

A training manual for agricultural extension agents:

The use of RICCAR climate data in a crop model (APSIM) to identify context-based climate adaptation and mitigation options



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The United Nations Economic and Social Commission for West Asia





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PREFACE

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) is a joint initiative of the United Nations and the League of Arab States.

RICCAR was launched under the auspices of the Arab Ministerial Water Council in 2010 and derives its mandate from resolutions adopted by this council as well as the Council of Arab Ministers Responsible for the Environment, the Arab Permanent Committee for Meteorology and the ESCWA Ministerial Session.

RICCAR is implemented through a collaborative partnership involving 11 regional and specialized organizations. The RICCAR Regional Knowledge Hub (RKH) is managed by the United Nations Economic and Social Commission for Western Asia (ESCWA) and the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) with the Food and Agriculture Organization of the United Nations (FAO) hosting the Arab/Middle East and North Africa (MENA) Domain data portal. ESCWA coordinates the regional initiative under the umbrella of its Arab Centre for Climate Change Policies.

The present training manual was prepared through a collaborative partnership between ESCWA, ICARDA, and the APSIM initiative. The Morocco activity is partially supported by the CGIAR ClimBER initiative: Building Systemic Resilience Against Climate Variability and Extremes.

This training material is intended to comprehensively train a non-expert user on how to use RICCAR data to run the APSIM model such that the trainee could use it to further develop their skills in modelling-based analysis to support their climate adaptation projects. Considering the spatial resolution of the datasets and moderate levels of site-specific parameterizations will be required for site-level calibration and validation (CALVAL) and operational use. This is not an academic research document on the use of climate data to run the APSIM model. This should only be considered as training material.

Funding for the guide was provided by the Government of Sweden through the Swedish International Development Cooperation Agency (Sida) under a project focused on water and food security in a changing climate context and is implemented by ESCWA. The project component provides enhanced policy coherence across the water and agricultural sectors through institutional mechanisms and the provision of informed policy guidance and risk analysis, expanding the local knowledge base though science-based assessments and analysis of climate impacts on strategic sectors. It also empowers diverse communities through applied capacity building initiatives.

ABBREVIATIONS AND ACRONYMS

APSIM	Agricultural Production Systems Simulator
ICARDA	International Center for Agricultural Research in the Dry Areas
ESCWA	Economic and Social Commission for West Asia
IPCCN	Intergovernmental Panel on Climate Change
CBCAO	Context-Based Climate Adaptation Option
MENA	Middle East and North Africa
CSA	climate-smart agriculture
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio- Economic Vulnerability in the Arab Region
GCM	global climate model
CNRM	Centre National de Recherches Météorologiques
GFDL	Geophysical Fluid Dynamics Laboratory
RCP	representative concentration pathway
SSP	shared socioeconomic pathways
DBS	distribution-based scaling
GHG	greenhouse gas
APSRU	Agricultural Production Systems Research Unit
UI	user interface
NETCDF	Network Common Data Form
BE	Big-endian
LE	Little-endian
DOY	day of the year
ECMWF	European Centre for Medium-Range Weather Forecasts
ET	evapotranspiration
LMP	lower Mesopotamian plain
SOC	soil organic carbon

CONTENTS

PREF	ACE	111	
ABBR	REVIATIONS AND ACRONYMS	IV	
1.	GENERAL OVERVIEW OF THE TRAINING MATERIAL	1	
Α.	Introduction and purpose of this training material	1	
В.	The RICCAR climate data series	1	
C.	Climate-smart agricultural interventions studied	2	
D.	Climate dynamics in Morocco, Iraq and Jordan	4	
2.	THE APSIM CROP SIMULATION MODEL	6	
Α.	Introduction to the APSIM model	6	
В.	The developmental history of APSIM	6	
C.	The modular structure of APSIM	6	
D.	Familiarizing users with the APSIM interface	7	
3.	PREPARING INPUT CLIMATE DATA TO RUN APSIM USING RICCAR PRODUCT	17	
Α.	Extracting RICCAR data for a location or region in simpler formats	17	
В.	Developing derived weather variables from RICCAR	18	
C.	Preparing APSIM-specific climate data	18	
D.	Preparing a typical APSIM soil profile	19	
E.	Developing a soil library using APSoil	20	
4.	CLIMATE ADAPTATION IN A RAINFED AGROECOSYSTEM:		
	SUPPLEMENTARY IRRIGATION IN MOROCCO	23	
Α.	Problem statement	23	
В.	Setting up and parameterizing weather, soil, crop and management	24	
C.	Setting up output variables and reporting frequencies	31	
D.	Running the simulation (first scenario) and visualization	32	
E.	Explanation of results	33	
F.	Adding scenarios	33	
G.	Running scenarios simultaneously and visualization	37	
Н.	Summary and conclusions of this exercise	38	

5. CLIMATE ADAPTATION IN AN IRRIGATED AGROECOSYSTEM: ENHANCING WATER PRODUCTIVITY IN IRAO

	ENHANCING WATER PRODUCTIVITY IN IRAQ	39
Α.	Problem statement	39
В.	Setting up and parameterizing weather, soil, crop and management	40
C.	Creating the drip irrigation scenario	47
D.	Setting up output variables and reporting frequencies	49
E.	Summary and conclusions of this exercise	53
6.	CLIMATE MITIGATION IN AGROECOSYSTEMS:	
	CARBON SEQUESTRATION IN JORDAN VIA CROP DIVERSIFICATION	54
Α.	Problem statement	54
В.	Setting up the model and the necessary parameterizations	55
C.	Setting up output variables and reporting frequencies	67
D.	Summary and conclusions of this exercise	70
7.	SYNTHESIS AND CONCLUSIONS OF THIS TRAINING MANUAL	71

APPENDIX 1	74
APPENDIX 2	79
APPENDIX 3	80
REFERENCES	81

FIGURES

EI	C	н	D	E	1

4
7
1
8
17
17
18
20
23
23
40
54

TABLES

TABLE 1 Comparison of RICCAR-Arab Domain and RICCAR-Mashreq Domain	2
TABLE 2 Comparison of the various climate-smart interventions that will be studied	3
· · ·	5
TABLE 3 Variables selected to customize the output file for this simulation	14
TABLE 4 Comparison of the three scenarios considered in the Morocco test case	34
TABLE 5 Comparison of the two scenarios considered in the Irag test case	48
	40
TABLE 6 Consolidated table to be created using pivot tables	51
TABLE 7	
Crop-specific parameterization for the different managers used in this exercise	63
TABLE 8	
A synthesis of the findings made in the three test cases using RICCAR-based APSIM modelling	72

BOXES

D	NV	1
D	UΛ	

Definition of climate downscaling and bias correction	3
BOX 2	
Key climate change scenarios as defined by the IPCC	3
BOX 3	
Alternative climate data sets to run APSIM	28
BOX 4	
Good modelling practices #1	31
BOX 5	
Good modelling practices #2	38
BOX 6	
Scaling from point to region	49
BOX 7	
The Genotype x Environment x Management (GEM) approach in crop modelling	61
BOX 8	
How to output a variable of a single layer or as the average of several layers?	62
BOX 9	
Issues to consider: representing days in APSIM	64

1 GENERAL OVERVIEW OF THE TRAINING MATERIAL

A. Introduction and purpose of this training material

The Arab region in the Middle East and North Africa (MENA) represents a substantial area of the terrestrial landmass encompassing several countries and ecosystems. This area is generally drier and warmer compared to the rest of the world and has extreme resource limitations that are highly vulnerable to a changing climate, geopolitical instability and land degradation (Slimani & Aidoud, 2004). Agriculture (crops and livestock) is a critical source of employment and a potential option for engaging rural youth. However, environmental degradation coupled with declining and variable agricultural productivity may pose a massive challenge already beset by instability and declining oil reserves (Tagliapietra, 2017). The Arab region is also subjected to short and long-duration climate extreme events, and the overall impact of their cascading effects on ecosystems, societies and economies is still an open question. Climate change, along with post-war geopolitical complexities, has greatly affected the Arab region in terms of its economy and social balance. Climate change has penetrating effects on the region's agriculture sector and hence its economy. These are mainly manifested via changes in water resources and extreme weather conditions such as heatwaves and a drastic decline in precipitation.

Although several downscaled and bias-corrected climate datasets are available, their operational use is too challenging for lay and novice users. To make the data meaningful, it must be assimilated into crop models to support context-specific climate-smart agriculture (CSA) solutions that often present technical challenges. To overcome these, and to support increased utilization of the data, a training manual on how to use the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) data in a popular crop simulation model has been developed. The main objective of this training material is to develop instructional materials for agriculture extension agents and practitioners interested in using crop modelling in their activities on how to integrate and utilize long-term climate data in a typical and commonly used crop model such as APSIM and identify a Context-Based Climate Adaptation Option (CBCAO).



Representation of the RICCAR-Arab Domain and the RICCAR-Mashreq Domain available through ESCWA

B. The RICCAR climate data series

An ensemble climate product developed under the RICCAR project is used for the long-term future climate data inputted into the crop simulation model. RICCAR is an outcome of a collaborative effort between the Economic and Social Commission for Western Asia (ESCWA), the League of Arab States and respective specialized organizations in response to the request of the Arab Ministerial Water Council and the Council of Arab Ministers Responsible for the Environment to deepen the understanding of the impact of climate change. The RICCAR initiative aims to assess the impact of climate change on freshwater resources in the Arab region through a consultative and integrated assessment that seeks to identify the socioeconomic and environmental vulnerability caused by climate change impacts on water resources in the Arab region. There are two series of RICCAR climate

products as shown in table 1: (1) the RICCAR-Arab Domain and (2) the RICCAR-Mashreq Domain. In this training manual, the datasets will be used according to the context. The RICCAR-Arab Domain consists of the outputs of three global climate models (GCMs) (CNRM-CM5, GFDL-ESM2M and EC-EARTH¹) that were downscaled and bias-corrected (1951-2100) for different climate change scenarios (representative concentration pathway (RCP) 4.5 and 8.5). The spatial resolution is 50 km with a daily time step from 1951 to 2100. The RICCAR-Mashreq Domain consists of the outputs of six GCMs (CMCC-CM2-SR5, CNRM-ESM2-1, EC-Earth3-Veg, MPI-ESM1-2-LR, MRI-ESM2-0 and NorESM2-MM²) that were downscaled and bias-corrected for the SSP5-8.5 climate change scenario. The geographical area of these two domains is shown in the map. In this manual, these climate products were strategically analysed, and the climate change dynamics of the Arab region were studied.

	Arab Domain	Mashreq Domain
Spatial extent	27W-76E, 7S-45N	24E-69E, 0N-46N
Spatial resolution	0.44° (~50 km)	0.10° (~10 km)
Temporal extent	1951-2100	1961-2070
Temporal resolution	Daily	Daily
Scenarios	RCP 4.5, RCP 8.5	SSP5-8.5
Driving GCM (the average of these GCMs is used)	CNRM-CM5 GFDL-ESM2M EC-EARTH	CMCC-CM2-SR5 CNRM-ESM2-1 EC-Earth3-Veg MPI-ESM1-2-LR MRI-ESM2-0 NorESM2-MM
Downscaling regional climate model (RCM)	RCA4	HCLIM-ALADIN
Bias correction method	Distribution-based scaling (DBS)	Multi-scale bias adjustment (MidAS v0.1)
Use in this manual	Morocco (chapter 4)	Iraq (chapter 5) and Jordan (chapter 6)

TABLE 1: Comparison of RICCAR-Arab Domain and RICCAR-Mashreq Domain

C. Climate-smart agricultural interventions studied

To train the non-expert user on how to use long-term climate data (RICCAR) along with a crop simulation model, three test cases with unique climate adaptation needs were identified. Further to this, comprehensive numerical experiments were designed to explore climate vulnerabilities and climate adaptation options employing a scenario-based approach. The novice user will acquire broad knowledge in using APSIM if the three exercises are carefully worked through. The three studies identified for this manual include:

- Case study of Morocco, an example of a rainfed agroecosystem: The training manual demonstrates yield gap evolution under climate change in a rainfed agroecosystem and shows the relative effects of two Intergovernmental Panel on Climate Change (IPCC) scenarios (RCP 8.5 and RCP 4.5). Additionally, supplementary irrigation is applied as a key climate adaptation measure in a location suffering from increasing droughts in order to augment water supply in extremely dry weather conditions.
- Case study of Iraq, an example of an irrigated agroecosystem: The training manual demonstrates changes in water productivity
 and yield dynamics in an arid but irrigated agroecosystem. It demonstrates how judicious irrigation techniques as opposed to
 conventional irrigation as a climate adaptation measure can enhance water productivity while also maintaining and possibly
 maximizing yield.
- Case study of Jordan, an example of a semi-arid agroecosystem: The training manual demonstrates crop diversification and defines optimum cropping patterns (through the selection of alternate resilient crops) as a key climate adaptation measure and assesses impacts on soil carbon sequestration.

BOX 1: Definition of climate downscaling and bias correction

Downscaling is the procedure of using coarse-scale climate models to make climate predictions at finer temporal and spatial scales for local level analysis and planning. There are two approaches to downscaling: (1) dynamical – where outputs from GCMs are used to drive higher resolution regional climate models with a better representation of local terrain and other conditions, and (2) statistical – where statistical links are established between large-scale climate phenomena and observed local-scale climate.

Bias correction is the process of scaling climate model outputs to account for their systematic errors, in order to improve their fitting to observations.

TABLE 2: Comparison of the various climate-smart interventions that will be studied

	Case study	Context	Hypothesis-based CSA intervention
Climate adaptation	Morocco Region of interest (ROI): Rabat-Salé-Kénitra	Rainfed system	Climate analysis shows that the annual precipitation in this area is significantly reduced and as such rainfed farming is no longer viable. Thus, supplementary irrigation is the most appropriate climate adaptation measure suggested in this context to sustain agriculture. Adaptation: RICCAR-based crop modelling will be used to explore how well supplementary irrigation can help to sustain crop yields under climate change under the business-as-usual scenario (RCP 8.5).
	lraq ROI: Lower Mesopotamian plain	Irrigated system	Climate analysis shows that the annual temperature in this area significantly increases and as such irrigated farming can be sustained only by increasing irrigation quantities, which is a huge burden on water resources. Adaptation: RICCAR-based crop modelling will be used to explore water produc- tivity under the conventional inefficient flooding method in comparison to the efficient drip irrigation method and under climate change.
Climate mitigation	Jordan ROI: Jordan valley	Irrigated system	Under the currently existing cropping pattern, the ability to sequester carbon as climate mitigation is minimal. It is hypothesized that crop diversification will enhance soil carbon sequestration. Mitigation: RICCAR-based crop modelling will be used to explore how much carbon sequestration gain can be achieved by increasing the diversity of crops in the crop rotation using a scenario-based approach.

BOX 2: Key climate change scenarios as defined by the IPCC

RCP 8.5: Business-as-usual climate change scenario or the worst-case scenario where the climate changes without any mitigation actions.

RCP 4.5: Best case scenario where the climate change happens with very good mitigation actions.

SSP5-8.5: Fossil-fuelled development, leading to very high greenhouse gas (GHG) emissions. Carbon dioxide (CO₂) emissions triple by 2075.

D. Climate dynamics in Morocco, Iraq and Jordan

A brief narrative on the plausible pathways of climate change at the three test case sites are shown. The RCP 8.5 scenario is displayed here because it corresponds to the "business-as-usual" scenario of climate change. The climate change trends are briefly explained in the adjacent boxes.

FIGURE 1: Interannual variability of the mean annual temperature and annual precipitation in the business-as-usual scenario (RCP 8.5) in the three test cases



Morocco

The mean annual temperature is projected to change from 17°C during the baseline period to as much as 23°C by 2100. A steady decline of precipitation from 480 mm in 1980 to as little as 250 mm in 2100 is expected.



Iraq

The mean annual temperature is projected to change from 25°C in the baseline period to as much as 28.5°C by 2100. Regarding precipitation, the variability with climate change is very uncertain. The general trend shows a slight increase.

RICCAR



Jordan

The mean annual temperature is projected to change from 20°C in the baseline period to as much as 23°C by 2100. Regarding precipitation, there is a general decline after 2040, although there is a slight increase between 2020 and 2040.

2. THE APSIM CROP SIMULATION MODEL

A. Introduction to the APSIM model

APSIM, the Agricultural Production Systems Simulator is a dynamic, daily time step modelling platform that combines biophysical and management modules within a central engine to simulate the production and resource consequences of agricultural systems. It simulates biophysical processes in cropping systems, particularly those relating to the production and ecological outcomes of management practices in the face of climate risk. It contains a suite of modules that enable the simulation of systems that cover a range of plant, animal, soil, climate and management interactions. The APSIM (Keating et al., 2003, Holzworth et al., 2014) cropping systems model has a proven track record in modelling the performance of diverse cropping systems, rotations and fallowing, as well as crop and environmental dynamics (Whitbread et al., 2010, Hochman et al., 2017). A distinctive innovation and philosophical departure from most other "crop models" is the primary focus of APSIM on simulating crop resource supply (rather than a primary focus on resource demand), with the soil forming the central simulation component. Crops, with their resource demands impacted by weather and management, find the soil in one condition and leave it in another condition for the next crop (McCown et al., 1996). This emphasis on simulation of soil resource dynamics positions APSIM strongly in comparison with other models for investigations into long-term changes to soil conditions and sustainability associated with different cropping strategies and practices. With a particular focus on research into adaptation strategies, another notable strength of the APSIM model is its unique capacity to capture intricate detail and subtleties of dynamic farmer management practices through a highly flexible "Manager" module allowing the user to specify detailed farmer decision-trees using simple "if-then-else logic" (Holzworth et al., 2014). Evaluation of APSIM is well-established and well-documented in Australia, Africa and Asia. The first step in evaluating a model's credentials is to define model capacities required for addressing research questions around some of the issues. A model for the simulation of cropping system performance should be capable of several key functions: (i) robust crop development and yield simulation for a wide variety of crops; (ii) the ability to simulate cropping sequences and the effect of different fallow, tillage and residue management strategies on system performance; (iii) robust simulation of soil water and nutrient dynamics in conjunction with crop performance; (iv) flexibility to capture detailed management practices, including subtle changes to farmer decisions and strategies, and evaluate their impact on system performance; and (v) robust simulation of crop response to CO, and temperature variation (Rötter et al., 2011).

B. The developmental history of APSIM

The APSIM framework was originally developed by the Agricultural Production Systems Research Unit (APSRU), based in Toowoomba, Queensland. APSRU was a partnership involving researchers from Australian Government research agency CSIRO (the Commonwealth Scientific and Industrial Research Organization), the University of Queensland and the Queensland State Government, established in 1990. The APSIM model has been the result of this collaboration. Ever since its start in the early 2000, APSIM has evolved into a framework containing many models required to explore changes in agricultural landscapes.

