5 (far)
Historical P (mm)	1351.1	1351.1	1351.1	1351.1
Change in P [mm (%)]	244.4 (18.1)	236.7 (17.5)	262.9 (19.5)	346.8 (25.7)
Change in PET [mm (%)]	146.8 (11.8)	183.4 (14.7)	190.9 (15.3)	284.3 (22.9)
Change in ETa [mm (%)]	20 (3.9)	13.4 (2.6)	1.9 (0.4)	-0.8 (-0.2)
Change in WYLD [mm (%)]	269.1 (35.8)	266.8 (35.5)	304 (40.5)	388.5 (51.7)

Historical mean annual precipitation based on the ensemble mean of bias-corrected RCM simulations (1957–2005) and the absolute and relative changes of precipitation, and corresponding impacts on selected water balance components in SWAT model simulations for near future (2031-2060) and far future (2071-2100) time horizons based on the projections under the RCP4.5 and RCP8.5 scenarios. The numbers in parentheses represent the percentage changes. P represents the precipitation, PET the potential evapotranspiration, ETa the actual evapotranspiration, and WYLD the total water yield.

- The changes in precipitation indicate the wetter future (Table 3) with an increase ranging between 17% (for the RCP4.5 [2071-2100]) and 25% (for the RCP8.5 [2071-2100]).
- The changes in water yield also show similar trend as the changes in precipitation, which highlights consistent in the projected wetter future.
- The potential evapotranspiration is increasing across all scenarios between 146 mm and 284 mm.
- In contrary, changes in the actual evapotranspiration show the mixing results among the RCPs scenarios with the relatively higher values under the RCP4.5 (for both near and far futures) scenarios compared to their corresponding values under the RCP8.5 scenarios.
- The relatively low values in the actual evapotranspiration, might partly be attributed to the increase in temperature and the spatio-temporal water deficit.

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Uncertainties associated with climate change impacts on water resources

- It is clear that there are several uncertainties in the results presented in this study. For example, estimates of water balance components under RCP4.5 and RCP8.5 scenarios for the same simulation period (e.g. 2031-2060) are different
- Based on the changes in the precipitation signals together with the increasing in high flow, the future of Kilombero River Basin might experience moderate to severe floods especially during the rainy season.
- The consistent rising of temperature within the basin due to climate change in combination with low flows during the dry season, suggests the possibility of drought-related risks.
- Thus, relevant strategies to manage water resources wisely have to be formulated and implemented.

3. Can current rice farming practices build Soil organic Carbon stocks in the face of Climate Change?

- The carbon module within the Decision Support System for Agrotechnology Transfer (DSSAT) cropping system model (CSM), -DSSAT –CENTURY

- Calibration of the same with crop, soils, climate and management prevalent in the study area.

- The farming practices (i) traditional flooding (rain-fed) without intensification (TFI0), (ii) traditional flooding with intensification, (TFI1) (iii) alternative wetting and drying (AWD) farming practice involving SRI for one farming season (AWD1) and (iv) AWD farming practice involving SRI for two seasons (AWD2).

- Future climatic data was obtained from the Coordinated Regional Climate Downscaling (CORDEX) Regional Climate Models (RCMs) namely CCLM4-8-17, and CRCM5 within the Representative Concentration Pathway (RCP4.5) climate change scenario.