C. The modular structure of APSIM

APSIM has a modular framework consisting of numerous individual modules that describe the plant, soil, climate and management processes. These modules include a diverse range of crops, pastures, trees, soil processes including water balance, nitrogen (N) and phosphorus (P) transformations, soil pH, erosion and a highly flexible range of management controls. It is also used in a broad spectrum of research applications from cropping systems to agroforestry and ecology. In this sense, APSIM is a highly customizable modelling framework that can do different things for different users. The APSIM modelling framework is made up of the following components:

- · A set of biophysical modules that simulate biological and physical processes in farming systems.
- A set of management modules that allow the user to specify the intended management rules that characterize the scenario being simulated and that control the simulation.
- · Various modules to facilitate data input into and output from the simulation.
- A simulation engine that drives the simulation process and facilitates communication between the independent modules.

- Various user interfaces for model construction, testing and application, database tools for visualization, and further analysis of output.
- A web-based user and developer support facility that provides documentation, distribution and defect/change request tracking.



FIGURE 2: A conceptual representation of the modular approach adopted in the APSIM model. Various modular approaches can be pluggedin as and when needed

D. Familiarizing users with the APSIM Interface

This section will introduce the APSIM user interface (Apsim UI) and described the process of building, running and graphing a typical simulation. This section is not comprehensive regarding the overall capability of APSIM UI as its purpose is to shed light on what APSIM UI provides, after which the user may explore and self-learn using this section as a base. The primary buttons that users will be working with are highlighted below. They will be used frequently throughout the tutorials in this manual.

The APSIM UI consists of four panels:

- The main toolbar at the top.
- A simulation tree on the left that lists all the components in the loaded file.
- · A module properties pane on the right.
- · A bar at the bottom that lists available toolboxes.

FIGURE 3: Screenshot showing the APSIM UI panels



Zoom into main toolbar components

1	🗚 ApsimUI - C:\FourthTraining\Session-2\ClimateChange_Practice\CC_Kirkuk_RCP85.apsim												
	2	pi .			Π.	- 📙 .	. 🧭	X	20	1	2.		
							Insert a new graph						

The main toolbar items include:

- Export this exports a graph created in the APSIM UI in several formats (.jpeg, .png, .bmp etc).
- Checkpoint this creates a snapshot of a simulation allowing the user to do before and after comparisons or to revert a change.
- Inserting a new graph this brings up the "add new" graph wizard.
- Excel this allows output files to be exported as comma-delimited text files.
- Factorials this is an advanced topic that will be looked at in a separate module.
- Generate this generates a ZIP file required for running remotely.
- Help this directs the user to the local help files; however, there are many support options that are discussed in a separate module.

To familiarize the interface, we will walk through a simple simulation initially.

1. The APSIM toolbox

All available components in APSIM are included in toolboxes. Whenever the user needs to add a new component to the simulations, one of the toolboxes along the bottom of the screen is to be used. It is possible to add toolboxes; for instance, components that users need often and want to make easier to access can be added, including written scripts that the user would like to share with a colleague or a customization of some of the standard components.

Use the following instructions to add a toolbox:

- Load a premade toolbox to make it easier to access some soil data.
- Click the Options button. Click on Add a toolbox.
- <u>Navigate</u> to the APSIM installation folder (by default it will be in C:\Program Files (x86)\Apsim[version]-r[revision]\UserInterface\Toolboxes folder.
- Click Training.xml and click Open. You should now see the following (your path will be different):

Options	2
General options	ок
Include the revision number in .out / .sum files?	Cancel
User toolboxes Plugins	Revert all
C:\APSIM\UserInterface\ToolBoxes\Training.xml	options
Add a toolbox	
Remove a toolbox Create a new empty toolbox	

 <u>Click</u> OK to see the new toolbox in the toolbox bar at the bottom of the APSIM window. This toolbox contains components to be used in the training session.



You can add your own components to toolboxes by dragging and dropping them from a simulation. Alternatively, you can also copy them directly from another toolbox. Note that you can't add anything to this training toolbox as the Program Files folder is write-protected.

2. Running a typical APSIM simulation

The first step is to familiarize users with the APSM UI and understand how to run a typical simulation in APSIM so that users get an idea of how things work. As it takes some effort to prepare site-specific data and soil input, in the APSIM familiarization step, we will just go through an inbuilt example so that the user can seamlessly practice. As we familiarize the interface, we will deal with our specific cases with context-specific inputs. Click the New button to create a new simulation. You will be presented with the following screen:

rganize 🔻 New folde					8== ▼	
	Name	Date modified	Туре	Size		
Quick access	💋 Bambatsi Pasture.apsim	3/22/2016 10:13 AM	APSIM File	2	19 KB	
OneDrive - CGIAR	Blank Simulation.apsim	3/22/2016 10:13 AM	APSIM File		1 KB	
	💋 Butterfly Pea.apsim	3/22/2016 10:13 AM	APSIM File	1	2 KB	
r r	Canopy.apsim	3/27/2018 4:12 PM	APSIM File	4	18 KB	
3D Objects	Centro.apsim	3/22/2016 10:13 AM	APSIM File	2	10 KB	
Cesktop	🖉 Continuous Cotton.apsim	4/19/2017 9:58 AM	APSIM File	11	0 KB	
Documents	Continuous Maize and Weeds.apsim	3/27/2018 4:12 PM	APSIM File	5	67 KB	
Downloads	💋 Continuous Maize Bimodal.apsim	3/27/2018 4:12 PM	APSIM File	5	i5 KB	
Music	🖉 Continuous Maize.apsim	3/27/2018 4:12 PM	APSIM File	4	I2 KB	
	Continuous Sorghum.apsim	5/10/2016 2:36 PM	APSIM File	3	I3 KB	
Pictures	🖉 Continuous Wheat with Climate Change	3/22/2016 10:13 AM	APSIM File	3	IO KB	
Videos	Continuous Wheat with SWIM3.apsim	3/22/2016 10:13 AM	APSIM File	5	i8 KB	
🛀 OS (C:)	🖉 Continuous Wheat.apsim	5/10/2016 2:36 PM	APSIM File	3	6 KB	
Avenue (D:)	💋 Defoliated Wheat.apsim	3/22/2016 10:13 AM	APSIM File	3	13 KB	
A 11.1	🖉 Effluent-irrigated Eucalypt Forest.apsim	3/22/2016 10:13 AM	APSIM File	1	7 KB	
Network	🖉 Eucalypt Forest.apsim	3/22/2016 10:13 AM	APSIM File	1	6 KB	
	💋 Maize Legume and Weeds Rotation.apsim	3/27/2018 4:12 PM	APSIM File	8	14 KB	
	Maize PSample.apsim	3/27/2018 4:12 PM	APSIM File	2	19 KB	
File na	me			~	Apsim files (*.apsim)	~

Because all simulations generally share the same base components, we do not recommend starting from scratch. The best method is to choose the simulation closest to the one you want to build then modify it. For this exercise, we will use the "Continuous Wheat" simulation.

- Click Continuous Wheat. Apsim then click Open.
- <u>Click Save</u>.
- <u>Create</u> a new folder in your C drive called <u>Apsim Training</u> to save all of your work in. Remember this location; all training modules will be saved in this location.
- Save the file as Training_Lesson1.apsim. You will now see the new simulation loade



<u>Closely examine</u> the simulation tree on your left panel that describes the components pictorially. The hierarchy of the modules in the simulation tree is shown. Roughly speaking, each simulation tree has four components (met, clock, summary file and paddock) of which the paddock is the most elaborate component with several subcomponents such as Soil, Surface Organic Matter, Crop, Manager and outputfile.



First make sure the user is using the right weather data. To do this:

Click the met component in the simulation view. Now it is possible to see the weather data for Goondiwindi loaded.

Cartingan Millard	%apsim%/Exar	nples/MetFiles/Go	ona.met			
	🔡 Raw data 🚺	Rainfall chart	Monthly rainfall char	t 👔 Temperatu	e chart 🗣 Radiation chart	
	!Title = G	oondiwindi 1	940-1989			
	[weather.m	et.weather]				
	! TAV a tav = 19		! annual av	erage ambie	10/1999 at 13:02 : ent temperature mean monthly tempe	1/1940
🕀 🔟 outputfile	site year	day radn	maxt min	t rain	evap	
	() ()	() (MJ/m [^])	2) (oC) (o	C) (mm)	(mm)	
	GOON 1940	1 28.66	35.0 17	.2 0.0	8.48	
	GOON 1940	2 26.30	32.2 19	.4 0.0	8.48	
	GOON 1940	3 27.19	32.7 18	.3 0.0	8.48	
	GOON 1940	4 26.73	32.7 18	.3 0.0	8.48	
	GOON 1940	5 25.92	32.7 19	.4 0.0	8.48	
	GOON 1940	6 24.68	32.7 20	.0 0.0	8.48	

 <u>Click</u> the other tabs in this window to visualize the climate (meteorological) data. The user may click the Radiation chart to see solar radiation, radiation, etc., superimposed as shown in the next screenshot.



• **Define** which section of the available meteorological time frame the user would like to run the model on. In the simulation tree below the **met**, one can see the **clock**, with the **start date** as 1/1/1989 and the **end date** as 31/12/1989.



To change the soil:

- **<u>Click</u>** the **Training toolbox** that you loaded earlier.
- Drag the Heavy Clay soil node from the toolbox.
- **<u>Drop</u>** it on the **paddock** node in your simulation.
- Delete the old soil by clicking it and clicking Delete. You can reorder components by right-clicking and choosing Move Up/Down.
- Set the starting water and nitrogen conditions for the soil.
- Expand the new soil node and click Initial Water. Make sure Filled from top is selected.
- Set the fraction available to 10 per cent.

completions	Description	Value						
Continuous Wheat	Soil Description	Heavy Clay						
-S clock	Classification	Generic Vertosol						
- 📝 summaryfile	Country	Australia						
maddock SurfaceOrganicMatte	Site	Generic						
- i fertiliser	Region	Darling Downs and Granite Belt						
-y wheat	LocalName							
 	Nearest town	Toowoomba						
	Natural vegetation							
	State	Queensland						
	Apsoil number							
	Latitude (WGS84)	-27.564333						
	Longitude (WGS84)	151.953991						
	Location accuracy	Regional Soil Type						
	Data source	YP. A Peake-CSIRO Sustainable Ecosystems, Toowoomba						
Toolbox		i						
🖓 Apsim Training	Description	Value						
Soils	Soil Description	Heavy Clay						
the avy Clay	Classification	Generic Vertosol						
Completed Exercises	Country	Australia						
1.00	Site	Generic						
	Region	Darling Downs and Granite Belt						
	LocalName							
100	Nearest town	Toowoomba						
10000	Natural vegetation							
		Queensland						

To find out how deep the profile is:

• Click the Water module. You will see that the soil profile is 180 cm deep and is split into seven layers.



- Click the Initial Nitrogen module.
- Set the starting NO₃ to 50 kg/ha and starting NH₄ to 3 kg/ha.
- First, it is essential to identify the working unit in APSIM. In this case it is kg/ha, not ppm. Notice the colour of the column header text. This indicates that the user can change units by right-clicking the column header.
- Change NO₃ and NH₄ to kg/ha, then enter the values below.

Depth	NO3	NH4	SW
(cm)	(kg/ha)	(kg/ha)	(mm/mm)
0-10	50	3	0.000

 For this exercise, the nitrogen should be spread evenly through the entire soil profile, so enter the same values for all the layers.

Next, in the SurfaceOrganicMatter node:

<u>Check</u> that the Organic Matter type is wheat and the Initial surface residue is 1,000 kg/ha. This means we start the simulation with 1,000 kg/ha of wheat stubble on the surface. This will decay over time putting nutrients back in the soil. It will also reduce surface evaporation.



To rename the simulation:

- Right-click Continuous Wheat and choose Rename. Type in Wheat Water Balance.
- Results for the simulation are found in the **outputfile** node. This is also where the user will specify what variables they want to be reported and how often.
- <u>Click</u> the outputfile node and delete all the variables except the first one (dd/mm/yyyy as date).

ApsimUI - D:\ESCWA\TRAINING1.apsir	n				o
New Open Save Save as Exp	nt Checkpoint Insert a new graph Excel Options Factorials Generate Help Run Stop				
Nex. Opm. Ser Ser a. Ep mulder Communications Communication	Constants to put in top of output file: (readonly) Title = Inheart/New Balance	Input_stat_date Input_stat_date_string Latitude MaxT MinT Radin Rain	Array? Units No No No µlian da No µlian da No No No No No No No No No No No No No No	✓ Search Description	
		Rain tav vp	No No No		

There are two ways to enter new variables:

- 1. Type them directly into the outputfile columns list, or
- 2. Select them (double-click or drag) from the pane on the right.

This panel shows all the available variables for the chosen component. You can change their order in the list by right-clicking and choosing Move Up/Down, or use the keyboard shortcut (Ctrl + Up/Down arrows). Enter the following variables to report:

TABLE 3: Variables selected to customize the output file for this simulation								
Variable	Unit	Explanation	Variable family					
Dd_mm_yyyy	NA	Date	Clock					
Simulation_days	NA	Day since simulation started	Clock					
Rain	mm	Daily rain	Met					
Tlai	m²/m²	Total leaf area index	Wheat					
Biomass	kg/ha	Total biomass	Wheat					
Extractable soil water (ESW)	mm	Extractable soil water	Soil					

· Click Reporting Frequency to specify how often you want the variables written to the output file.

The user may choose a regular interval such as every day or once a month/year. It is also possible to specify an event. For instance, you might want to write the output on sowing, harvesting or fertilizing. For this simulation, the needed output is daily, so delete harvesting and type in end_day.

This is the end of building the simulation:

- Click the 📩 Run button on the main toolbar.
- Once the run is complete, click the outputfile component to view the results.
- This is just a text file so users can easily import it into other programs for analysis. It will be saved in the same directory your simulation is in with the file name being <simulation_name>.out. If there is no file available, it means the run failed. Check the summary file for errors.

inulations	WheatWaterBalanc	e.out				
WheatWaterBalance	Search:	a				
- Ock	ApsimVersion = 7	7.10 r4158				
- 📝 summaryfile	Title = WheatWat	erBalance				
- M paddock	dd_mm_yyyy	simulation_days	Rain	tlai	biomass	esw
B-m Soil	(dd_mm_yyyy)	0	(mm)	(m^2/m^2)	(kg/ha)	(mm)
SurfaceOrganicMatter	01_01_1988	0	0.000	0.000	0.0	535.638
- fertiliser	02_01_1988	1	0.000	0.000	0.0	531.619
	03_01_1988	2	12.800	0.000	0.0	539.740
- D Manager folder	04_01_1988	3	0.400	0.000	0.0	536.598
- outputfile	05_01_1988	4	1.800	0.000	0.0	534.474
Variables	06_01_1988	5	0.400	0.000	0.0	533.145
	07_01_1988	6	0.000	0.000	0.0	532.089
- P Reporting Frequency	08_01_1988	7	0.000	0.000	0.0	531.185
Training 1-XYGraph	09 01 1988	8	0.000	0.000	0.0	530.382
	10 01 1988	9	0.000	0.000	0.0	529.652
	11_01_1988	10	0.000	0.000	0.0	528.977
	12 01 1988	11	0.000	0.000	0.0	528.347
	13_01_1988	12	0.000	0.000	0.0	527.753
	14_01_1988	13	0.000	0.000	0.0	527.190
	15 01 1988	14	0.000	0.000	0.0	526.653
	16 01 1988	15	4.400	0.000	0.0	529.962
	17_01_1988	16	6.800	0.000	0.0	533.637
	18_01_1988	17	0.000	0.000	0.0	529.989
	19 01 1988	18	22.800	0.000	0.0	546.865
	20_01_1988	19	16.400	0.000	0.0	557.587
	21_01_1988	20	0.000	0.000	0.0	552.791
	22 01 1988	21	5.400	0.000	0.0	552.904
	23 01 1988	22	0.600	0.000	0.0	551.419

3. Creating graphics

APSIM UI can do basic visualization and analysis right in the user interface. Several types of graphs can be developed. This section will use the inbuilt APSIM graphs to display the data in the output file in a graph and create a graph showing ESW and rain (Right Hand Axis) by simulation day. To do this:

• Click on the Graph toolbox to open it.

Toolbox				
⊡… <mark>© Graph</mark> ⊟© Graphs				
Graph Suites	Graphs	GraphBits	Graph Suites	
🏙 Standard 🛃 Graph 🏙 Soils 🁔	Management	t 🏙 Gener	icFunctions 🏙 AusFarm 🁔	Training 🏙 animal

- Expand the Graph folder then the Graphs folder. Click on the + symbol next to the Graphs folder to expand it.
- Drag an XY component onto the output file in your simulation.
- Right-click on the XY node, and rename it to Training1-XYGraph. This updates the chart title.
- Expand the Training1-XYGraph component.
- **<u>Click</u>** on the **Plot** subcomponent.
- <u>Click</u> on the X variables square to make sure the background of the square is pink (variables can only be added to it when the background is pink).
- <u>Click</u> on the simulation_days column heading. It should appear in the list in the square.
- Click on the Y variables square to make its background pink.
- Click on the ESW, tlai, biomass, and the Rain column headings. They should be added to the list in the square.

To make Rain and biomass appear on the right-hand axis:

Click Rain in the square to highlight it and right-click on it. In the popup menu click on Right Hand Axis.

- 📁 simulations 🔄 📄 Wheat WaterBalance	Select X variab	les by clicking on t	he column(s) at th	e bottom.						
II met ⊗ clock ⊠ summaryfile		ariables ulation_days	Y variables		Type Solid line	~				
Paddock Brown Sol			tlai Right axis: bi Right axis: Ri	in F	ur?	~				
- Reporting Frequency	dd_mm_yyyy	simulation_days	Rain	tlai	biomass	eew	ApsimVersion	Téle		
Training 1-XYGraph Image: A starting 1-XYGraph Im	01_01_1988	0	0	0	0	535.638	7.10 r4158	Wheat WaterBala		
ApsimFileReader	02_01_1988	1	0	0	0	531.619	7.10 r4158	WheatWaterBala		
	03_01_1988	2	12.8	0	0	539.74	7.10r4158	WheatWaterBala		
	04_01_1988	3	0.4	0	0	536.598	7.10 r4158	WheatWaterBala		
	05_01_1988	4	1.8	0	0	534.474	7.10r4158	Wheat WaterBala		
	06 01 1988	5	0.4	0	0	533.145	7.10r4158	Wheat Water Bala		
	07 01 1988	6	0	0	0	532.089	7.10 r4158	WheatWaterBala		
	08_01_1988	7	0	0	0	531,185	7.10r4158	Wheat Water Bala		
	09 01 1988	8	0	0	0	530.382	7.10r4158	Wheat WaterBala		
	10 01 1988	9	0	0	0	529 652	7.10r4158	Wheat Water Bala		
	11_01_1988	10	0	0	0	528.977	7.10r4158	WheatWaterBala		
	12.01.1988	11	0	0	0	528 347	7 10 # 158	Wheat Water Rala		
	13 01 1988	12	0	0	0	527 753	7 10 r4158	Wheat Water Bala		
	14_01_1988	13	0	0	0	527.19	7.10 4158	Wheat WaterBala		
	15_01_1988	14	0	0	0	526.653	7.10r4158	WheatWaterBala		

- Click Training1-XY Graph to see the following graph that shows the dynamics of ESW plotted with Rainfall.
- **<u>Click</u>** the legend items on the right for other variables to be plotted.