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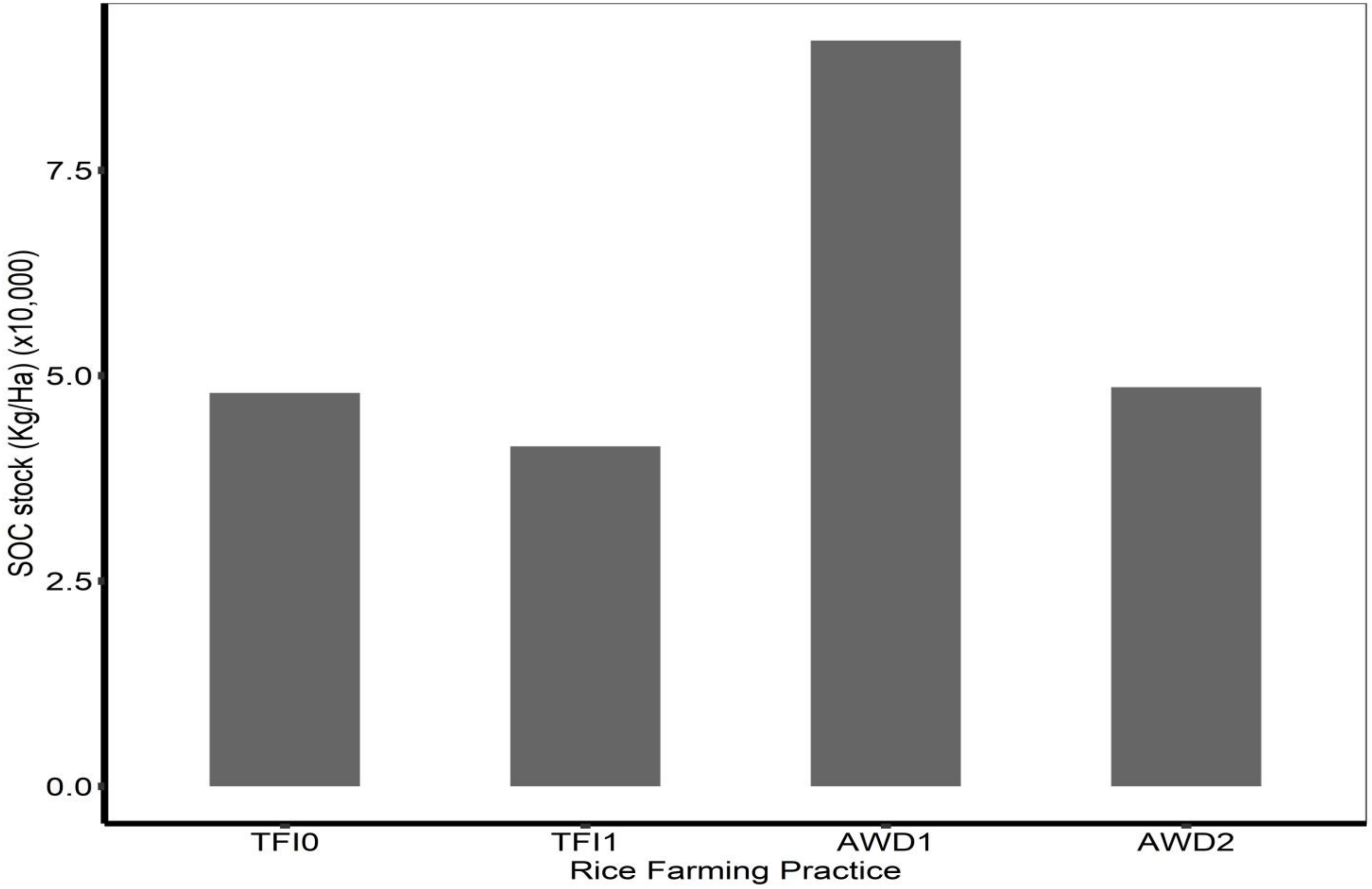
2. Can current rice farming practices build Soil organic Carbon stocks in the face of Climate Change?

- DSSAT-CENTURY was able to simulate SOC stock for each of the rice farming practices both for the baseline (1985-2015) and near future (2040-2069) climate.
- Rice seed sowing was done when the soil moisture is at 75% FC for TFI0 and TFI1 practices while transplanting is done when the fields have water at 100% FC for AWD1 and AWD2 practices.
- Planting under TFI0 and TFI1 practices was automatically triggered whenever 30mm or more of rains were received within five consecutive days, to ensure right start of cropping season.
- Crop growth limitations which are not explicitly simulated by DSSAT CSM for example weeds or bird attack, a soil fertility factor (SLPF) of 0.8 was set for fields under TFI0, else it was kept at 1.0 for other practices.
- Simulation period considered baseline or reference climate (1985-2014) and mid-century time period (2040-2069) as future climate under RCP4.5 scenario and RCM models