The user is encouraged to explore other graph options on their own.

<u>Right-click</u> the graphs to explore various saving options. <u>Explore</u> the Excel icon in the main toolbar to export the data of simulations.

3. PREPARING INPUT CLIMATE DATA TO RUN APSIM USING RICCAR PRODUCT

Although climate data is vital to many applications in many disciplines, handling climate data is often difficult for the non-expert user owing to its complex structure due to its spatiotemporal nature along with several variables arranged together. There are also variablespecific conversion requirements (coefficients and units). Most of the time climate data exists in NetCDF (Network Common Data Form) format. A NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access and sharing of array-oriented scientific data. This means that there is a header that describes the layout of the rest of the file, in particular the data arrays, as well as arbitrary file metadata in the form of name/value attributes. The format is platform-independent, with issues such as endianness³ being addressed in the software libraries. The data is stored in a fashion that allows efficient subsetting with several variables in space and time. Figure 4 shows an example of a complex climate data structure.



A. Extracting RICCAR data for a location or region in simpler formats

To understand the impact of climate change, the first step of long-term climate/weather data preparation for running APSIM is to extract climate data from the RICCAR in a format that is usable by the APSIM model. Usually, this is done using programing tools that can handle the NetCDF files. A code was developed for extracting the time series of a given variable and for a given RCP for any location in the RICCAR Domain. This source code is compiled in the R platform. The source code is provided in Appendix 1 for users who are interested. The user need not necessarily use this method to extract the time series for a location from the RICCAR data. Alternative time series extraction codes written in other languages such as C, Python, etc., may be used.

FIGURE 5: Example of a program written in the R language to extract time series of data from a location from the RICCAR (NetCDF) data. This code is provided in Appendix 1

<pre>library(ncdf) / prockage for netcof maripulation library(ncdf) / prockage for netcof maripulation library(ncdf) / prockage for proster maripulation library(ncdf) / prockage for plotting library(RcolorBrewer) library(RcolorBrewer) dutputfile <= "E\\[ClockAd\]APSIN\TO_Escut_TMAGS.txt" ##### 1000 to dut through each NETGOF file</pre>	
year <-seq(from=1999, to=2100, by=1)	
<pre>for(j in seq_along(year)) {</pre>	
A MARKAN DE LA TREMINENCIA ANT DE MARKANNA ANT	
KANANANANANANANANANANANANANANANANANANAN	

<pre># ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP4.S\\CNRM\\pn # ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP4.S\\CNRM\\pn # ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP4.S\\GFU\)pr</pre>	
# nc_data1 <- nc_open(ncfile1)	
# nc_data2 <- nc_open(ncfile2)	
<pre># nc_data3 <- nc_open(ncfile3)</pre>	
<pre># lon <- ncvar_get(nc_data1, "lon")</pre>	
<pre># lat <- ncvar_get(nc_data1, "lat", verbose = F)</pre>	
# if (year[j] %% 4== 0) dn=366 else dn=365 # day=(1:dn)	
<pre># pr.array1 <- ncvar_get(nc_data1, "pr")</pre>	
<pre># pr.array2 <- ncvar_get(nc_data2, "pr")</pre>	
# pr.array3 <- ncvar_get(nc_data3, "pr")	
## PPT RCP 85 ##	

#	
<pre># ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP8.5\\CNRM\\pr_M # ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP8.5\\EC-EARTH\\p</pre>	
<pre># ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP8.s\\EC-EARTH\\p</pre>	r_MNA-44_ICHEC-EC-EARTH_historicalandrcp85_r1
<pre># ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP8.5\\GFDL\\pr_M\ # nc_data1 <- nc_open(ncfile1)</pre>	A-44_NOAA-GFDL-GFDL-ESM2M_h1stor1calandrcp85_
# nc_data2 <- nc_open(ncfile2) # nc_data2 <- nc_open(ncfile2)	
# nc_data3 <- nc_open(ncfile3)	
# lon <- ncvar_get(nc_data1, "lon")	
<pre># lat <- ncvar_get(nc_data1, "lat", verbose = F)</pre>	
# if (year[j] %% 4== 0) dn=366 else dn=365	
# day=(1:dn)	
# pr.array1 <- ncvar_get(nc_data1, "pr") # pr.array2 <- ncvar_get(nc_data2, "pr")	
# pr.array3 <- ncvar_get(nc_data3, "pr")	

B. Developing derived weather variables from RICCAR

It is possible to extract daily maximum temperature (Tmax), daily minimum temperature (Tmin), and daily precipitation (Ppt) from the RICCAR database. However, incoming short-wave radiation (Rsw) is an essential variable for crop modelling. If the user is using climate data from other sources, then it is recommended that they use Rsw directly. In the event that Rsw data is not available, it is possible to calculate a value for Rsw using the basic meteorological variables, the latitude of the location and the time of the year. However, this is a modelled estimate of radiation. The necessary equations that can be used to calculate Rsw are provided in Appendix 1. On the other hand, if Rsw data is readily available, it is highly recommended to use that directly. Some crop simulation models also require the use of data on relative humidity and wind speed.

C. Preparing APSIM-specific climate data

APSIM met files (meteorology input files) consist of a section name, which is always **weather.met.weather**, several constants consisting of "name = value", followed by a headings line, a units line and then the data. Spacing in the file is not relevant. Comments can be inserted using the ! character. As a minimum requirement, three constants must be included in the file: latitude, mean average temperature (tav), and amplitude in mean monthly temperature (amp). The met file must also have a year and day column, as well as columns for incoming solar radiation (MJ/m²), maximum temperature (oC), minimum temperature (oC) and rainfall. In APSIM nomenclature, the column headings used for these are year and day, radn, maxt, mint, rain, respectively. The user may instead use RICCAR-based Tmax for maxt; Tmin for mint and Ppt for rain. The calculated Rsw can be used for radn. Other constants or columns can be added to the file. These then become available to APSIM as variables that can be reported or used in the manager script.

FIGURE 6: Example of a typical APSIM meteorology input file

IQ_RICCAR2.m	net						
Browse							
🔝 Raw data	🕢 Rainfall chart	Monthly rainf	all chart 👔 1	Temperature chart	Radiation	chart	
!title = I	RAQ RICCAR2						
!station n	ame = WASIT	-RICCAR2					
latitude	= 33.05 (DECIMAL DE	GREES)				
longitude	= 45.17 (DE	CIMAL DEGR	EES)				
tav = 10	.9 (oC)	! annual a	verage amb	bient tempe	rature		
amp = 11	(oC) ! a	nnual ampl	itude in m	mean monthl	y temperat	ure	
year	day	radn	maxt	mint	rain	co2	
()	()	(MJ/m^2)	(oC)	(oC)	(mm)	(ppm)	
2000.00	1.00	10.53	17.02	4.06	0.00	380.00	
2000.00	2.00	10.21	17.02	4.81	0.00	380.00	
2000.00	3.00	9.93	16.91	5.41	5.01	380.00	
2000.00	4.00	10.24	17.46	5.32	0.00	380.00	
2000.00	5.00	10.29	17.97	5.79	0.00	380.00	
2000.00	6.00	9.41	16.72	6.56	1.00	380.00	
2000.00	7.00	10.41	17.68	5.42	0.00	380.00	
2000.00	8.00	10.31	18.27	6.33	0.00	380.00	
2000.00	9.00	10.51	19.19	6.89	0.15	380.00	
2000.00	10.00	10.39	19.36	7.44	0.00	380.00	
2000.00	11.00	10.08	18.09	6.95	0.46	380.00	
2000.00	12.00	10.42	18.52	6.76	0.25	380.00	
2000.00	13.00	10.28	18.75	7.40	2.94	380.00	
2000.00	14.00	9.76	17.76	7.60	0.00	380.00	
2000.00	15.00	10.48	18.32	6.79	0.11	380.00	
2000.00	16.00	10.97	17.14	4.67	0.05	380.00	
2000.00	17.00	11.11	18.77	6.12	0.00	380.00	
2000.00	18.00	10.30	17.11	6.33	1.32	380.00	
2000.00	19.00	10.32	17.65	6.94	0.87	380.00	
2000.00	20.00	10.40	17.19	6.46	0.20	380.00	
2000.00	21.00	10.42	16.73	6.10	1.23	380.00	
2000 00	22 00	10 02	14 23	4 4 9	2 67	380 00	

AutoSave 💽	一日 り、 	୯ ନ ବ		REV	ISED_MR_RCP85	APSIM_delta.xls		
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[weather.m		1000-020 2000	is infined dur	inny uata				
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	-6.722 (DECIMA							
			1/01/2010 at	10.42 for pari	- 1 (0 to 265/2019	(ddd haaad	
TAV and A								
! TAV and A! tay = 18.04					od from 1/200	0 10 303/2013	(ddd/yyyy)	
tav = 18.04	(oC) ! annual	average ambie	nt temperatu	re	od from 1/200	0 (0 303/2013	(000/9999)	
tav = 18.04 amp = 16.5 (average ambie	nt temperatu	re	od from 1/200	0 10 303/2015	(000/9999)	
tav = 18.04 amp = 16.5 ((oC) ! annual oC) ! annual	average ambie	nt temperatu	re	rain	0 10 303/2015	(000/9999)	
tav = 18.04 amp = 16.5 (year	(oC) ! annual oC) ! annual day	average ambie amplitude in m radn	nt temperatu ean monthly maxt	re temperature mint	rain	0 10 303/2015	(000/9999)	
tav = 18.04 amp = 16.5 (year ()	(oC) ! annual oC) ! annual	average ambie amplitude in m	nt temperatu ean monthly	re temperature			(000/9999)	
tav = 18.04 amp = 16.5 (year ()	(oC) ! annual oC) ! annual a day ()	average ambie amplitude in m radn (MJ/m^2)	nt temperatu ean monthly maxt (oC)	mint (oC)	rain (mm)			
tav = 18.04 amp = 16.5 (year () 2006 2006	(oC) ! annual oC) ! annual day () 1	average ambie amplitude in m radn (MJ/m^2) 4.85	nt temperatu ean monthly maxt (oC) 15.87	mint (oC) 4.77	rain (mm) 2.70			
tav = 18.04 amp = 16.5 (year () 2006 2006 2006	(oC) ! annual oC) ! annual day () 1 2	average ambie amplitude in m radn (MJ/m^2) 4.85 5.12	nt temperatu ean monthly maxt (oC) 15.87 16.32	mint (oC) 4.77 4.33	rain (mm) 2.70 1.95			
tav = 18.04 amp = 16.5 (year () 2006 2006 2006 2006	(oC) ! annual oC) ! annual day () 1 2 3	average ambie amplitude in m radn (MJ/m^2) 4.85 5.12 4.99 4.72	maxt (oC) 15.87 16.32 15.40	re mint (oC) 4.77 4.33 4.03 4.41	rain (mm) 2.70 1.95 3.00 2.24			
tav = 18.04 amp = 16.5 (year () 2006 2006 2006 2006 2006	(oC) ! annual oC) ! annual day () 1 2 3 4	average ambie amplitude in m radn (MJ/m^2) 4.85 5.12 4.99 4.72 4.87	nt temperatu ean monthly maxt (oC) 15.87 16.32 15.40 14.80 14.77	re temperature (oC) 4.77 4.33 4.03 4.41 3.98	rain (mm) 2.70 1.95 3.00 2.24 2.36			
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tav = 18.04 amp = 16.5 (year () 2006 2006 2006 2006 2006 2006 2006 200	(oC) ! annual oC) ! annual oC) ! annual oC) day () 1 2 3 4 5 5 6	average ambie amplitude in m (MJ/m^2) 4.85 5.12 4.99 4.72 4.87 4.84 4.84	nt temperatu ean monthly maxt (oC) 15.87 16.32 15.40 14.80 14.77 14.69 14.62	re temperature mint (oC) 4.77 4.33 4.03 4.41 3.98 4.09 4.11	rain (mm) 2.70 1.95 3.00 2.24 2.36 5.59 4.30			
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- <u>Create</u> an Excel file using the required variables on a daily time step exactly in the same sequence as shown above. Ensure that header elements are entered as shown above by writing continuously in the first cell of a row. Ensure that you list the variables in APSIM notation (year, day, radn, maxt, mint and rain) and in the next line their units within brackets. It is important that the column widths are a bit wider than the data in them. Please note that in the screenshot, the maxt column is wider than it needs to be.
- <u>Save</u> the file as a Formatted Text (Space delimited) (*.prn) file, giving it a .met file extension. It is recommended that you keep your toolboxes, met files, etc., in a separate folder from the APSIM installation directory. Perhaps you could create a folder called c:/apsim_toolboxes for storing these types of files. It is advised that the first two columns (year and DOY) do not have any decimal places. The first several lines that represent the header file may be written as continuous text in the first column. You can first save it as a .prn file.

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								2006	1	4.85	15.87	4.77	2.70	380.83			
								2006	2	5.12	16.32	4.33	1.95	380.83			
								2006	3	4,99	15.40	4.03	3.00	380.83			
								2006	4	4.72	14.80	4.41	2.24	380.83			
							17	2006	5	4.87	14.77	3.98	2.36	380.83			
								2006	6	4.84	14.69	4.09	5.59	380.83			
							19	2006	7	4.84	14.62	4.11	4.30	380.83			

MERCHOUCHEMOROCCO_RICCAR_RCP4.5.prn.



Rename the file extension as .met as shown above: MerchoucheMorocco_RICCAR_RCP4.5.met.

D. Preparing a typical APSIM soil profile

Inputting soil characteristic data is vital to simulate plant growth adequately. There are several physical, chemical and biological properties that need to be parameterized adequately. In APSIM, there are two methods to characterize a soil profile so that it matches the study context.

Option 1: Modify the soil profile of an existing simulation (for example, **ContinuousWheat.apsim**) in the examples folder using the huge selection of soil profiles available in the APSIM database. Then modify the soil characteristics of the selected soil profile to further suit the context as the model set-up steps are carried out, as needed.

Option 2: Develop a soil library suited to your situation using an external program called APSoil. This also works similar to the method explained above. In other words, the user can use the extensive library already available as a template and develop a new soil profile by modifying it. The relative advantage is that the user can save it as a unique soil library. Because of this, this soil profile can be reused for other simulations directly or shared with other users without necessitating that the new user develops or parameterizes a new soil profile. A new soil library developed using APSoil can be imported into the APSIM UI through the main toolbar.

E. Developing a soil library using APSoil

APSoil is a database of soil water characteristics that enables the estimation of plant available water capacity for individual soils and crops. This platform covers many cropping regions of the world including Australia, Africa, North America and South-East Asia, and is regularly updated. As a wide variety of soil profiles are available in this database, it is suitable for parameterizing any type of soil profile across the world, with some modifications. It is designed for use in simulation modelling and agronomic practice. APSoil enables the user to view individual soil and crop species data in spreadsheet and graph formats. Users can download the APSoil database, which can be opened with the APSoil interface to visualize, modify and create new libraries.



Open the APSoil interface to see the screen as shown below.



• **Open** the **APSoil database** by browsing the interface.

🔍 , 💭 🔚 🔞 , 🤌 , 🐺 , 🖌 🏥 🍥 n Save Save as Add Import Export Check soils Sort soils Google Earth	Version Release notes	
n Save save as Add import Export Check sons Soft sons Google Later		
ustralia	Check soil	
💭 Queensland	Record number:	51
Darling Downs and Granite Belt	Australian Soil Classification Order:	Vertosol
Red Chromosol (Billa Billa No066)		
⊕ grey Vertosol-Mt Carmel (Billa Billa No036)	Australian Soil Classification Sub-Order	Black
er-se Grey Vertosol (Moonie No081)	Soil type, texture or other descriptor:	Clay
Er-g ² Grey Vertosol (Condamine No.33) Er-g ² Grey Vertosol-Kupunn (The Gums No.103)	Local name:	
Erger Grey Vertosol-Kupunn mod for salt (Moonie No092)	Site:	Jimbour
Grey Vertosol-Kupunn (Moonie No082)		
😥 🛷 Grey Vertosol-Belah (Moonie No080)	Nearest town:	Jimbour, Q 4352
🗄 🛷 Grey Vertosol-Kupunn (Condamine No105)	Region:	Darling Downs and Granite Belt
🕀 🥜 Red Chromosol (Enarra No216)	State:	Queensland
⊞ grey Vertosol (Enarra No217)	Country:	Australia
Bed Chromosol (Enarra No218)		
Grey Vertosol (Goondiwindi No219)	Natural vegetation:	Grassland, mainly Qld bluegrass
Breger Vertosol (Billa Billa No220) Breger Vertosol (Tarewinnabar No221)	APSoil number:	16
Grey Vertosol (Tarewinnabar No221)	Latitude (WGS84):	-26.972
Red Chromosol (Bundah No223)	Longitude (WGS84):	151.123
Grey Vertosol (Tarewinnabar No224)		
🖈 🛷 Grey Vertosol (Tarewinnabar No225)	Location accuracy:	+/- 20m
🖅 🛷 Red Chromosol (Goodar No226)	Year of sampling:	0
🖅 🧬 Grey Vertosol (Goondiwindi No227)		
Erect Chromosol (Yelarbon No228)		
⊞		
Red Chromosol (Enarra No230)	Data source:	CSIRO Sustainable Ecosystems, Toowoomba
Grey Vertosol (Tarewinnabar No231)	Data source:	CSINO Sustainable Ecosystems, Toowoomba
e@ [®] Red Chromosol (Coomrith No232)		
Black Vertosol-Anchonfield (Yandilla No007)		
Grey Vertosol-Box_Cecilvale (Kommanurra No012)		
Black Vertosol-Bongeen (Dalby No027)		
Black Vertosol-Waco (Jimbour No014)		
🗄 🛷 Grey Vertosol-Brigalow (Chances Plain No028)		
🖅 💣 Grey Vertosol-Brigalow transition (Hopeland No025)	Comments:	Clay -
🗈 💣 Grey Vertosol-Brigalow (Brigalow west No023)	Comments:	Cidy -
Grey Vertosol-Brigalow (Haystack No022)		
Grey Vertosol-Brigalow (Jandowae No020)		
Grey Vertosol-Brigalow (Warra No019)		
æ– <i>"e</i> ⁶ Grey Vertosol-Brigalow_Cecilvale transition (Chances Plain No029) ⊕– <i>"e</i> ⁶ Grey Vertosol-Box_Brigalow (Millwood No035)		
Black Vertosol-Glengallan (Massie No032)		
Black Vertosol-Mywybilla (Bongeen No001)		
Black Vertosol-Norillee (Bongeen No002)		
Black Vertosol-waco (Bongeen No003)		
🗄 🧬 Grey Vertosol-Cecilvale (Brookstead No004)		
Black Vertosol-Anchorfield (Brookstead No006)		
🗈 🛷 Black Vertosol-Condamine (Yandilla No008)		
⊞		
Grey Vertosol-Cecilvale (Beverley No010)		
Black vertosol-Irving (Kaimkillenbun No011)		
Black Vertosol-Waco (Jimbour No016)		
Grey Vertosol-Cecilvale (Jandowae No017)		
er-ge ^A Grey Vertosol-Kupunn (Hopeland No021) ⊡ge ^A Black Vertosol-Bongeen (Macalister No026)		

• Select a soil that resembles your situation. In this case choose Black Vertisol-Waco (Jimbour No016).