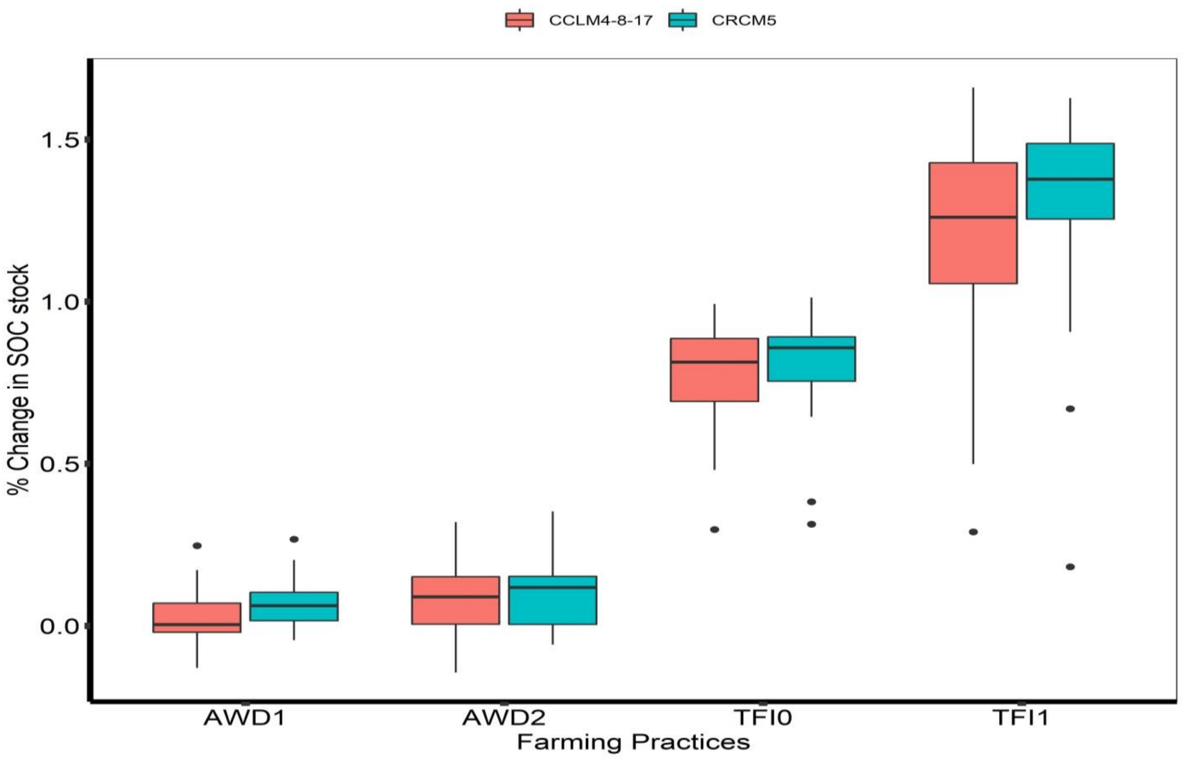
Simulated baseline SOC



- DSSAT-CENTURY module within DSSAT CSM was able to simulate SOC stock in the study area for each of the rice farming practices in the baseline climate (1985-2015).
- Although the effects of farming practice was very highly significant (P≤0.001) on SOC, there was less variation within the practice across years of simulations.
- However, TFI1 had the least mean SOC (cf. 41000 Kg C/ha) while AWD1 exhibited the highest (cf. 90,000 kg C/Ha) (Fig.).
- SOC is determined by the balance between gains and loss of soil organic materials as result of farming practices, climate and hydrology of the area in question.

Effect of rice farming practices on the SOC during the base line period (1985-2015)

Climate change impact on SOC stock



Box plot indicating variation of percent change in SOC stocks with respect to four rice farming practices under two RCMs

- SOC stock did not significantly change under RCP4.5 climate scenario in the mid-century time period, for AWD group of practices unlike those under traditional flooding.
- With respect to the baseline climate, median SOC stock increase of between 0-0.15% was recorded for AWD group of practices while it ranged between 0.75-1.4% for the traditional flooding practices (Fig).
- AWD1 rice farming strategy indicates least SOC change in the future climate with respect to baseline condition and it is not statistically different from AWD2, regardless of the RCMs used.
- FFI0 and TFI practices exhibit significant difference in SOC stock change in the future climate, also irrespective of RCMs used.

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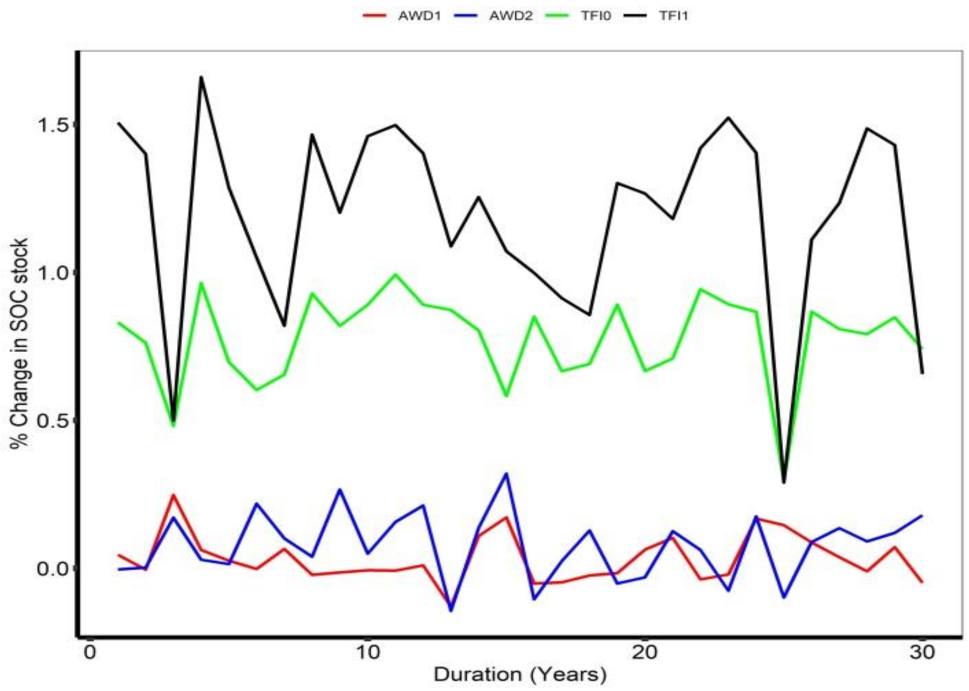

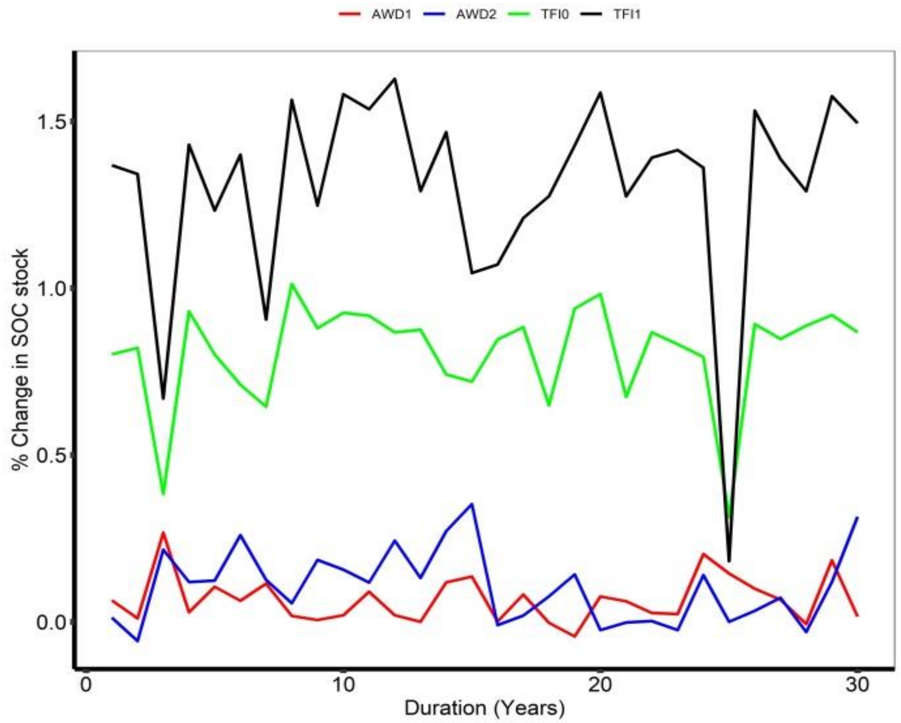

Relative change in Soil Organic Carbon stock as influenced by RCP4.5 Climate Change scenario during mid-century time period (2041-2070) under (a) **CCLM4-8-17** and (b) **CRCM5** RCMs and rice farming practices (AWD1 = Alternating Wet and Drying with SRI for one Season, AWD2 = Alternating Wet and Drying with SRI for **two s**easons, TFI0 = Traditional Flooding without Intensification, TFI1 = Traditional Flooding with intensification)

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Conclusion and recommendations

- Climate change during the mid-century time period will have considerable positive effects on SOC stock for TFI0 and TFI1 rice farming practices.
- These practices will not be ideal for maintaining or enhancing soil quality, but rather the increase in simulated SOC stocks may be due adverse effects the climate change impacts will have on partitioning of assimilates by the rice crops.
- The AWD group of practices will be little upset by climate change, hence less change in future SOC stocks. However, AWD1 rice farming will be an ideal approach to improving soil quality and resilience to climate change impacts.
- We recommend further research on the mechanisms by which soil fertility under aerobic and anaerobic conditions influence carbon sequestration.