40	Grey vertosol (Myali vale 140057)		Site:				ieny hie hie
1.0	Black Vertosol (Spring Ridge No094)		Neare	st town:	c		Teny Hie Hie, NSW 2400
• · · · · · · · · · · · · · · · · · · ·	Grey Vertosol-Plain (Bellata No083)		Decis				
t-0	Grey Vertosol (Terry Hie Hie No079)		Region	n:			
10	Grey Vertosol (Terry Hie Hie No0	Add		•			New South Wales
1.0	Grey-Black Vertosol (Spring Ridg Grey-Black Vertosol (Spring Ridg	Import					Australia
0		-		<u> </u>	-	_	
· 0	Grey Vertosol (Merrywinebone No	Export		•	To	another .soil file	grassland
10	Grey Vertosol (Merah North No 12	Check soils			To	a spreadsheet	
10	Grey Vertosol (Narrabri No 124)			N.S.			Is to another .soils file
10	Grey-Black Vertosol (Breeza No1 💥	Delete	Del	-	1		
• · · · · · · · · · · ·	Grey-Black Vertosol (Boggabri No	Rename	F2	PW I	(GS84):		150.058
+-G	Brown Clay (Bellata No121)	Renorme	12		uracy:		+/- 20m
±-0	Grey Vertosol mod for salt (Bellata Black Vertosol (Breeza No119)	Cut	Ctrl+X	nol	ling:		0
	Black Vertosol (Garah No233)	Copy	Ctrl+C	F			-
			C				
G	Black Vertosol (Ashley No234) Black Vertosol (Moree No235)	Paste	Ctrl+V				
₩ B	Red Chromosol (North Star No23	Move up	Ctrl+Up				
	Black Vertosol (North Star No237		Ctrl+Down	e:			CSIRO Sustainable Ecosystems, Toowoomba
1	Grey Vertosol (North Star No238)	Move down	Ctri+Down				
	Grey Vertosol (Croppa Creek No2	Collapse all					
+-~~	Red Chromosol (North Star No24	5					
	Black Vertosol (Croppa Creek No	Expand all					
	Red Chromosol (Croppa Creek No242)			_			
1	Vertosol (Croppa Creek No865)						
I 💪	1/		~				

• <u>Close</u> the currently open large database and open the exported .soil file. Note that within a given .soil file, it is possible to have several soil profiles. For example, when creating a .soil file for the MENA region, it is possible to create several soil profiles within this library. When opening the new exported .soil file, users can see the following:

🕂 Apsoil - C:\Users\AGovind\Desktop\TEST.soils		
New Open Save Save as Add Import Export Check so	oils Sort soils Google Earth Version	e lease notes
□- isoils □- ¹ / ₂ Grey Vertosol (Terry Hie Hie No078)	🥩 Check soil	
🔤 👌 Water	Record number:	207
SoilWater 	Australian Soil Classification Order:	Vertosol
	Australian Soil Classification Sub-Order:	Grey
	Soil type, texture or other descriptor:	Clay
	Local name:	
	Site:	Teny Hie Hie
	Nearest town:	Terry Hie Hie, NSW 2400
	Region:	
	State:	New South Wales
	Country:	Australia
	Natural vegetation:	Open grassland
	APSoil number:	78
	Latitude (WGS84):	-29.708
	Longitude (WGS84):	150.058
	Location accuracy:	+/- 20m

• **<u>Rename</u>** all the necessary components on the panel to the right as required by right-clicking and selecting **Rename**. For example, you may rename the soil profile, change the details in the metadata, etc. See below for an example of how to change the details.

Apsoil - C\Users\AGovind\Desktop\TEST.soils * New Open Save Save ss Add Impo	rt Export Check soil	soils Google Earth Version Release notes				
👌 Water	Record number:	207				
SoilWater	Australian Soil Classification Order:	Vertosol				
Analysis	Australian Soil Classification Sub-Ord	er: Grey				
	Soil type, texture or other descriptor:	Clay				
	Local name:					
1	Site:	Merchouche				
	Nearostion	Rommani (SE) and Sidi Bettache (W)				
	Region:	55km SE of Rabat				
·····	I					
		Могоссо				
		Open grassland				
ia	k Clav Soil	1				
		33.36 -6.43				
····· 💩 Water						
👌 SoilWater		+/- 20m				
Joii vvatei		0				
	Data source:	ICARDA SOIL SURVEY REPORT OF ICARDA FARM-MARCHOUCH				
	Comments:	Prepared by Att Govind on 3 November 2021, using the information from the ICARDA SOIL SURVEY REPORT OF ICARDA FARIN-MARCHOUCH				

• <u>Click</u> the various components of the soil profile to edit them based on local needs. You can save this and use it for future modelling needs. The user may create several soil profiles under this library.

4. CLIMATE ADAPTATION IN A RAINFED AGROECOSYSTEM: SUPPLEMENTARY IRRIGATION IN MOROCCO

A. Problem statement

One of the wettest areas in the MENA region is the Maghreb region encompassing northern Morocco, Algeria and Tunisia. Under a changing climate, the region is experiencing a rapid decline in precipitation in recent years (Mohamed & Saeid, 2021). Analysis of the long-term climate data using RICCAR, and other climate datasets have demonstrated that, at the regional scale, the Maghreb region has a high probability of precipitation decline under a changing climate (Filahi et al., 2017). Most of the farming in this region is rainfed although there is sizable acreage of irrigated agriculture. As the annual rainfall patterns are changing under climate change, it is expected that rainfed agriculture may not be viable in the long run. Often supplementary irrigation is required to secure a good crop yield. There are many reports of increasing drought frequency and related crop failures in Morocco (Driouech, et al. 2017). This may have a profound implication on the sustainability of the agrifood system and has implications on regional food security.

To address this, the APSIM model is used to simulate the crop production trends under long-term climate data using the RICCAR climate product.

Taking wheat as a representative crop, this section will:

- 1. Simulate how a typical wheat crop in Morocco would behave under the two IPCC scenarios (RCP 4.5 and RCP 8.5).
- 2. Compare the crop yield evolution under RCP 8.5 (the business-as-usual climate scenario) and a scenario in which a climate adaptation measure is applied: "supplementary irrigation".⁴ Comparing the simulation of the evolution of interannual wheat yields in a rainfed scenario (under RCP 8.5) with the simulation of supplementary irrigation (under RCP 8.5) will provide an idea of how valid this climate adaptation intervention for Morocco is.



FIGURE 8: Supplementary irrigation being applied in a field in Morocco

Source: International Center for Agricultural Research in the Dry Areas (ICARDA), "Climate-resilient supplementary irrigation", n.d. https://www. icarda.org/research/innovations/climate-resilient-supplementary-irrigation.

In the following sections, a step-by-step procedure is presented. The assumption is that users have already practised the APSIM interface based on the previous chapters. If not, it is highly recommended that users practise the interface using the simple case provided as an example. The climate files required to run APSIM for the specific case have to be prepared as instructed in chapter 3.

B. Setting up and parameterizing weather, soil, crop and management

First, simulate the interannual variability of a hypothetical wheat crop in the Morocco context for several years under the effects of climate change to understand how the wheat yields might change. Unlike the introductory exercise in chapter 1, where the crop growth simulation for a single year was done on a daily time step, in this section the simulation is for 100 years but the outputs will be analysed using an annual time step.

Launch APSIM and select an example simulation file already available in the APSIM database. Use it as a template simulation first and then customize it for our needs rather than building a simulation from scratch. When you launch APSIM UI, you will see the previously worked simulations (if any) on the left panel.

Click Open and browse for the APSIM example folder in the following file path.

C:\Program Files (x86)\APSIM710-r4158\Examples.



Open the .apsim file called Continuous Wheat.apsim.

ApsimUI - D:\PROJECTS\ESCWA\Rotation	. 📙 . 🜌	🕅 🍾 🗱 🚅	🕜 - 🕨 🔳					
⊕- imulations ⊕- Diversified	🗚 Open							×
B-B Undiversified-Cereal-Cereal B-B Undiversified-Cereal-Legume XY	← → ~ ↑ <mark> </mark> > r >	OS (C:) > Program Files (x86) > APSIM710-r41	58 > Examples	`	ō	, P Sear	rch Examples	
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		Name	Date modified	Туре	Size			^
	🖈 Quick access	Soils	2/6/2019 1:55 PM	File folder				
	OneDrive - CGIAR	South Asia Examples	2/6/2019 1:55 PM	File folder				
		🌌 agpasture.apsim	10/4/2016 9:53 PM	APSIM File		94 KB		
	n 📃 r	💋 Bambatsi Pasture.apsim	3/22/2016 10:13 AM	APSIM File		29 KB		
	3D Objects	Blank Simulation.apsim	3/22/2016 10:13 AM	APSIM File		1 KB		
	Desktop	Sutterfly Pea.apsim	3/22/2016 10:13 AM	APSIM File		12 KB		
	Documents	🖉 Canopy.apsim	3/27/2018 4:12 PM	APSIM File		48 KB		
	Downloads	Centro.apsim	3/22/2016 10:13 AM	APSIM File		20 KB		
	h Music	🧭 Continuous Cotton.apsim	4/19/2017 9:58 AM	APSIM File		110 KB		
	Fictures	Sontinuous Maize and Weeds.apsim	3/27/2018 4:12 PM	APSIM File		57 KB		
		🖉 Continuous Maize Bimodal.apsim	3/27/2018 4:12 PM	APSIM File		55 KB		
	Videos	🖉 Continuous Maize.apsim	3/27/2018 4:12 PM	APSIM File		42 KB		
	🔛 OS (C:)	🖉 Continuous Sorghum.apsim	5/10/2016 2:36 PM	APSIM File		33 KB		
	Rew Volume (D:)	Continuous Wheat with Climate Change	3/22/2016 10:13 AM	APSIM File		30 KB		
	A Maharada	🛃 Continuous Wheat with SWIM3.apsim	3/22/2016 10:13 AM	APSIM File		58 KB		

If you are not familiar with the simulation tree and the components, it is recommended that you revisit chapter 2.

The first step involves two main alterations to the Continuous Wheat example that was loaded as a template, and which will be customized for this exercise:



The first alteration involves replacing the meteorological file with the one relevant for our case study (Morocco).

The second alteration involves replacing the soil profile.

To replace the meteorological file:

- Click the met icon in the simulation tree.
- Save this as a new simulation giving a New File Name.
- Save this Continuous Wheat simulation as MoroccoSupplementary Irrigation.apsim.
- <u>Replace</u> the meteorological station file for the example simulation (Goondiwindi, Australia) with the meteorological file created for the site in Morocco by browsing for it and opening it in the relevant location.

ApsimUI - C:\Program Files (x86)\APSI	M710-r4158(Examples)Continuous Wheat.apsim -
New Open Save Save as Expo	ort Checkpoint Inset New graph Excel Options Factorials Generate Help Run Stop
	%apsim%/Example MetFiles/Goond.met
ien is Continuous Wheat	Erowse A
clock Summaryfile	🐻 Raw data 🙀 Rainfall chart 🙀 Monthly rainfall chart 👔 Temperature chart 🖝 Radiation chart
e-m paddock	!Title = Goondiwindi 1940-1989
Soil	[weather.met.weather]
💮 📔 fertiliser	Latitude=-28.33 ! TAV and AMP inserted by "tav amp" on 28/10/1999 at 13:02 for period from 1/1940 to 365/1989 (ddd/yyyy)
🛓 🖓 Manager folder	tav = 19.86 (oC) ! annual average ambient temperature
i∎ outputfile	<pre>amp = 15.96 (oC) ! annual amplitude in mean monthly temperature</pre>
	site year day radn maxt mint rain evap
	() () ()(MJ/m^2) (oC) (oC) (mm) (mm)
	GCON 1940 1 28.66 35.0 17.2 0.0 8.48
	GOON 1940 2 26.30 32.2 19.4 0.0 8.48 GOON 1940 3 27.19 32.7 18.3 0.0 8.48
	GOON 1940 3 27.19 32.7 18.3 0.0 8.48 GOON 1940 4 26.73 32.7 18.3 0.0 8.48
	GOON 1540 5 25.92 32.7 10.3 0.0 0.48
	GOON 1940 6 24.68 32.7 20.0 0.0 8.48
	GOON 1940 7 26.68 32.7 21.6 0.0 8.48
	GOON 1940 8 22.91 32.2 16.1 14.7 8.31
	GOON 1940 9 26.42 34.4 20.0 0.0 8.31

- <u>Replace</u> the dataset with Morocco data. In the Morocco input folder, two meteorological files should be created, each one corresponding to each IPCC scenario (RCP 4.5 and RCP 8.5).
- Load RCP 8.5 as it is the business-as-usual scenario.



When the selected file is loaded, the name Merchouch can be seen, which is a field location in the Moroccan plains.

Scroll down through the data to see that the data ranges from 2006 to 2100. An additional column can be seen called CO_2 (ppm), which was not there in the previous meteorological file example. In this exercise, we will be simulating the long-term effect of climate change (2006-2100) on the wheat yield in Morocco. This is a function of changing climate as well as the atmospheric CO_2 concentration. Thus, it is beneficial to take CO_2 concentration into account in the datasets throughout the modelling period. This data can be obtained from IPCC and can be incorporated into the meteorological file directly.

🚜 ApsimUI - C\Program Files (x86)\APSIM710-r4158\Examples\Continuous Wheat.apsim								
New Open Save Save as Expo	rt Checkpoint	Insert a new gr	aph Excel Option	s Factorials G	enerate Help	Run Stop		
… imulations	D:\PROJECTS\ESC	WA\Morocco\i	nputs\RCP85_MR.m	net				
Continuous Wheat	Browse							
	🕅 Raw data 🚺	D. (
			Monthly rainfall char					
paddock	!title = Mer		m !Oct	-DEC 2009 is	infilled du	mmy data		
i≣…@ [®] Soil	[weather.met							
SurfaceOrganicMatter	<pre>!station num !station nam</pre>							
📔 fertiliser	latitude =		DECIMAL DEGRE	FS)				
wheat			CIMAL DEGREES					
Managerfolder					0 at 10:43 f	or period fr	rom 1/2000 to 365/203	L9 (ddd/vvvv)
Outputile	tav = 18.0		! annual aver					
	amp = 16.5	(oC) !	annual amplit	ude in mean	monthly temp	erature		
	year	day	radn	maxt	mint	rain	co2	
	()	()	(MJ/m^2)	(oC)	(OC)	(mm)	(ppm)	
	2006	1	4.85	15.87	4.77	2.70	380.83	
	2006	2	5.12	16.32 15.40	4.33 4.03	1.95	380.83 380.83	
	2006	4	4.99	14.80	4.03	2.24	380.83	
	2006	5	4.87	14.77	3.98	2.36	380.83	
	2006	6	4.84	14.69	4.09	5.59	380.83	
	2006	7	4.84	14.62	4.11	4.30	380.83	
	2006	8	5.04	14.63	3.54	6.00	380.83	
	2006	9	5.07	15.42	4.22	2.62	380.83	
	2006	10	5.26	16.01	4.25	1.11	380.83	
	2006	11	5.09	15.70	4.61	3.16	380.83	

 <u>Adjust</u> the simulation clock. In APSIM, although a long range of climate data is available, we can simulate for subset periods (such as 2010-2015) from a temporal domain ranging from 2006 to 2100. We will, however, simulate for the entire duration in this case. Thus we will need to adjust the clock accordingly with the start date as 1/1/2006 and end date as 12/31/2100.



- The next set of parameterizations is to <u>set up</u> the <u>paddock</u>. In APSIM, the <u>paddock</u> is the modelling unit that consists of soil, crop and management each of which has a complex set of parameterizations for various components within each of these broad categories.
- Replace the soil profile with the one created. There are two solutions to parametrize the soil profile in APSIM. Either choose a
 soil profile from the huge database of soils already in APSIM and then parameterize as the simulation proceeds or externally
 develop a soil profile (using APSoil software) as described in chapter 2 and include them in the simulation through the Add a
 toolbox option. For this exercise, we will continue using the soil profile that came along with the Continuous Wheat simulation
 and parameterize it to suit the Merchouche (Morocco) conditions. This also has the same effect as the above, with the only
 difference being soil file is not separately provided.

📁 simulations 📄 Continuous Wheat	🧳 Check soil	
👔 met	Record number:	0
🕑 clock 📝 summaryfile	Australian Soil Classification Order:	
□ m paddock	Australian Soil Classification Sub-Order:	
E & Soil	Soil type, texture or other descriptor:	Black Vertosol
SurfaceOrganicMatter	Local name:	Waco
💆 wheat	Site:	Jimbour
	Nearest town:	Jimbour, Q 4352
	Region:	South East Queensland
	State:	
	Country:	
	Natural vegetation:	Grassland, mainly Qld bluegrass
	APSoil number:	
	Latitude (WGS84):	0
	Longitude (WGS84):	0

If you keep the cursor on the soil and right-click, you can rename the soil (optional). You can also edit the auxiliary information on the right panel (replacing the highlighted text).

<u>Click Save</u>.

ApsimUI - C:\Program File	es (xi	86)\APSIM710-r4158\Examples\Continu	ous W	heat.apsim *	_	Ø	\times	日 5・ひ =	
New Open Save Save as Export									
⊟ i simulations		V Check soil						Paste → [©] Format Painter ^B I <u>U</u> → db X	
- I met		Record number:		0			^	Clipboard 5 Fr	
		Australian Soil Classification Orde	n:	NA				T	
E M paddock		Australian Soil Classification Sub-	Order:	NA					
B Merchor	. (Cut Ctrl+X	r.	Black Vertosol					
fertilser	h (Copy Ctrl+C		Merchouche series					
y wheat		Vaste Ctrl+V		Merchouche					
⊕ 📁 Manage ⊞ 🚺 outputfil 💥		Delete Del		Merchouche					
		lename F2		Morocco North West					
-	, (Ouplicate this node							
80	F	ind Rename the selected node		Merchouche					
0	•	Nove up Ctrl+Up		Grassland, crops					
0		Nove down Ctrl+Down						h.	
2-	. (Collapse this node Ctrl+Left	L	0					
	E	xpand this node Ctrl+Right		0					
	E	nable					_		
	0	Disable		2021			_	•	
-0	2 1	Jnlink •	1						
e	L	ink all if possible							
6	17	dd folder		You can type any auxiliary information about the soil here if you want					
2		rint							
		heck soil							
		ave all simulations to disk Ctrl+S							
•		xport to .sim							
		et tooltip					~		
🕍 Standard 📈 Graph			unctio	ons 🏙 AusFarm 🎁 Training 🏙 animal					
and a subset of	-	Contraction Contraction							

Click the + beside the Soil (renamed now as Merchouche) to expand the list. Several modules can be seen for parameterization of the soil characteristics. The next requirement is to parameterize each of these to suit the soil characteristics of the study site.



The parameterizations of these modules are quite similar to the procedures mentioned in chapter 2 and may be followed if needed to suit your site soil parameterization. The most important is the soil module called **Water** where the plant water relations are parameterized.

<u>Click</u> the <u>Water</u> icon to see the parameterizations available for various crops. Here we see that this soil is a 3 m deep soil profile that has 11 layers. Here you can edit the values of soil-plant water relations specific to each layer as a function of the crop that you are planning to simulate. Let us edit this soil profile for our needs.


Delete the layers from 150 cm onwards such that only 6 layers are there in the soil profile. Then, edit the values in the wheat plant water relations as shown in the screenshot below. Scroll right to see the wheat parameterizations.



Likewise, the user may parameterize other aspects of the soil such as **Soil Water**, **Soil Organic Matter**, **Analysis** and **Initial Nitrogen** to better suit the site. Most of these parameterizations and their distribution on the vertical characteristics of the soil can be visualized graphically and are displayed in the panel below. Such visualization is good for efficient parameterization of the soil characteristics.

Moving to other components of the **paddock**. In APSIM there are specific modules for various crop management topics such as the choice of **Surface Organic Matter**, **Crop**, **Fertilizer**, **Irrigation**, etc. Each of these modules needs to be listed under the **paddock** to be used in a simulation. Each of these modules can be given one or more specific management rules, which are listed in the **Management folder**. For example, instructions can include explicitly adding crops and fertilizer.

First, edit the Surface Soil Organic Matter module. Change the C:N ratio of the initial residue to 90 and the fraction of residue standing to 0.15.

BOX 3: Alternative climate data sets to run APSIM

The procedure set out in this training manual may be used, even if you are using climate data from sources other than the RICCAR database (including climate products such as ECMWF, TerraClimate or measured meteorological datasets). It is always advised to do modelling with measured datasets, do calibration and validation (CALVAL), and use long-term climate data for ex ante assessments.



Ensure that the right crop module is present. In this case, the crop Wheat is already there. To change the crop, drag and drop any crop that is available in the APSIM environment from the panel below (by selecting Standard, Standard Toolbox and then Crops).



- Ensure that the fertilizer module is also listed as a module. Now, under the Management folder, we see two management actions: (1) Crop Management and (2) Fertilize at Sowing.
- Click on Crop Management. The following tables will appear. Edit it using the text shown in red below:



As this is a multi-annual simulation running for many years to clearly understand the long-term effects, two more management options are needed.

Locate the common management functions on the lower panel of the APSIM interface that can be brought into the simulation.
 Select the Management folder, then open Manager (common tasks) and drag the two highlighted management functions and bring them to the paddock of the simulation tree.

^	1	1	V2	12	YA.	1	1	1	1	V2	1
÷	Imgation Rules	Sow using a fasw in to	Sow on a fixed date				Sorghum Sowing wi	SUGAR management	Luceme Ley fixed sow	Luceme Ley variable s	Harvesting n
	Cotton			Fertilise on	Fetilse in a	Fetilise on	Fertilise on				Report on d
	Reset water,	Reset water,	Rotations	Yield moisture correction	Simple gross	Publish an	Create a	Establish	Manage Bambatsi	Canola Oll Conc C	Residue
	Wheat Frost	CanolaFrost	FrostMultiplier								
v											
		Coton Deriolation a Reset water. ntrogen. suf	farw in to Cotton End Grop on a Defolition a fried date Preset water. Reset water. ntrogen. suf ntrogen. suf Wheat Frost Canola Frost	fasw in to date Cotton Erd orgo on Forelise at Defoliation fixed data Reset water, Reset water, ntrogen, suf ntrogen, suf WheatFrost CanolaFrost FrostMuttpler	faw in to date vanable rule Cotton Erbid corpo na Fortilae at Defolitiona fined date Reset water, Reset water, ntrogen, suf ntrogen, suf WheatFrost CanolaFrost FroatMutpier	IngationRules Sorr umon a Sorr on find Sorr umon a Coton rewing farm in to of date vande rule Coton rewing Coton a. Find date for the sorr of the s	IngetionRules Sow using a Sor on a fixed of Sow using a Coton Sowing a Soron prive date vanishe rule rule sowing rule sowing rule Cotton a. End crop on a Fixed set of fixed date rule Defolation a. Fixed date a Feetilise at fixed date rule Reset water, Reset water, Rotations Theid molture Single gross Publich an entropy. Cotton and rule rule rule and	IngationTules Sovurang a Sovurang a Cotton sewing Sortham Sortham Sovurang a Cotton sewing souring nucleon Soving nucleon and the soving	IngatonRules Sour uing a Sour an fand Sour uing a Coton Souring Sogrium Sogrium Souring in SubAR management faser in to to define the faser in to to souring the Souring in the So	IngationTules Sow umong a Sow umong a Sow umong a Cotton newing Sowhig mit Sownig mit Sow umong a Cotton newing Sowhig mit Sownig mi	IngationRules Sourbarg a Sourbarg a Cotton sourborg Sordham Sordham Subarg R Luceme Ley Luceme Ley Variable a.C. Sourbarg W. Sourbarg W. Subarg R Luceme Ley Variable s.c. Variable n.de n.de n.de n.de Sourbarg W. Sourbarg W

• Go back to the paddock to see these management functions and edit the details.

⊟- <mark>C</mark> simulations	Properties	(modulename].[eventname]		P									
Continuous Wheat			Description	Value										
— II met —⊗ clock	and the second se	i nati	When should a reset be done											
			The module the event is to come from :	wheat	•									
ia-m paddock		1.00	On which event should a reset be done :	sowing										
Soll Soll Soll Soll SurfaceOrganicMatter	100		Reset details											
- fertiliser			Name of your soil module :	select the name of soil (here "Soil") from dropdowr	•									
			Name of your surface organic matter module :	SurfaceOrganicMatter	•									
⊟- 🟳 Manager folder												Name of your phosphorus module :	Phosphorus	•
			Reset soil water?	yes	•									
			Reset soil nitrogen?	yes	•									
Reset water, nitrogen, surfaceOM and phosphorus on sowing			Reset surface organic matter?	yes	•									
⊕-1 outputfile			Reset phosphorus?	no	•									

Care should be taken to sequence the management actions. The sequencing can be managed by right-clicking on a management tool and moving it up or down as needed. The sequence of events in the management folder is important and should be sequenced as shown in the picture below.

isimulations isimulations → → → → → → → → → → → → → → → → → → →		Properties [n	nodulename]	[eventr	name]	
Continuous Wheat		-		Descr	iption	Value
		Charles and the		When	should a reset be done	
📝 summaryfile				The mo	odule the event is to come from :	wheat
ia mini paddock				On whi	ich event should a reset be done :	sowing
⊕_g^ Soil 				Reset	details	
fertiliser				Mana	f your soil module :	
wheat	*	Cut	Ctrl+		f your surface organic matter module :	SurfaceOrganicMatter
🖻 📁 📁 Manager folder		Сору	Ctrl+	С	f your phosphorus module :	Phosphorus
Reset water, nitrogen, surfaceOM and phosph Crop Management		Paste	Ctrl+	V	oil water?	yes
Erop Management	×	Delete	D	el	oil nitrogen?	yes
Harvesting rule	1	Rename	F	2	urface organic matter?	yes
		Duplicate this node			hosphorus?	no
	1	Find				
	0	Move up	Ctrl+U	р		
	0	Move down	Ctrl+Dow	n		
	1-	Collapse this not Move	e the select	ed nod	es up	
olbox		Expand this node	Ctrl+Rig	nt		
	1	Enable			ntname]	
		Disable			scription	Value
Fertilise incrop on critical NO3 level-top up	-	11-P-1			en should a reset be done	value
Tillage on fixed date	*	Unlink		•	module the event is to come from :	wheat
Report on date	D	Link all if possible			which event should a reset be done :	
Reset water, nitrogen, surfaceOM and phosphorus on	fo 🗔	Add folder			et details	sowing
	SI 🏊	Print			and the second	
Rotations	5	Check soil			ne of your soil module :	Cufere Oracia Matter
		Save all simulations to	dick Ctrl	c	e of your surface organic matter module e of your phosphorus module :	e : SurfaceOrganicMatter Phosphorus

Note that although the simulation name is Morocco_Suppl_Irrig.apsim, the name of the specific simulation tree is still named Continuous Wheat.

 <u>Right-click</u> the simulation name, <u>Continuous Wheat</u> and rename it as <u>Morocco_Rainfed_RCP85</u>. This will be just one experiment listed under the simulation file. More than one experiment under this simulation can be added as a <u>scenario</u>.

C. Setting up output variables and reporting frequencies

So far, the modelling environment and the necessary parameterizations have been set up. This lengthy and tedious process is now finalized. The following steps are to be followed to determine which variables to write out as outputs and the frequency of their reporting. This is a critical step, especially when we want to intercompare different simulations.

 In the simulation window, <u>click</u> Variables under the outputfile. This should be the first module listed under the outputfile.

New Open Save Save as Export Checkpoin		100 %
Initiation with the set of t	Constants to put in top of output file: (readonly) Title = Continuous Wheat select from the huge variety of	f variables that can be written out.
- ♥ olock - ₩ summayfie - ₩ paddock	Output file columns: Output file columns:	ed into broad classes, which can be menu
Gran Son SufaceOrganicMatter		Component filter: met Search
Anager folder Manager folder Reset water, nitrogen, surfaceOM and pho Crop Management	Veld	Variable name Array? Units Description met amp No
- 2 Fertilise at Sowing Harvesting rule - 1 outputfile	grain_size esw	CO2 No day_length No h hasDataToday No
Reporting Frequency	Delete unwanted variables and	Input_end_date No julian da Input_end_date_string No
	resequence the variables in the output file by moving up and	Input_start_date No julian da Input_start_date_string No Latitude No
	downby right clicking	MaxT No MinT No Radin No
		Rain No tav No
		vp No

Although the APSIM simulation runs at daily time steps, the results can be written out at different temporal resolutions. This is often helpful while doing long-term experiments such as the current exercise where the daily results for 100s of years for different variables are difficult to manage and analyse. This is more relevant when different scenarios in the numerical modelling experiment are available.

- In this simulation, delete dd/mm/yy as date in the variable list and replace it with Year.
- Find Year under the Clock on the right panel.
- Delete grain_size and ESW variables.

BOX 4: Good modelling practices #1

It is advised to have a thorough understanding of the system that you are trying to model. This means that you should have a clear understanding about the soil characteristics and general climatology of the location you are modelling. This means you should know the start and end timings of the seasons, maximum and minimum magnitudes of various meteorological variables and the nature of their seasonal patterns.

□-	Output file frequencies:	Frequency list - drag to the grid.
In met Ock Ock Sol Sol	various reproting frequency can be customized, based on various criteria. The most popular frequency can be found under "Clock" or "Crop"	Component filter: 5253 Search Variable name Uhits description clock end dags end gamutation end gweek end gweer end

D. Running the simulation (first scenario) and visualization

Up to this step, the user has adequately set up the modelling environment and provided the necessary parameterization and also customized the output file. It is now time to run the Morocco_Rainfed_RCP85 experiment.

Click the Run button in the main toolbar.



 Once the simulation has loaded to 100 per cent, <u>click</u> on the **outputfile** (not the subcomponents) to see the output file based on the configurations that were designed during the simulation set-up phase.

New Open Save Save as Export	• 🛃 int Insert a new graph E	xcel Options I	Factorials Generate	🕜 - 🕨 Help	Stop	100 %
	Morocco_Rainfed_RCP	85.out				
ia in Morocco_Rainfed_RCP85	Search:	100 100				
···································	ApsimVersion = 7.10	0 r4158				
📝 summaryfile	Title = Morocco_Ra:	infed_RCP85				
paddock	year	biomass	yield	grain_size	esw	
🕀 🛷 Soil	(year)	(kg/ha)	(kg/ha)	(g)	(mm)	
SurfaceOrganicMatter	2007	11032.4	4149.1	0.024	134.599	
fertiliser	2008	10512.5	3755.3	0.022	123.927	
	2009	11148.5	4384.4	0.026	140.651	
- 🔁 Manager folder	2010	10451.9	3725.4	0.023	129.552	
Reset water, nitrogen, surfaceOM and	2011	10636.5	4017.6	0.025	128.609	
Crop Management	2012	10350.8	3592.7	0.022	119.299	
Fertilise at Sowing	2013	11708.5	4578.6	0.026	139.312	
Harvesting rule	2014	11042.2	4069.9	0.024	131.996	
	2015	10896.3	3769.3	0.021	133.001	
Variables	2016	11051.7	4028.8	0.024	131.324	
	2017	11287.4	4552.1	0.027	140.543	
	2018	10450.8	3545.9	0.021	122.829	
	2019	10296.5	3513.2	0.021	114.987	
in Mot	2020	10912.8	4071.3	0.024	128.816	
< AnoimFileRearder	2021	10463.0	3834.6	0.023	123.614	
· /	2022	10535 0	3716 0	0 022	125 881	

To plot this data, recollect the procedure mentioned in the chapter 2.

- From the bottom panel, <u>click</u> the Graph button.
- Select XY and drag it and keep it under the Simulations folder.
- Click the + next to the XY graph icon to expand the list and see two child icons: Plot and AspimFileReader.
- <u>Browse</u> for the output file <u>Morocco_Rainfed_RCP85</u>. It should be in the same folder where the simulation was saved as <u>Morocco_Suppl_Irrig.apsim</u>. You can see that it is loaded into the <u>Plot</u> icon.
- Click on the X variable to activate it (the background should turn pink) and click on the relevant year to list it in the X variable box.
- <u>Click</u> on the Y variable to activate it (the background should turn pink) and click on yield so that it is listed in the Y variable box. Note that the X variable box will be white now.
- To visualize the graph, click on the main XY icon.



E. Explanation of results

The user has now successfully simulated the trends in wheat yields in Morocco under the IPCC RCP 8.5 scenario with the assumption of rainfed agriculture. The yield shows a significant decline from 4,000 kg/ha (4t/ha) to as low as 1.5 t/ha towards the end of the century if no climate adaptation measure is taken.

The next step is to explore how supplementary irrigation may improve the situation.



F. Adding scenarios

Adding scenarios is an easy process in APSIM. Once a standard simulation is established, the user can duplicate it and use it to create another scenario by changing specific elements and keeping other elements the same.

- Right-click on the experiment Morocco_Rainfed_RCP85.
- Click duplicate this node.



As soon as you click this, a pop-up window appears and asks how many duplicates are required and if they should be **linked**. This is a very critical step. If the **linked** option is pressed, all the duplicates will have all the variables linked (this means that a change made in one version will be reflected in the other versions). It is possible to **unlink** the selected portions later on to create specific scenarios. But, to start the process of creating scenarios, it is recommended that all the duplicates are **linked** initially when they are created.

• Create 2 duplicates that are linked.

You will now see that two copies of Morocco_Rainfed_RCP85 are created with numbers 1 and 2. These are default names and you may rename the scenarios later on. We can rename them as Morocco_Rainfed_RCP45 and Morocco_SI_RCP85. What we plan to do is to create three scenarios.

TABLE 4: Comparison of the three scenarios considered in the Morocco test case

Scenario	Description
MOROCCO_RAINFED_RCP45	Rainfed agriculture under RCP 8.5 climate scenario
MOROCCO_RAINFED_RCP45	Rainfed agriculture under RCP 4.5 climate scenario
MOROCCO_SI_RCP85	Rainfed agriculture with supplementary irrigation as a climate adaptation under RCP 8.5 climate scenario

You may, however, notice that these newly created duplicate scenarios are in blue. The blue colour implies that these are linked. What we will do now is make them into different scenarios. At the moment, all three scenarios have the same characteristics and are only different in their names. We will follow the steps as mentioned below:

Expand the simulation tree of the scenario Morocco_Rainfed_RCP45.



- Since the only changes needed in this scenario are to the meteorology, <u>click on</u> the met module and unlink it (select Unlink all child nodes).
- **Replace** the file in the met with another file using the browse option mentioned previously.
- Click Save. Now there is another scenario that uses RCP 4.5 climate but the outputs are not yet generated.

New Open Save Save as Export Checkpoin	Insert a nev	graph Excel	Options Factorials	Generate Help	Run Stop	100 %	
	D:\PROJECTS	ESCWA\Moro	cco\inputs\RCP45_MR.	met			
e Morocco_Rainfed_RCP85 e WY	Browse			←			
Morocco Rainfed RCP45	🗐 Raw data	🔛 Rainfall ch	art 📓 Monthly rainfall ch	nart 👔 Temperature c	hart 🛛 🏶 Radiation cha	rt	
		Merch long		t-DEC 2009 is i	infilled dummy d	data	
summaryfile		met.weathe					
e maddock		number = 8					
Soil		name = Me					
🗑 Initial water		= 33.604	(DECIMAL DEGR				
💩 Water			(DECIMAL DEGREE				1/0000 005/001
<u>SoilWater</u>			! annual ave			eriod from	1/2000 to 365/201
SoilOrganicMatter			! annual ampli			170	
	ang) - 10	(00)	. annuar ampri	.cude in mean m	Jucity cemperate		
SufaceOrganicMatter	year	day	radn	maxt	mint	rain	co2
fertiliser	0	0	(MJ/m^2)	(oC)	(oC)	(mm)	(ppm)
wheat	2006	1	4.92	16.35	4.95	2.57	380.83
E- d Manager folder	2006	2	5.24	16.83	4.38	1.80	380.83
e outputfile	2006	3	5.09	15.82	4.04	2.82	380.83
H- Morocco SI RCP85	2006	4	4.75	15.25	4.73	2.20	380.83
	2006	5	4.81	15.25	4.60	2.29	380.83

- Press ctrl or shift, select both the experiments Morocco_Rainfed_RCP45 and Morocco_Rainfed_RCP85 and click Run.
- Through the ApsimFileReader under Plot, read both Morocco_Rainfed_RCP45.out and Morocco_Rainfed_RCP45.out files.
- <u>Click</u> the XY icon to see the following graph that compares how RCP 8.5 and RCP 4.5 simulates interannual wheat yields in Morocco using the RICCAR data in a rainfed situation.