Trade-offs and synergies between sectoral policies, strategies and plans related to climate change adaptation in rice farming in Tanzania: Lessons from Kilombero valley

The overall objective of this study was establishing synergies and trade-offs of agriculture climate change adaptation policies in relation to rice farming systems in Kilombero valley.

- Identify key conflicting and synergy policy in the area of climate adaptation in rice sub sector.
- Generate new knowledge to support ongoing efforts in climate adaptation in the rice sub sector through existing relevant policies.

Data and Methods

- Data collection was done through farmer's checklist to understand practices in four farming systems: SRI irrigation, SRI non-irrigation and traditional irrigated and traditional non-irrigated.

- Stakeholder consultation was conducted at national and district level with several institutions that are linked in one way or the other with agriculture and climate adaptation in the agriculture sector.
  - Ministry of Agriculture, Ministry of water, Vice President's Office-Department of Environment, The National Irrigation Commission and the Tanzania Agriculture Development Bank.
- To complement primary data, secondary data capture was done through an extensive literature review carried out through scholarly data bases;
  - Scopus, Web of Science, Science Direct, Directory of Open Access Journals, and JSTOR.

- Attention was given to peer reviewed journals with combination of key words climate + adaptation + agriculture, between 2010-2020, the search was further narrowed to Tanzania.

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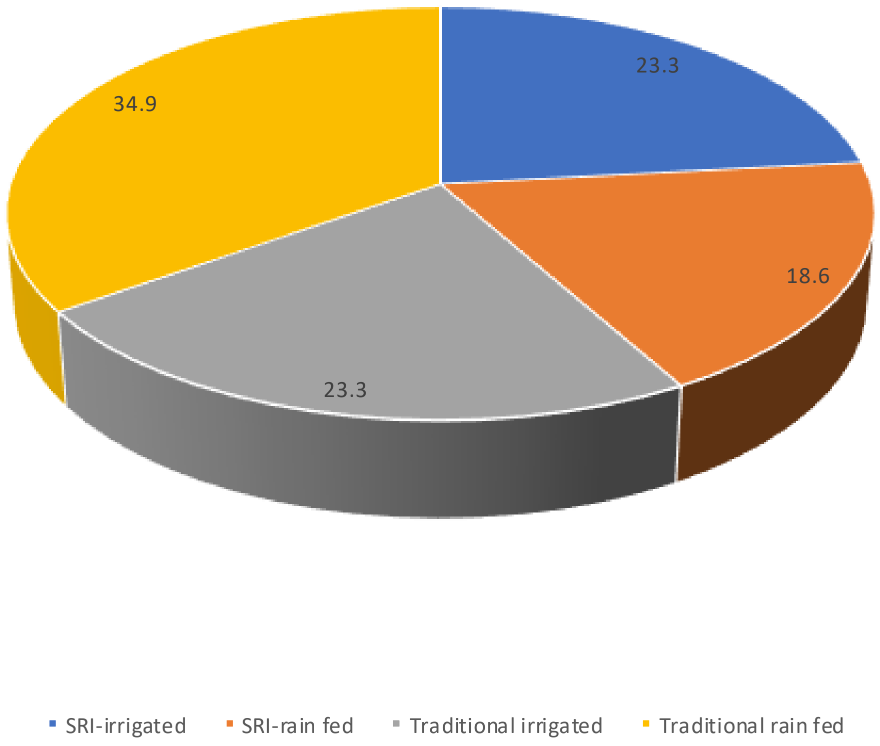
Results

Percentage of people involved in the farming systems



- SRI-irrigated and SRI-rain fed system reported an average yield of 25 and 32 bags of rice weighing between 100-150 Kgs per acre respectively.
- There is a substantial difference in yields between the SRI systems and the traditional rain fed and irrigated, average yields on traditional irrigated systems averages 13-14 bags of rice weighing between 100-150 kgs of rice/acre
- Results suggests that SRI farming system as a whole contributes to high productivity in rice farming as opposed to irrigation alone as a factor of improving productivity.

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Results

- A number of farm practices in the visited villages are well linked to policy statement, directions, and plans, however there is no direct evidence that such practices are linked with implementation of national climate change and agriculture policies.
- Interviews with farmers have mentioned the Kilombero Plantation as the main influencer of SRI farming practices. Farmers in the area have benefited from the Kilombero Plantation Limited (KPL) a large scale producer of rice and maize.
- The company introduced SRI among smallholder farmers in the area who have adopted selectively according to local conditions and access to resources
- The role of private investors stimulating adoption of best practices cannot be under estimated, however the partnership between the private investors and the local governments expedites acceptance and smooth introduction of such practices.
- Results from this research shows that traditional practices are still popular (58%) of interviewed farmers do not practice SRI despite the many benefits it offers;
- Some of the reasons attributed to this observation include initial high investment cost, labour intensity nature and market driven factors such as higher prices offered for local varieties as opposed to SARO 5 commonly planted in in SRI systems.