Now that the rainfed scenarios have been created for the two climate scenarios RCP 8.5 and RCP 4.5, a third scenario will be created where climate adaptation under RCP 8.5 (supplementary irrigation) is taken into account.

This will be done using the experiment Morocco_SI_RCP85, which was created as the duplicate of Morocco_Rainfed_RCP85. Note that Morocco_SI_RCP85 is currently a replica of Morocco_Rainfed_RCP85 and is only different in name. It is important to adequately set up the model as the third scenario in this study.

The following three preparatory things is to be done:

- Bring down (right click to see the option) the XY module and keep it at the bottom.
- Contract the simulation trees of Morocco_Rainfed_RCP85 and Morocco_Rainfed_RCP45.
- Expand the simulation tree of Morocco_SI_RCP85 as shown below.



Ensure that Morocco_SI_RCP85 is using the climate of RCP 8.5.

Add an irrigation module to the paddock of Morocco_SI_RCP85. It is found in the lower panel (select Standard, then Standard Toolbox, then Water Component, then Irrigation).

- <u>Drag</u> and place the <u>Irrigation</u> module in the <u>paddock</u>. As mentioned earlier, these types of modules can have one or more management tools plugged in.
- <u>Plug</u> in a manager for irrigation on soil water deficit in the Manager folder. There are several types of irrigation managers located under the menu below in this folder under Manager.NET (common tasks). The one we will use is called Irrigate on sw deficit.

Drag and place Irrigate on sw deficit in the paddock of Morocco_SI_RCP85. See the figure for details.

It is essential to customize the irrigation module as shown so that it mimics a supplementary irrigation mode.



The following parameterization is needed for the Irrigation module. Note that Automatic Irrigation should be kept in OFF mode. Here, we keep the irrigation efficiency as 1 (100 per cent) but later on, using the specific manager that comes under this module, we can adequately parameterize the efficiency.



 Parameterize the Irrigate on sw_deficit irrigation manager as shown below. Note that supplementary irrigation is provided between 15 and 30 April if the soil moisture falls below a threshold.



G. Running scenarios simultaneously and visualization

With these three scenarios parameterized and set up well, now it is time to run APSIM.

- Collapse the modelling trees of all three scenarios.
- · Press the ctrl button and select all three scenarios.
- Click Run. We are now running all three scenarios simultaneously.
- · After the scenarios have loaded 100 per cent, load the three output files through the ApsimFileReader under Plot.
- Read the files Morocco_Rainfed_RCP45.out, Morocco_Rainfed_RCP45.out and Morocco_SI_RCP85.out.
- Click on the XY icon.



The following graph compares how RCP 8.5 and RCP 4.5 simulates interannual wheat yields in Morocco using the RICCAR data in a rainfed situation and also how the climate adaptation scenario (with supplementary irrigation applied) effects are manifested.

The **Excel** icon on the main toolbar can be used to export all of the data contained in the three scenario output files (even the variables that are not graphed) for use externally in spreadsheet software such as Microsoft Excel.

<u>Right-click</u> on the graph to save the graph as an image or copy the data of only those variables used in the graph. The option of
customizing the graph according to user preferences is also available.



It is important to get familiar with a new type of graphing option available in APSIM called **Probability Exceedance**. This option is useful in this type of long-term simulation.

- Drag and drop the Probability Exceedance plot from the toolbox bar and place it under the simulations folder. As with the XY plot, load the necessary files first.
- Place yield on the X axis and Probabilities calculated on the Y axis.

BOX 5: Good modelling practices #2

It is advised to have a thorough understanding of the system that you are trying to model. This means that you should have a clear understanding of the management activities of the location that we are modelling. This includes crop rotation and management factors for each agronomic intervention (including sowing, plant density, irrigation, fertilizer application, intercropping, harvesting and residue management).



This will provide a very useful graph, as shown below, that can help us interpret many things.



H. Summary and conclusions of this exercise

In Morocco, in a rainfed agriculture situation and under a business-as-usual climate change scenario (RCP 8.5), the yields of a currently popular wheat variety may decline drastically after 2030 (reducing from approximately 4t/ha in 2020 to as little as 1.5t/ha). However, under the best-case scenario of climate change (RCP 4.5), there is no major threat. Supplementary irrigation is the best climate adaptation in this context and may only lose its efficiency by the 2080s.

5. CLIMATE ADAPTATION IN AN IRRIGATED AGROECOSYSTEM: ENHANCING WATER PRODUCTIVITY IN IRAQ

A. Problem statement

The Arab region is one of the hottest and driest regions on the planet. This region encompasses the great Sahara desert and the Arabian desert. The agroecosystems in the Arab region are predominantly arid and are extremely vulnerable to climate change, and it is believed that they will become warmer and drier as climate change progresses. Agriculture under these circumstances is unsustainable due to the intense heat and water stress (ESCWA, 2017; ESCWA, 2019). Nevertheless, the region possesses large groundwater (large aquifers) and surface water (large river systems) resources. Thus, irrigated agriculture is also widespread in the Arab region. The large river systems include the Euphrates-Tigris river system as well as the Nile river system. If adequate water is available for irrigation, irrigated agriculture is not greatly affected by climate change. However, this is not always the case. Water resources are degrading both in quantity (amount available) and quality (salinity issues). Under climate change, the crop water requirement is greatly increased. This is because of increased evapotranspiration as the atmospheric demand is greatly affected by drier and warmer air. This means that larger amounts of water (possibly more than double) need to be applied to a crop to sustain the comparable yield recovery (Mostafa et al., 2021; Fader et al., 2016; Kang et al. 2009). This means that the water productivity (ratio of yield to water consumed) shows a declining trend. If conventional irrigation practices (such as flooding) with a very low irrigation efficiency are still employed, the water productivity under a changing climate is projected to continue declining. Besides this, several secondary problems emerge which warrant a feedback loop. For example, increased application of irrigation water under arid contexts with high evapotranspiration increases soil salinity (because irrigation water itself is saline and the salt content accumulates in the soil). As the soil becomes more saline, one needs to apply more water than required (due to leaching requirements) and this combined with evapotranspiration (ET) demands makes the soil even more saline, thus demanding more irrigation water needed under a changing climate. This is not sustainable for natural resources (as it leads to depletion of water resources and degradation of the soil). Thus, it is extremely critical that in irrigated systems, the water productivity has to be increased (if not sustained) under a changing climate as an important climate adaptation measure. Improving water productivity is the most influential climate adaptation for irrigated agroecosystems in the Arab region. Water productivity can be increased by several means, including: (1) increasing the irrigation efficiency by employing techniques such as drip irrigation, (2) irrigation scheduling based on crop water demand by either using evapotranspiration as a proxy or understanding the soil water deficit, or (3) a combination of the above.

In this exercise, taking wheat as a representative crop, the objective is to simulate and compare how a typical wheat crop is grown in the lower Mesopotamian plain (LMP) region would behave under the business-as-usual climate scenario (RCP 8.5). The region benefits from the availability of water resources from the Euphrates-Tigris river system in Iraq and is an irrigated situation (using the conventional flooding-based irrigation method). Secondly, a comparison will be made between agriculture using floodingbased irrigation and agriculture with the use of highly efficient drip irrigation combined with soil water need as a climate adaptation measure. The interannual variability of irrigation water use along with the nature of wheat yields will be used as indicators of water productivity. Thus, it is possible to prove that this climate adaptation intervention is valid for an arid, but irrigated ecosystem in the Arab region, such as the LMP region in Iraq.

In the following sections, the trainee will undertake a step-by-step procedure for this task. The assumption is that the user has already become familiar with elements of the APSIM interface based on the previous chapters. If not, it is highly recommended that the user practices the interface using the simple cases provided in previous chapters as examples. In the present chapter, the aim is to introduce certain procedures directly. The climate file (.met) and soil file (.Soils) required to run APSIM for this case have to be prepared as instructed in chapter 3. In the present chapter the user will be exposed to new options that can be implemented using APSIM (such as exporting data to Excel for external analysis). The climate data for this exercise will be taken from the RICCAR-Mashreg Domain.

FIGURE 9: Improving water productivity in the Arab region is the most influential climate adaptation option in irrigated agroecosystems



Source: ICARDA, "To improve food security, increase water productivity", 23 October 2018. https://www.icarda.org/media/news/improve-food-security-increase-water-productivity.

B. Setting up and parameterizing weather, soil, crop and management

The first step is to simulate the interannual variability of yield for a hypothetical wheat crop grown in the LMP region of Iraq in an irrigated context. The simulation project the effects of climate change over many years to understand how the wheat yields might change. Unlike the introductory exercise, in chapter 1, which was for crop growth over a single year on a daily time step, the simulation in this exercise will be for 70 years, but the outputs will be analysed using an annual time step.

- Launch the APSIM UI. When you launch the APSIM UI, you will see the previously used simulations (if any) on the left panel.
- Click Open and browse for the APSIM example folder using the following file path:

C:\Program Files (x86)\APSIM710-r4158\Examples.



- **Browse for and open** an example simulation file already available in the APSIM database. It will be used as a template simulation and will be customized for the current modelling needs rather than building a simulation from scratch.
- Open the .apsim file called Continuous Wheat.apsim.

simulations	A Open					
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		Name	Date modified	Туре	Size	
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	Desktop	Sutterfly Pea.apsim	3/22/2016 10:13 AM	APSIM File	12 KB	
	🗄 Documents	Canopy.apsim	3/27/2018 4:12 PM	APSIM File	48 KB	
	Downloads	🖉 Centro.apsim	3/22/2016 10:13 AM	APSIM File	20 KB	
	h Music	🜌 Continuous Cotton.apsim	4/19/2017 9:58 AM	APSIM File	110 KB	
	Pictures	Continuous Maize and Weeds.apsim	3/27/2018 4:12 PM	APSIM File	57 KB	
		🖉 Continuous Maize Bimodal.apsim	3/27/2018 4:12 PM	APSIM File	55 KB	
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	- Heliton	🦉 Continuous Wheat.apsim	5/10/2016 2:36 PM	APSIM File	36 KB	
		Sefoliated Wheat.apsim	3/22/2016 10:13 AM	APSIM File	33 KB	
		Fffluent-irrigated Eucalynt Forest.ansim	3/22/2016 10:13 AM	APSIM File	17 KB	

It is assumed that you are already familiar with the simulation tree and its components. If not, it is recommended that you revisit chapter 2 and familiarize yourself with the components.

This example simulation will be modified and customized for the needs of this specific exercise. As a first step, two main alterations are required to the **Continuous Wheat** example that was loaded: replacing the meteorological and soil files.

• **<u>Replace</u>** the meteorological file with the one relevant to this case study (Iraq). To replace the meteorological file, <u>click</u> the met icon in the simulation tree.



The meteorological station for the example simulation will be shown as **Goondiwindi**, **Australia**. You may also notice that the dataset is for the period 1940 to 1989.

In the user's Iraq input folder, a meteorological file may be created for a location in Iraq for RCP 8.5 scenario before starting this exercise.

Replace the meteorological file with the one for Iraq (Wasit) by browsing for it and importing it in the relevant location.

When the user loads the selected meteorological file, note that the name is Wasit-RICCAR2. Wasit is a field location in the LMP region of Iraq. When scrolled down through the file's data, you will see that the data ranges from 2000 to 2070. You will also see that there is an additional column called CO_2 (ppm) listed which was not there in the previous meteorological file example. In this exercise, the long-term effect of climate change (from 2000 to 2070) on wheat crops in Iraq will be simulated as a function of the changing climate as well as the atmospheric CO_2 concentration. It is beneficial to take CO_2 concentration into account in the datasets throughout the modelling period. This data can be obtained from IPCC and can be incorporated into the meteorological file directly.

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2000.00 6.00 9.41 16.72 6.56 1.00 380.00	2000.00	5.00	10.29	17.97	5.79	0.00	380.00	
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The next step is to adjust the simulation clock. In APSIM, although a long range of climate data is available, we can simulate for subset periods (such as 2010-2015) from a temporal domain ranging from 2000 to 2070. We will, however, simulate for the entire duration in this case.

Adjust the simulation clock, setting the start date to 1/1/2000 and the end date to 12/31/2070.



- Save this as a new simulation giving a New File Name: Iraq_WaterProductivity.apsim.
- <u>Change</u> the name of the scenario from Continuous Wheat to Flooding. This can be done by right-clicking and choosing rename option.
- Rename the existing numerical experiment as Flooding.

The next set of parameterizations is to set up the paddock.

In APSIM, a paddock is the modelling unit that consists of **Soil, Crop** and **Management**, each of which has a complex set of parameterizations for various components within each of these broad categories. There are two solutions to parametrize a soil profile in APSIM: either choose a soil profile from the huge database of soils already in APSIM and then parameterize as the simulation proceeds or externally develop a soil profile (using the APSoil software, chapter 3) and include the profile in the simulation though the **Add a toolbox** option. For this exercise, the existing soil that came along with the **Continuous Wheat** simulation will be replaced with a new soil profile that was created using the APSoil to parameterize it to mimic local conditions in Iraq. Please carefully follow the steps.

Delete the soil in the paddock of the Flooding experiment.

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E M paddock	Australian Sol Classification Sub-C	irder:		
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Export to	.sim			
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Unlike the previous exercise, this exercise does not require the soil to be parameterized as we are plugging in a soil that is characterized for the location already. To plug in a new soil profile that is externally located (rather than using the soil provided internally by APSIM UI), do the following:

Click the Options button on the main toolbar.

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wheat ⊕∽í Manager folde ⊛-∏ outputfile	Revert all options	
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• Click Add a toolbox and browse for the soil file (.soils file) you created externally and bring it into the APSIM UI.

Now you will be able to see a new item in the toolbox bar. In this case, you will see only one soil profile. However, it is possible to create a library of several soil profiles and plug them in APSIM UI through this approach.

New Open Save Save as Expo	rt Checkpoint Inser	t a new graph Excel	Options Factorials	Generate Help	Stop
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🏙 Standard 🛃 Graph 🏙 Soils 👔	Management 🏙 Gene	ericFunctions i 🏙 Au	sFarm 🏙 Training	🏙 anima 🚺 IRAQ_G	eneric

• Drag and drop this new soil into the paddock.

If the soil (here called IRAQ) is clicked, the details can be seen on the right panel. If needed, it is possible to adjust these details further in the same way that a soil profile can be modified and parameterized from the inbuilt soil files. It is possible to parameterize all the aspects of the soil profile such as Soil Water, Soil Organic Matter, Analysis and Initial Nitrogen to better suit your site characteristics. We are not going to elaborate soil profile parametrization here because we already covered this topic in the previous chapter.

Click the Save button.

Now let us move to other components of the **paddock**. In APSIM there are specific modules for various crop management topics such as choice of **Surface Organic Matter**, **Crop**, **fertilizer**, **Irrigation**, etc. Each of these modules needs to be listed under the **paddock** to be used in a simulation. Each of these modules can be given one or more specific management instructions, which are listed in the **Management folder**.

- Keep the parameters for the Surface Soil Organic Matter as they are.
- Ensure that C:N ratio is 90 and that the fraction of residue standing to 0.
- Click the Save button.

It is important to ensure that the right crop module is available. In this case, the crop Wheat is already there. If the crop needs to be changed, it is possible to drag and drop any crop that is available in the APSIM environment from the panel below (by selecting **Standard**, then **Standard Toolbox** and then **Crops**). Simply drag the crop and place it in the **paddock**. But in this exercise, Wheat will be used so there is no need to change the crop.



• Ensure that the fertilizer module is also listed as a module.

Under the Management folder, two management actions can be seen: (1) Crop Management and (2) Fertilize at Sowing.

- Click Crop Management to see the table in the screenshot.
- Edit it as shown and click the Save button.

As this is a multi-annual simulation running for many years to clearly understand the effects, two more management options are needed.



• Locate the common management functions on the lower panel of the APSIM interface that can be brought into the simulation by clicking Management folder, then Manager (common tasks).

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Gow on a fixed date Gow using a variable rule Gotton sowing rule	18	1	1	1	1	1	1	1	1	1	18
Sorghum sowing rule Sorghum Sowing with Tillers	Cotton Defoliation a	End crop on a fixed date	Fertilise at sowing	Fertilise on fixed date	Fertilise in a zadok sta	Fertilise on fixed date -t	Fertilise on days after	Fertilise incrop on critical N	Tillage on fixed date	Tillage on an event	Report on da
- '@ SUGAR management - '@ Luceme Ley VatAble sow harvest at flowering - '@ Luceme Ley VatAble sow harvest at flowering - '@ Luceme Ley VatAble sow harvest at flowering - '@ Cotton Decivation and Harvesting sule - '@ Luceme Ley VatAble Sow harvest at flowering - '@ Luceme Ley VatAble Sow harvest at flowering - '@ Luceme Ley VatAble Sow harvest at flowering - '@ Luceme Ley VatAble Sow harvest at flowering - '@ Luceme Ley VatAble Sow harvest at flowering - '@ Luceme Ley VatAble Sow harvest at flowering - '@ Cotton Decivation and Harvesting sule - '@ Cotton Decivation and Harvesting - '@ Cotton Decivation and	Reset water, nitrogen, surf.	Reset water, ntrogen, surf.	Rotations	Yield moisture correction	Simple gross margin (pu	Publish an event when	Create a yes-no varia	Establish Bamba	Manage Bambatsi	Canola Ol Conc C	Residue precipitati
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Vil Rotations	~										

- Drag the two highlighted functions and bring them to the paddock in our simulation tree.
- **<u>Go back</u>** to the **paddock** to see these management functions and edit the details.



• Care should be taken to sequence the management actions.

The sequencing can be managed by right-clicking on a management tool and moving it up or down as needed. The sequence of events in the management folder is important and should be sequenced as shown in the picture below.



Now an irrigation module will be added to the paddock of Flooding.

- Find it from the lower panel under (selecting Standard, then Standard Toolbox, then Water Components, then Irrigation).
- **Drag it** and place it in the **paddock**.

As mentioned earlier, these types of modules can have one or more management tools plugged in. The user will use a manager for irrigation on soil water deficit.

- <u>Note</u> that there are several types of irrigation managers located under the menu below the Management folder, under Manager. NET (common tasks). The one called Irrigate on sw deficit will be used.
- Drag Irrigate on sw deficit and place it under the Manager folder under the paddock of Flooding. See the screenshot below for details.
- Customize the Irrigation module as shown so that it mimics a flood irrigation mode.



- Keep the parameterization similar to the previous chapter for the Irrigation module.
- Note to keep Automatic Irrigation in OFF mode.
- Keep the irrigation efficiency as 1 (100 per cent) but later on, using the specific manager that comes under this module, it is
 possible to adequately parameterize the efficiency.
- Click the Save button.



The next step is to parameterize the Irrigate on sw_deficit irrigation manager.

Parameterize the Irrigate on sw_deficit manager.

Note that irrigation is provided between 1 January to 31 May if the soil moisture falls below a threshold. To mimic a floodingbased irrigation scheme, we have instructed APSIM that the irrigation efficiency is just 50 per cent and that the amount of water applied per irrigation is 30 mm.