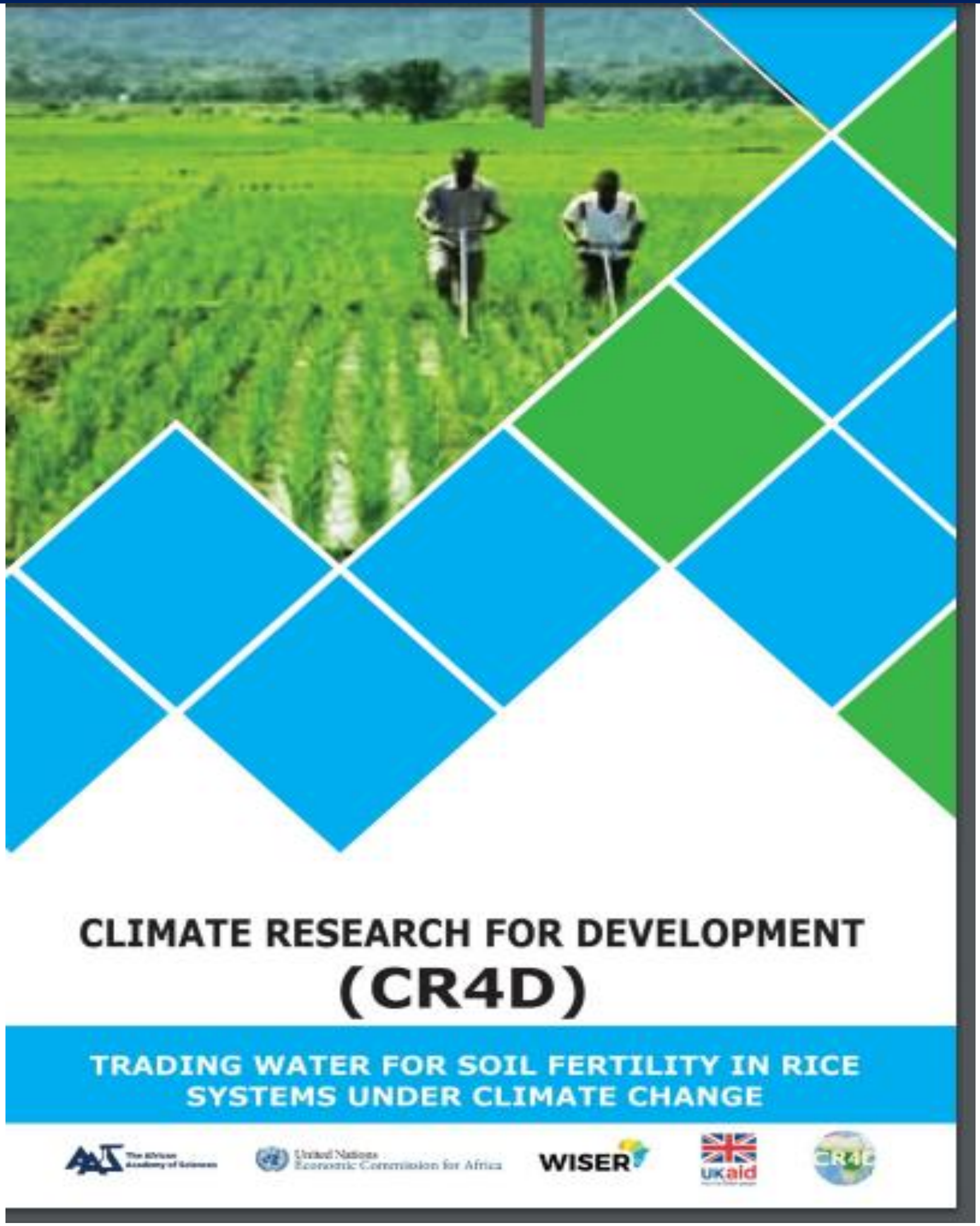
Results

- The national rice development strategy phase II envisages to double rice production between 2018 and 2030 to 2.2 million Ha under three ecosystems: Upland rain fed, low land rain fed and low land irrigation.
- Expansion under irrigation ecosystem is planned under new construction of irrigation canals, rain water harvesting and rehabilitation of irrigation infrastructure;
- This may enhance efficiency at damming level of schemes but may not necessarily increase efficiency at farm level.
- Observations made during field visit showed significant water loses in farms, expanding irrigation scheme construction without modernising and improving water management practices in farms is likely to lead to higher water loses under increasing demand by various users and decreased stream flow as projected by various climatic models.
- Sustainable water management practices, water use efficiency and storage in agriculture water use has featured strongly in the agriculture and related policies, strategies and national plans analysed in this paper, however irrigation expansion if not planned carefully may have maladaptation effects in the water and other related sectors.

Conclusions and Discussions

- Water and climate change policies in Tanzania have tried to address pertinent issues related to agriculture adaptation in rice farming in Tanzania,
- However some key guiding policies/plans and strategies apposite to development of rice sector in the country like the National Rice Development Strategy, National irrigation master plan and water development master plan need to incorporate more explicitly the issues of water use efficiency not just addressing investment in irrigation infrastructure but more importantly the on farm management practices.
- Establish mechanisms in uptake and adoption of technology and practices that will enhance climate adaptation practices in the rice subsector through budgeting at local institutions to ensure desired practices are made known, customised by local farmers and applied widely to allow water use sustainability practices that enhance economic gains and protect the environment.
- Translation of policy statement and strategies need to be made explicit in sector plans and further translation at District level in all the relevant sectors in order to realise the desired impact in water, soil and land use management practices that support climate adaptation in the rice subsector.
- Generally the policy landscape in Tanzania is pro climate change adaptation of the rice sub sector, however, there is still a large gap between policy statement, strategies, and plans with the reality on the ground. More effort should be directed towards addressing this challenge to effect desired change.

Communication of research findings



Meeting Invitation

Dear Esteemed Partner,

Climate Research for Development (CR4D) - Kilombero Project,Invites you to a side event on "Agricultural Sustainability: Meeting Growing Demand with Limited Space, Water & Soil Resources"

Venue – APC Conference Center (**Room Antelope 2**)
Time – 16:30 – 18:00 hrs on 17th March 2020

Event to be followed by a Cocktail

Side Event Synopsis

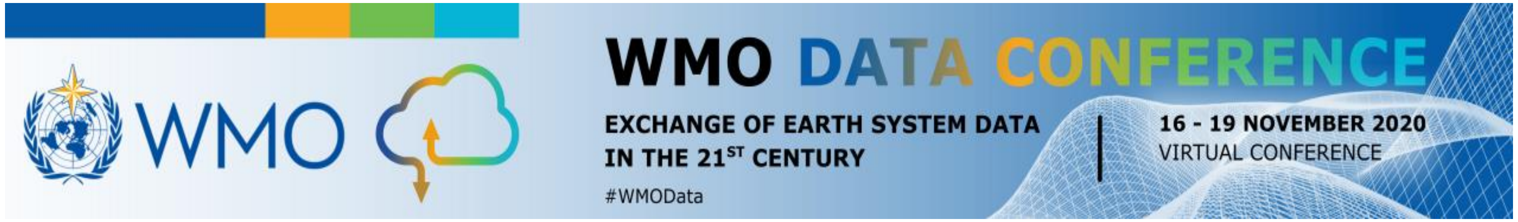
The session will cover the feedbacks between agricultural productivity and soil resources, water quality and quantity, climate change, and biodiversity. Participants will explore opportunities for sustainable agricultural systems within the water-food-energy-climate change nexus, focusing on agriculture intensification, increased resource use efficiency, enhancing ecosystem services provisionin, diversifying agricultural systems (including integrated crop-fish farming), planning for long-term soil health, and varying water management strategies. The ambition is to frame the discussion around the farmers' needs and perspectives, leveraging ongoing stakeholder-researcher interactions, and as a way to develop sector relevant research.

Organisers

- Dr. Madaka Tumbo - Climate Research for Development(CR4D)
- Jacqueline Senyagwa - University of Cape Town
- Dr. Elikana Kalumanga - University of Dar Es Salaam
- Dr. Ronald Ndesanjo - University of Dar es Salaam
- Dr. Sixbert Mourice - Sokoine University of Agricultural
- Dr.Adolphine Kateka - Tanzania Water Partnership