Click the Save button.



C. Creating the drip irrigation scenario

Adding scenarios is an easy process in APSIM. Once a standard simulation is established, the user can duplicate it and use it to create another scenario by changing specific elements and keeping other elements the same.

- Collapse the Flooding simulation tree.
- Right-click on the experiment Flooding.
- Click duplicate this node.



As soon as this is pressed, a pop-up window appears and asks how many duplicates are required whether they should be **linked**. This is a very critical step. If the user presses **linked**, all the duplicates will have all the variables linked (this means that a change made in one version will be reflected in the other versions). It is possible to **unlink** the selected portions later on to create specific scenarios. But, to start the process of creating scenarios, it is recommended that all the duplicates are **linked** initially when they are created.

Create 1 duplicate scenario that is linked.

A copy of Flooding will be created as Flooding1. This is a default name.

Rename Flooding1 as Drip.

The plan is to create two scenarios as shown in table 5:

TABLE 5: Comparison of t	he two scenarios considered in the Iraq test case
Scenario	Description
Flooding	Irrigated agriculture (Flooding-based) under RCP 8.5
Drip	Irrigated agriculture (Drip Irrigation-based) under RCP 8.5

You may, however, have noticed that this newly created duplicate scenario is blue in colour. The blue colour implies that these are linked. What we will do now is make them into different scenarios. At the moment, these scenarios have the same characteristics and are only different in their names.

<u>Expand</u> the simulation tree of scenario Drip.

As only irrigation components need to be changed in this scenario, do only the following:

• Unlink the following items (Unlink all child nodes).



<u>Parameterize</u> the Irrigate on sw_deficit manager of the Drip experiment.



Now another scenario that conceptualizes drip irrigation has been created, but the outputs are not yet generated.

D. Setting up output variables and reporting frequencies

So far, the modelling environment and the necessary parameterizations have been set up. This lengthy and tedious process is now finalized. The following steps are to be followed to determine which variables to write out as outputs and the frequency of their reporting. This is a critical step, especially when we want to intercompare different simulations.

· Click Variables on the simulation window under the outputfile module.

If closely observed, the output file exists for each of the experiments (Flooding and Drip). As they are linked, if the user makes a change in any one of them changes will be made in the other automatically.

Set up the outputfile (review the previous chapter if there is any confusion). It should look like the two figures below, with the variables and frequency of reporting (end_day).

BOX 6: Scaling from point to region

APSIM is a point-scale model. This means it can only simulate one homogeneous unit at a given time. This is also known as lumped simulation. To make spatially explicit simulations, APSIM needs to simulate for each location separately and then analyse it spatially. This is only possible using high-performance computing platforms because the amount of computation on a point-based simulation itself is intensive.



Because adequate setting up of the modelling environment has been done, the necessary parameterization has been provided and the output file has been customized, it is now time to run the two experiments as scenarios.

• Pressing the ctrl button, select the experiments Flooding and Drip, and click Run.

APSIM will run and once the simulation has loaded to 100 per cent, a buzzing sound can be heard. If there are errors, an error message will be shown and the user may review the error message and carry out the remedial actions.



• **Click** on **outputfile** (not the subcomponents) to see the output file based on the set up of the output file, once the simulation has loaded to 100 per cent.



The user can now plot this data and analyse the results. In this exercise, we will export the simulated data as Excel files and do the analysis externally.

- Collapse the simulation trees of both the experiments.
- Press the ctrl button and select both simulation trees, then click the Excel icon on the main toolbar.

The following pop-up window will appear.

ExcelExport	-		×
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• Click OK to see Excel files of the two output files launched on your screen.

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6 2000	02_Jan_2000	0	0				
7 2000	03_Jan_2000	0	0				
8 2000	04_Jan_2000	0	0				
	05_Jan_2000	0	0				
10 2000	06_Jan_2000	0	0				
11 2000	07_Jan_2000	0	0				

There are two files like this. One for Flooding and another for Drip. Note that these are on daily time steps. The pivot table function in Microsoft Excel should be used to aggregate this data in a suitable format for further analysis.

- Delete the rows that we don't need. They are highlighted in the picture above.
- Select all of the data and click the Insert button.
- Using the pivot table function, **<u>develop</u>** a summary table.

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Repeat these actions with the Flooding file. Then, using the pivot tables, develop a consolidated table and do the further analysis.

TABLE 6: Consolidated table to be created using Pivot tables										
Flood irrigation Drip irrigation										
i cui	Total irrigation	Yield	WP	Total irrigation	Yield	WP				
2000										
2001										

Based on this tabulation, the following analysis can be made graphically in Excel.



The flood irrigation technique consumes more water than drip irrigation every year between 2000 and 2100. This has a significant toll on the long-term sustainability of water resources.

The wider impact of this issue can be seen when the cumulated values of the irrigation water applied are analysed. The difference is as high as 15,000 mm/ha. Scale that to the region to understand the amount of water that could be saved based on this climate adaptation intervention.



It is clear that drip irrigation and judicious water use always enhances water productivity. Thus, this should be scaled up as an adaptation measure.



E. Summary and conclusions of this exercise

A simulation of the long-term yield and irrigation water use was performed in the irrigated agricultural context of Iraq under the influence of a changing climate using the RICCAR data under two scenarios of irrigation practices: (1) conventional flooding irrigation, where water is copiously applied, and (2) drip irrigation, where an adequate amount of water is applied. It was clear that the interannual yield dynamics do not significantly vary in either of the two scenarios. However, the irrigation water applied was significantly higher in the flooding system compared to the drip irrigation system to maintain the same level of yields in a changing climate. It was noted that flooding-based irrigation yields were slightly higher than drip irrigation-based systems. The amount of water consumed for irrigation increased in both cases as the years progressed because of changing climatic conditions. Because the yields were comparable, the water productivity of drip irrigation systems was significantly higher than flood-based irrigation systems. Although water productivities decreased with climate change, it was clear that it is essential to opt for climate adaptation measures, including using technologies such as drip irrigation, to make the system climate-smart. Thus, RICCAR-based crop modelling activities are useful for exploring such context-specific climate adaptation efforts by the stakeholders.

6. CLIMATE MITIGATION IN AGROECOSYSTEMS: CARBON SEQUESTRATION IN JORDAN VIA CROP DIVERSIFICATION

A. Problem statement

Soil is an invaluable natural resource that acts as the living medium where vegetation proliferates under the influence of climate (weather) and management. It is in the soil that the carbon from the atmosphere is assimilated by vegetation and is recycled into the biosphere in the long term. Thus, enhancing soil carbon through vegetation is an important aspect of climate mitigation action as it brings atmospheric carbon to the biosphere. Beyond mitigation, enhancing soil carbon can also be considered as an efficient climate adaptation intervention because soil carbon favours optimal plant growth and a healthy rhizosphere. Many studies show that enhanced soil organic carbon (SOC) in the soil favours resilience and soil health. Enhanced SOC facilitates the retention of soil moisture and nutrients because it acts as a chelating agent which can retain these molecules that favour plant growth. The macromolecules of SOC enhance the soil structure, positively favour the soil hydraulic properties and regulate the physicochemical properties of the soil such as pH and electrical conductivity (EC).

FIGURE 10: Fertile soil through better CO₂ sequestration



Source: ICARDA, "Carbon sequestration for better soil and food security", 8 September 2021. https://www.icarda.org/media/news/carbon-sequestration-better-soil-and-food-security.

The enhanced SOC also favours the proliferation of soil micro- (bacteria and fungi) and macro-organisms (earthworms) that will positively affect the rhizosphere, making it a self-sustaining system that can withstand shocks and quickly recover from shocks. Thus, soil with enhanced SOC will have lower chances of degradation in terms of physical conditions (structure, hardness, etc.) and chemical conditions (salinity, pH, etc.). Overall, SOC is vital for the long-term resilience of the soil, and maintaining adequate SOC in the soil is vital for ecological sustainability (whether in natural systems or agroecosystems). In agroecosystems, because of continued monocropping and repeated tillage and other management activities, the chances of SOC decline are quite high. This is especially true for a climate change context where the increased tillage and exposure of SOC to decomposition outweighs the SOC replenishment due to carbon recycled from the biomass (residue) of the crop grown. Continued monocropping is likely to bring a similar kind of residue to the soil year after the year, which may not favour the build-up of SOC. On the other hand, a more diversified crop rotation scheme is likely to bring a diverse range of SOC constituents into the soil. SOC diversity occurs when the SOC has a wide variety of C:N ratios. Different plant residues have different C:N ratios. The higher the C:N ratios, the more difficult decomposition of the soil becomes. This in turn helps SOC to accumulate. Legumes have a lower C:N ratio and decompose rapidly.

Assuming that you are now familiar with most of the functionalities in APSIM, this exercise will focus on simulating how soil organic matter might change under a diversified system of crop rotation with the effects of climate change in the Jordan valley situation (irrigated). Further to this, we will create more simplified (undiversified crop rotation) scenarios using this one as the template. Unlike the previous exercises, in this exercise, more than one crop will be included in the simulations for 100 years and the outputs will be analysed with an annual time step. This exercise is a bit advanced and thus, it is strongly recommended that the user has thoroughly practice the previous two exercises before embarking on this one. The three scenarios that are conceptualized in this exercise are shown in the figure below.

Crop Diversification with a crop rotation pattern that repeats only every 4 years from 2000-2100.

Yea	r-1	Yea	ir-2	Yea	ir-3	Year-4		
Wheat	Soybean	Chickpea	Maize	Fababean	Maize	Barley	Soybean	

Simple Cereal-Cereal sequence done continuously from 2000-2100.

Yea	ır-1	Yea	nr-2	Yea	ır-3	Year-4		
Wheat	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize	

Simple Cereal-Legume sequence done continuously from 2000-2100.

Yea	ar-1	Yea	ar-2	Yea	ir-3	Year-4		
Wheat	Wheat Soybean Whe		Soybean	Wheat	Soybean	Wheat	Soybean	

B. Setting up the model and the necessary parameterizations

First, the APSIM interface is launched and an example simulation file already available in the APSIM database is selected. It will be used as a template simulation first and then the user will customize it for the specific needs of the current simulation rather than building from scratch.

• **<u>Click</u>** Open and browse for the APSIM example folder in the following file path.

C:\Program Files (x86)\APSIM710-r4158\Examples.

						xperiment.apsim								
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• Open the .apsim file called Continuous Wheat.apsim.

B- ☐ Diversified B- ☐ <u>Undiversified-Cereal-Cereal</u>	A Open						
		> OS (C:) > Program Files (x86) > APSIM710-r41	58 > Examples		<u>م</u> 5		
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	Desktop	Sutterfly Pea.apsim	3/22/2016 10:13 AM	APSIM File	12 KE	3	
	Documents	danopy.apsim	3/27/2018 4:12 PM	APSIM File	48 KE	3	
	Downloads	🖉 Centro.apsim	3/22/2016 10:13 AM	APSIM File	20 KE	3	
	h Music	🔀 Continuous Cotton.apsim	4/19/2017 9:58 AM	APSIM File	110 KE	3	
	Pictures	Continuous Maize and Weeds.apsim	3/27/2018 4:12 PM	APSIM File	57 KE	3	
		🜌 Continuous Maize Bimodal.apsim	3/27/2018 4:12 PM	APSIM File	55 KE	3	
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	- Herion	🌌 Continuous Wheat.apsim	5/10/2016 2:36 PM	APSIM File	36 KE		
		🖉 Defoliated Wheat.apsim	3/22/2016 10:13 AM	APSIM File	33 KE	3	
		Fffluent-irrigated Eucalynt Forest ansim			17 KF		

The user may already be familiar with the simulation tree and the components. If not, it is recommended that you revisit chapters 3 and 4 and familiarize yourself with the components. In this exercise, the first step involves two main alterations to the **Continuous Wheat** that was loaded as a template, and which will be customized for the needs of this exercise: (1) replace the meteorological file with the one relevant for our case study (Jordan) and (2) replace the soil profile.

To replace the meteorological file, click the met icon in the simulation tree.

First of all, save this as a new simulation and give it a New File Name.

Save this Continuous Wheat simulation as Jordan_CropDiversification.apsim.



The meteorological station for the example simulation will be shown as **Goondiwindi, Australia**. You may also notice that the dataset is for the period 1940 to 1989. Firstly, the user may replace this file with the meteorological file that was created for the site in Jordan (Dar Alaa) by browsing for it and opening it in the relevant location. In the input folder, the user should have should created a meteorological file for a location in Jordan valley from the RICCAR data, for the IPCC scenario RCP 8.5, prior to this exercise.

Load the Jordan valley meteorological file.

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	()		J/m^2) (oC)	(0C)	(mm)	
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	2000.00	2.00 3.00	9.15 16.51 9.77 16.68		0.02	
	2000.00	4.00	9.24 16.06		0.02	
	2000.00	5.00	9.24 16.35		4.03	
	2000.00	6.00	9.15 16.17		2.23	
	2000.00	7.00	9.48 16.92		2.21	
	2000.00	8.00	9.18 15.81		0.51	
	2000.00	9.00	9.25 16.51		0.15	
	2000.00	10.00	9.69 17.00		1.62	
	2000.00	11.00	9.51 16.25	6.59	0.33	
	2000.00	12.00	8.98 15.28	6.71	3.05	
	2000.00	13.00	8.83 14.56	6.33	4.55	
	2000.00	14.00	8.99 15.87	7.44	1.24	
	2000.00	15.00	9.62 15.60	6.10	5.01	

Rename the existing numerical experiment as Diversified.

When the selected file is loaded, it can be seen that the name **Dar Alaa** appears, which is a field location in the Jordan valley. When scrolling down through the data, it is possible to see that the data ranges from 2000 to 2070. In this exercise, the simulation of the long-term effects of climate change (from 2006 to 2070) will be done without the specific influence of atmospheric CO_2 concentration as APSIM has not yet parameterized the plant physiological mechanisms of CO_2 fertilization for all the crops.

The next step is to adjust the simulation clock. In APSIM, although the extent of climate data is longer, it is possible to simulate for subset periods, for example, 2010-2015 from a temporal domain of 2000 to 2070. We will, however, simulate for the entire duration in this case.

Adjust the simulation clock, setting the start date to 1/1/2000 and the end date to 12/31/2070.



The next step is to parameterize various components of the paddock. The user may replace the soil profile with the one we want for this location. There are two solutions to parametrize soil profile in APSIM. For this exercise, the user will continue using the soil profile that came along with the Continuous Wheat simulation and parameterize it to suit the Dar Alla (Jordan) conditions.



 Keep the cursor on the soil and right-click to rename the soil (optional). It is possible to also edit the auxiliary information on the right panel (by replacing the highlighted text). After this, click Save.

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Click the + beside the soil (renamed now as Dar Alla Soil) to expand the list. Several modules can be seen for parameterization of the soil characteristics. It is necessary to parameterize each of these sections to suit the soil characteristics of the study site.



The parameterizations of these modules are quite similar to the procedures mentioned in chapter 2 and may be followed if needed to suit your site soil parameterization. The most important is the soil module Water where plant water relations are parameterized.

• Click the Water icon to see the parameterizations available for various crops.

You can see that this soil is a 3 m deep soil profile that has 11 layers. Here the user can edit the values of soil-plant water relations specific to each layer as a function of the crop they plan to simulate. Let's edit this soil profile for the current modelling needs.

Click the Manage crops icon. We will delete some crops and add some new crops, as detailed below.

🐜 Manag	ge crops												
Depth (cm)	BD (g/cc)	AirDry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	KS (mm/day)	Wheat KL (/day)	Wheat XF (0-1)	soybean LL (mm/mm)	soybean PAWC 0.0	soybean KL (/day)	soybean XF (0-1)	Sorghum LL (mm/mm)
0-15	1.020	0.150	0.290	0.540	0.590		0.10	1.0		0.0			0.290
15-30	1.030	0.260	0.290	0.530	0.580		0.10	1.0		0.0			0.290
30-60	1.020	0.290	0.290	0.540	0.590		0.08	1.0		0.0			0.290
60-90	1.020	0.290	0.290	0.540	0.580		0.06	1.0		0.0			0.379
90-120	1.060	0.300	0.300	0.520	0.570		0.04	1.0		0.0			0.393
120-150	1.110	0.310	0.310	0.500	0.550		0.02	1.0		0.0			0.407
150-180	1.120	0.320	0.320	0.500	0.550		0.01	1.0		0.0			0.423
180-210	1.150	0.330	0.330	0.480	0.530		0.00	0.0		0.0			0.423
210-240	1.180	0.340	0.340	0.470	0.520		0.00	0.0		0.0			0.423
240-270	1.200	0.350	0.350	0.460	0.510		0.00	0.0		0.0			0.423
270-300	1.250	0.360	0.360	0.440	0.490		0.00	0.0		0.0			0.423

- Delete Sorghum, Lucerne and Perennial Grass and click OK.
- <u>Add</u> the missing crops soybean and fababean. We should now have 6 crops in the soil for the plant-water relations
 parameterizations. When a crop is deleted, you can see that its parametrization columns are also deleted (except for the pinkcoloured columns). When a crop (soybean in this case) is added, you may notice that a space is created for the crop. These
 columns need to be filled by the user for parameterizing the plant water relations.

Depth (cm)	BD (g/cc)	AirDry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	KS _ (mm/day))	Wheat XF (0-1)	soybean LL (mm/mm)	soybean PAWC 163.5	soybean KL (/day)	soybean XF (0-1)	Sorghum LL (mm/mm)	Sorghum PAWC 334.1
0-15	1.020	0.150	0.290	0.540	0.590	0	1.0	0.290	37.5	0.10	1.0	0.290	37.5
15-30	1.030	0.260	0.290	0.530	0.580	0	1.0	0.290	36.0	0.10	1.0	0.290	36.0
30-60	1.020	0.290	0.290	0.540	0.590	8	1.0	0.360	54.0	0.08	1.0	0.290	75.0
60-90	1.020	0.290	0.290	0.540	0.580	6	1.0	0.430	33.0	0.06	1.0	0.379	48.3
90-120	1.060	0.300	0.300	0.520	0.570	4	1.0	0.510	3.0	0.04	1.0	0.393	38.0
120-150	1.110	0.310	0.310	0.500	0.550	2	1.0	0.500	0.0	0.02	1.0	0.407	28.1
150-180	1.120	0.320	0.320	0.500	0.550	1	1.0	0.500	0.0	0.01	1.0	0.423	23.3
180-210	1.150	0.330	0.330	0.480	0.530	0	0.0	0.480	0.0	0.00	0.0	0.423	17.3
210-240	1.180	0.340	0.340	0.470	0.520	0	0.0	0.470	0.0	0.00	0.0	0.423	14.3
240-270	1.200	0.350	0.350	0.460	0.510	0	0.0	0.460	0.0	0.00	0.0	0.423	11.3
270-300	1.250	0.360	0.360	0.440	0.490	0	0.0	0.440	0.0	0.00	0.0	0.423	5.3

 First, simply <u>copy</u> the values of a similar crop and fill it in. Later the user may modify it. Here we will copy and paste the values of chickpea for soybean and save it.