Moderator

- Onesmo Sigalla - Water Right



5 Papers – have been submitted for publication in peer reviewed journals(under review)

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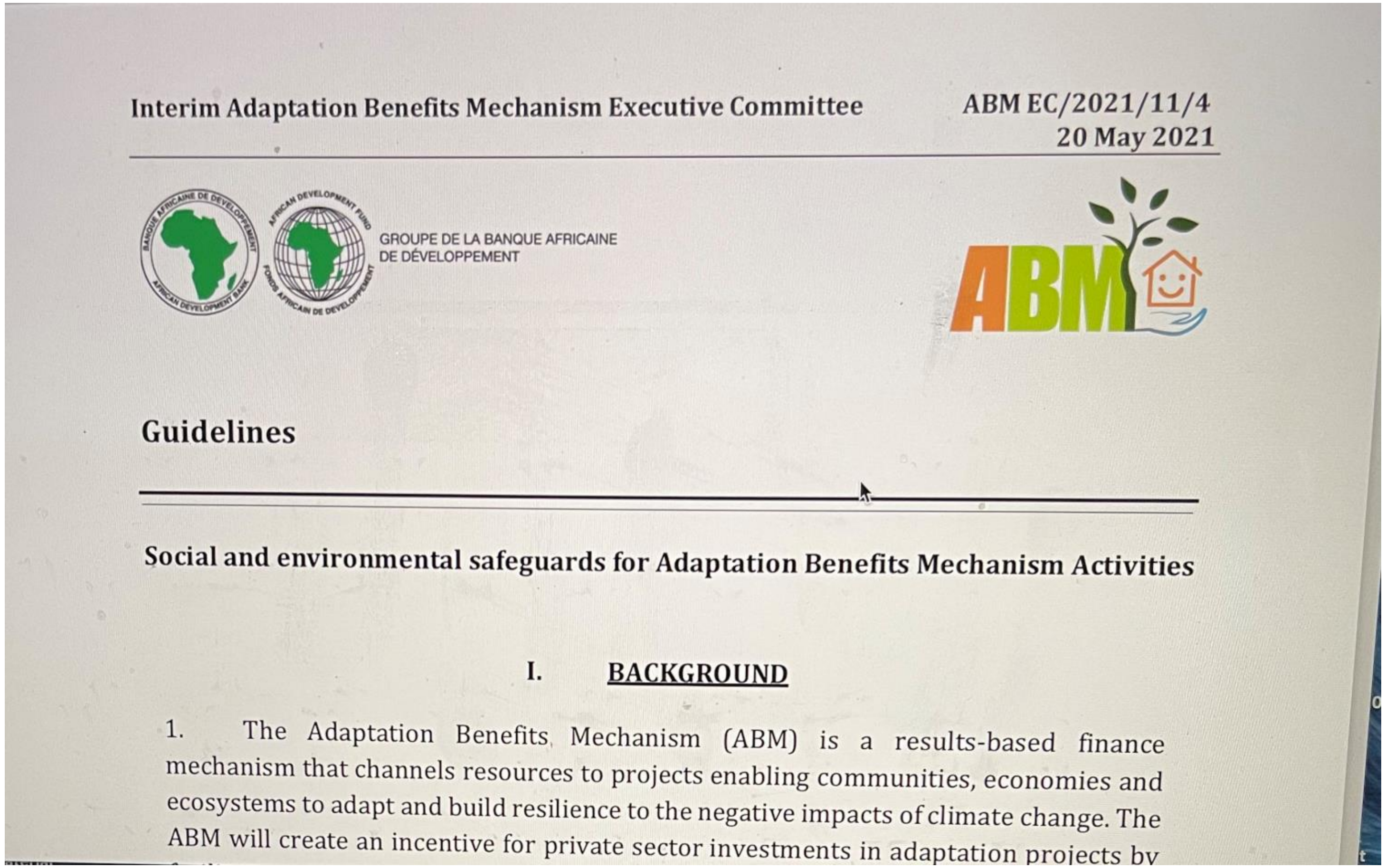
Achievements

- Research Grants
    - From Climate Change Adaptation to Climate Resilience – Identifying the missing links Research Grant No 2020-03254_3, Funded by Swedish Research Council
        - Duration 2021-2023
        - Amount SEK 140,000
- African Development Bank- Adaptation Benefit Mechanisms (ABM) Panel of experts
    - Two years contract


Interim Adaptation Benefits Mechanism Executive Committee ABM EC/2021/11/4
20 May 2021

GROUPE DE LA BANQUE AFRICAINE DE DÉVELOPPEMENT

ABM

Guidelines

Social and environmental safeguards for Adaptation Benefits Mechanism Activities

I. BACKGROUND

1. The Adaptation Benefits Mechanism (ABM) is a results-based finance mechanism that channels resources to projects enabling communities, economies and ecosystems to adapt and build resilience to the negative impacts of climate change. The ABM will create an incentive for private sector investments in adaptation projects by

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