Care should be taken to click and paste on the first cell ONLY while pasting the copied text (in other words, do not highlight all the four columns and paste).

 <u>Repeat</u> this action for the other crops and <u>click</u> the <u>Save</u> button. The user may use the visualization mode to adequately see how various plants behave in terms of water availability to determine optimal parameterization. This is beyond the scope of this exercise and the user may explore this further to make the most appropriate parameterizations.



Likewise, the user can parameterize other aspects of the soil such as **Soil Water, Soil Organic Matter, Analysis and Initial Nitrogen** to better suit their site characteristics. Most of these parameterizations and their vertical soil distribution can be visualized graphically in the panel below. Such visualization is good for efficient parameterization of the soil characteristics.

<u>Click Save.</u>

The next step is to parameterize the baseline **Soil Organic Matter** of the soil profile. This is a very important part of this exercise as the present chapter is focused on analysing the long-term change in SOM as influenced by a diversified cropping system.

- · Parameterize the Soil Organic Matter component exactly as shown below.
- <u>Visualize</u> how the user-defined parameterization affects the Soil Organic Matter distribution in the soil by using the graphs below the parameterization panel.
- Click Save.

j simulations ⊨…] Diversified	Root C:N ratio:	50	Depth (cm)	OC (Total %)	FBiom (0-1)	Finert (0-1)	ln (kg
i met	Root Weight (kg/ha):	100	0-15	0.450	0.025	0.400	(ng
clock	Soil C:N ratio:	12.5	15-30	0.700	0.020	0.600	
isummaryfile □ iii paddock	Erosion enrichment coefficient A:	7.4	30-60	0.890	0.015	0.800	2
🖃 🧬 Dar Alla Soil	Erosion enrichment coefficient B:	0.2	60-90	0.890	0.010	0.900	2
Initial water			90-120	0.770	0.010	0.950	2
SoilWater		120-150	0.450	0.010	0.950	14	
SoilOrganicMatter		150-180	0.270	0.010	0.950	1	
lnitial nitrogen			180-210	0.220	0.010	0.950	
SurfaceOrganicMatter			210-240	0.160	0.010	0.950	1
📔 fertiliser 💛 wheat			240-270	0.130	0.010	0.950	
🕀 🔂 Manager folder			270-300	0.120	0.010	0.950	1
🗄 📲 outputfile							

The next step is to move to other components of the **paddock**. In APSIM there are specific modules for various crop management topics such as the choice of **Surface Organic Matter, Crop, Fertilizer, Irrigation**, etc. Each of these modules needs to be listed under the paddock to be used in a simulation. Each of these modules can be given one or more specific management instructions, which are listed in the **Management folder**. For example, instructions can include explicitly adding crops and fertilizer.



First, let's edit the Surface Soil Organic Matter module.

• Change the C:N ratio of the initial residue to 100 and the Fraction of residue standing to 0.5.

Now we need to ensure that we have the right crop modules. We have seen in the initial description of the present chapter that we are going to have a diversified crop system involving several crops. To this end, we should have all the 6 crops listed in the crop rotation diagram: Wheat, Maize, Barley, Soybean, Fababean and Chickpea. In this simulation, the crop Wheat is already there.

As seen in the previous chapters, if the user wants to add or change the crop, it is possible to drag and drop the necessary crops from the panel below (selecting Standard, then Standardoolbox, then Crops) from the crops available in the APSIM environment.

- Simply drag and drop the crops into the paddock. You should then have all 6 selected crops in the paddock.
- <u>Click Save</u>.



After this step, the paddock should look like the screenshot shown on the next page.

BOX 7: The Genotype x Environment x Management (GEM) approach in crop modelling

In addition to climate, soil and management, the cultivar type of a given crop has a significant influence on the nature of the end results. Thus, it is not always easy to make generalizations about the impact of soil and climate alone on a given crop. Climate-smart crop improvement plays a major role in climate adaptation in addition to agronomical interventions. For example, with conventional wheat varieties even under irrigated conditions, yield might decline under climate change due to the vernalization requirements of wheat. With the availability of low vernalization requiring heat tolerant varieties, farmers may be able to adapt adequately. Thus, simulating wheat crop under future climates without thinking about varietal differences may be insufficient to draw conclusions.



Ensure that the paddock has the fertilizer module and the Irrigation module in addition to the 6 crop modules.

It is important to provide the necessary management instructions that will be plugged into these modules. Under the **Management Folder**, only two management actions can be seen: (1) **Crop Management** and (2) **Fertilize at Sowing**. These are crop-specific managers. In this case, they are currently specific to the wheat crop as wheat is already there. It is necessary to add a few more managers here. Please note that this exercise is a bit complicated in comparison to the previous one.

- <u>Add</u> two generic management actions (in other words, actions that are applicable to all the crops). We need to add 2 managers: <u>Rotations and Irrigate on sw deficit</u>. Both of these are available in the toolbox bar under the <u>Management folder</u>, in <u>Manager</u> (common tasks).
- Drag and drop both managers to the Management folder under the paddock.
- <u>Add</u> one non-generic manager called Harvesting rule. It is available in the toolbox bar under the Management folder, in Manager (common tasks).

Now there should be 5 managers in the Manager folder: Irrigation, Rotation, Crop Management, Fertilize at Sowing and Harvesting rule. Among these, the first two are applicable to all the crops in the rotation sequence while the other three are crop-specific.

<u>Rename</u> these 3 crop specific managers as shown below by right-clicking, selecting <u>Rename</u> and adding "wheat", to indicate that they are for the wheat crop.



Click Save.

The next step is a bit tedious and can easily go wrong. So, please be careful. Each of these three crop-specific managers needs to be replicated and renamed specifically for each of the six crops.

- <u>Create</u> a duplicate of a manager by simply dragging it and placing it in the <u>Manager folder</u> or right-clicking and creating a duplicate using the <u>duplicate this node</u> option. As soon as you do this, a duplicate will be instantly created with a default name.
- Rename this duplicate by right-clicking it and choosing the Rename option.
- Repeat this process for all 6 crops for all the three managers, such that a list of managers is created.

BOX 8: How to output a variable of a single layer or as the average of several layers?

In APSIM, the variables that are simulated for each soil layer (variables that are written in an "Array", appearing as "Array? YES") have to be explicitly denoted in the output file structure. Taking "ESW" as an example, if we put a square bracket "[]" soon after the variable, esw[], then the value that is written out will be the average of the entire soil profile. If not, values for each soil layer will be written out in the output file.



- Click Save.
- Click each of these managers and enter the parameters using the values displayed in table 7.

It is not practical to show the screenshot for each of the managers for each crop (as this would require 18 screenshots). Thus, data is provided in table 7 for the user to enter.

	Wheat	Maize	Chickpea	Fababean	Barley	Soybean
Sowing window start date	15 November	15 May	15 November	15 November	15 August	15 November
Sowing window end date	10 December	10 June	10 December	10 December	10 September	10 June
Must sow?	Yes	Yes	Yes	Yes	Yes	Yes
Amount of rainfall (mm)	10	0	5	2	5	0
NO. of days of rainfall	7	0	5	1	5	0
Min. allowable water (mm)	50	5	70	50	70	5
Name of the crop to sow	Wheat	Maize	Chickpea	Fababean	Barley	Soybean
Sowing density (plants/m2)	100	3	100	70	100	50
Sowing depth (mm)	30	50	30	30	30	30
Cultivar	Shatabdi	C79	Amethyst	Warda	Schooner	Davis
Crop growth class	Plant	Plant	Plant	Plant	Plant	Plant
Row spacing (mm)	250	1 000	250	250	250	500
		Fertilizer appli	ication			
Which module should the event come from?	Wheat	Maize	Chickpea	Fababean	Barley	Soybean
On which event fertilizer be applied?	Sowing	Sowing	Sowing	Sowing	Sowing	Sowing
Module to apply fertilizer	Fertilizer	Fertilizer	Fertilizer	Fertilizer	Fertilizer	Fertilizer
Amount of fertilizer (Kg/ha)	150	100	40	40	100	30
Fertilizer type	Urea N	Urea N	Urea N	Urea N	Urea N	Urea N
	н	arvesting param	eterization			
Name of the crop to harvest when ripe	Wheat	Maize	Chickpea	Fababean	Barley	Soybean

• Click Save after every step.

Now we will parameterize the two generic managers: Irrigation and Rotation.

· For the irrigation manager (Irrigate on sw deficit), simply enter the values shown in the screenshot below:

Description	Value
Imgate when soil water deficit reaches this amount (mm)	200
Imigation efficiency (0-1)	0.5
The earliest date irrigation will be applied (dd-mmm)	1-jan
The latest date inigation will be applied (dd-mmm)	31-dec
Amount of irrigation to apply (0 for deficit)	20
Module to apply the irrigation	Irrigation

The next step is to set up the **Rotations manager**, which is a generic manager (in other words, a manager that is applicable for all the crops) for a **Diversified** scenario. Setting up this manager is a bit challenging as it requires extreme care. The **Rotation manager** tells APSIM which crops to choose from the 6 crops listed and defines the rotational sequence. This means it defines how the 200 crops (in other words, 2 crops per year over 100 years) will be sequenced.
	Description	Value	
	Fallow options		
	Enter summer fallow name :	sf .	
and section	Enter summer fallow END date (dd-mmm) :	15-mar	
-	Enter winter fallow name :	wf	Right Click
	Enter winter fallow END date (dd-mmm) :	23-aug	Right Click
- ALTERNATION OF	Crop rotation sequence		
	Enter 1st crop :	ni	Edit mode
	Enter 2nd crop :	ni	Copy Ctrl+C
	Enter 3rd crop :	ni	Paste Ctrl+V
	Enter 4th crop :	ni	Delete Del
Contract of the	Enter 5th crop :	ni	Delete Del
	Enter 6th crop :	ni	Move down Ctrl+Down
Contraction of the local division of the loc	Enter 7th crop :	ni	Move up Ctrl+Up
-	Enter 8th crop :	ni	
	Enter 9th crop :	ni	
	Enter 10th crop :	This section should be edited	. It should be explicitly
of an	Enter 11th crop :	instructed to APSIM on how to	select each crop for ea
1 64 3	Enter 12th crop :	ol	
	Enter 13th crop :	season addressing the overal	crop rotation strategy
1 and	Enter 14th crop :	adopted in a given scenario.	
- del	Enter 15th crop :	ni	
- Alinetter	Enter 16th crop :	Right Click to get into edit mo	de

- Open the Rotation manager and see its content.
- Edit it by right-clicking when placing the cursor anywhere on the manager and selecting Edit mode.

Because in this case, there are 200 crops to be simulated (2 crops per year over 100 years) and the crops are different for each season, it is important that APSIM is clearly instructed on the sequencing of the crops. The sequence can be developed eternally in Excel and can be pasted here.

	Name	Туре	List items (CS	V) Description	Value
	SummerFallowNa	text	•	Enter summer fallow name :	sf
	SummerFallowEn	text	•	Enter summer fallow END date (dd-mmm) :	15-mar
	WinterFallowName	text	•	Enter winter fallow name :	wf
	WinterFallowEnd	text	•	Enter winter fallow END date (dd-mmm) :	23-aug
	category	category	•	Crop rotation sequence	
	crop1	crop	-	Enter 1st crop :	nil
	crop2	crop	-	Enter 2nd crop :	nil
	crop3	crop	•	Enter 3rd crop :	nil
	crop4	crop	•	Enter 4th crop :	nil
	crop5	crop	-	Enter 5th crop :	nil
	crop6	crop	-	Enter 6th crop :	nil
	crop7	crop	-	Enter 7th crop :	nil
and the second	crop8	crop	-	Enter 8th crop :	nil
	crop9	crop	•	Enter 9th crop :	it's important to select the
	crop10	crop		Enter 10th crop :	discolumns to be edited by
the second second	crop11	crop	-	Enter 11th crop :	
	crop 12	crop	-	Enter 12th crop :	selecting them from
000	crop 13	crop	•	Enter 13th crop :	🖬 below. There after, paste
for the a	crop 14	crop	•	Enter 14th crop :	the text from an external
Contraction of the local division of the loc	crop 15	crop	•	Enter 15th crop :	ⁿⁱ Excel sheet to here
in the second	crop 16	crop	-	Enter 16th crop :	nil
all the second	crop17	crop	-	Enter 17th crop :	nil
and the second	crop 18	crop	•	Enter 18th crop :	nil
and the second s	crop 19	crop	•	Enter 19th crop :	nil

In spreadsheets such as Microsoft Excel, it's easy to prepare long-time series that have a logical pattern. As an example, the following file was prepared in Microsoft Excel. This can be cut and pasted here using the procedure mentioned above. Below is an excerpt of a sequence that will be used for the **Diversified** scenario (see column N, highlighted in blue).

• Paste the sequence from the external spreadsheet into the Rotation manager.

BOX 9: Issues to consider: representing days in APSIM

In APSIM, care should be taken when entering the dates. They should be entered in dd-mmm format (for example, 07-apr, and not 7-Apr, 7-APR, or 07-APR).

	= =	Alignm	🖶 Merge &	. Center 👻	\$ ~ % Nu	9 €0 mber			mat as Cal	culation	Check (
F	G	н	1 1	L L	ĸ	Ι.	М	N	0	P	Q	
		Crop1	crop	Enter 1st o	crop:	wheat	wheat	wheat	W			
		Crop2	crop	Enter 2nd	crop :	soybean	maize	soybean	S			
		Crop3	crop	Enter 3rd	crop :	wheat	wheat	chickpea	W			
		Crop4	crop	Enter 4th	crop :	soybean	maize	maize	S			
		Crop5	crop	Enter 5th	crop :	wheat	wheat	fababean	W			
		Crop6	crop	Enter 6th	crop :	soybean	maize	maize	S			
		Crop7	crop	Enter 7th	crop :	wheat	wheat	barley	W			
		Crop8	crop	Enter 8th	crop :	soybean	maize	soybean	S			
		Crop9	crop	Enter 9th	crop :	wheat	wheat	wheat	W			
		Crop10	crop	Enter 10th	n crop :	soybean	maize	soybean	S			
		Crop11	crop	Enter 11th	n crop :	wheat	wheat	chickpea	w			
		Crop12	crop	Enter 12th	n crop :	soybean	maize	maize	S			
		Crop13	crop	Enter 13th	rop :	wheat	wheat	fababean	W			
		Crop14	crop	Enter 14th	rop :	soybean	maize	maize	S			
		Crop15	crop	Enter 15th	rop :	wheat	wheat	barley	w			
		Crop16	crop	Enter 16th	rop :	soybean	maize	soybean	S			
		Crop17	crop	Enter 17th	crop :	wheat	wheat	wheat	w			

After this sequence is pasted, the **Rotations** manager (in editing mode) should look like the screenshot below. Only crops 1 to 17 are visible in this window. In reality, there will be 200 crops but with the same sequence.

Name	Туре		List items (CSV)	Description	Value
category	category	•		Fallow options	
SummerFallowNa	text	-		Enter summer fallow name :	sf
SummerFallowEn	text	-		Enter summer fallow END date (dd-mmm) :	23-aug
WinterFallowName	text	-		Enter winter fallow name :	wf
WinterFallowEnd	text	-		Enter winter fallow END date (dd-mmm) :	10-mar
category	category	-		Crop rotation sequence	
Crop 1	сгор	-		Enter 1st crop :	wheat
Crop2	сгор	•		Enter 2nd crop :	soybean
Crop3	crop	-		Enter 3rd crop :	chickpea
Crop4	crop	-		Enter 4th crop :	maize
Crop5	crop	-		Enter 5th crop :	fababean
Crop6	crop	-		Enter 6th crop :	maize
Crop7	сгор	-		Enter 7th crop :	barley
Crop8	crop	-		Enter 8th crop :	soybean
Crop9	crop	-		Enter 9th crop :	wheat
Crop 10	сгор	-		Enter 10th crop :	soybean
Crop 11	crop	•		Enter 11th crop :	chickpea
Crop 12	crop			Enter 12th crop :	maize
Crop13	crop			Enter 13th crop :	fababean
Crop 14	crop	•		Enter 14th crop :	maize
Crop 15	crop	•		Enter 15th crop :	barley
Crop 16	сгор	-		Enter 16th crop :	soybean
Crop 17	crop	-		Enter 17th crop :	wheat

In the **no editing** mode, the Rotation manager will look like shown in the next page. Note that **start_of_day** is highlighted. This is required for the next step.

<u>Click Save</u>.

operties init star	t_of_day	
	Description	Value
	Fallow options	
	Enter summer fallow name :	sf
	Enter summer fallow END date (dd-mmm) :	23-aug
	Enter winter fallow name :	wf
	Enter winter fallow END date (dd-mmm) :	10-mar
	Crop rotation sequence	
	Enter 1st crop :	wheat
	Enter 2nd crop :	soybean
	Enter 3rd crop :	chickpea
	Enter 4th crop :	maize
	Enter 5th crop :	fababean
	Enter 6th crop :	maize
and the second	Enter 7th crop :	barley
	Enter 8th crop :	soybean
	Enter 9th crop :	wheat
	Enter 10th crop :	soybean
	Enter 11th crop :	chickpea
	Enter 12th crop :	maize
	Enter 13th crop :	fababean
and the second second	Enter 14th crop :	maize
and and	Enter 15th crop :	barley
all the second	Enter 16th crop :	soybean
and an all and and	Enter 17th crop :	wheat

So far, only the sequencing of the crops has been provided to APSIM. But it is necessary to explicitly instruct APSIM on how to choose the crop one after the other. For this, it is necessary to edit a piece of code with which one can interact with the core kernel of APSIM. For this, it is necessary to do the following.

 <u>Click</u> the start_of_day item on the top right corner as shown in the previous screenshot. The user can see a set of codes there.

It is necessary to add a lengthy piece of code in the space highlighted in the yellow below. It has a similar pattern from Crop 1 to Crop 200. It can be written by hand, but as it is too long for 200 crops. It is hence recommended that this piece of code be developed externally and pasted here. In Appendix 3, a programme written in C language is provided that can generate this code.

- Using this generated code, edit the code block in APSIM UI.
- Click Save and return to the paddock.



C. Setting up output variables and reporting frequencies

So far, the modelling environment and the necessary parameterizations have been set up. This lengthy and tedious process is now finalized. The following steps are to be followed to determine which variables to write out as outputs and the frequency of their reporting. This is a critical step, especially when we want to intercompare different simulations.

- · On the simulation window, click Variables under the outputfile module.
- In this simulation, you may <u>delete</u> the dd/mm/yy as date variable and <u>replace</u> it with Year. Find Year under the Clock on the right panel.
- Delete grain_size and ESW variables.
- Add another variable called oc in %. This refers to SOC. It can be seen under Dar Alla Soil.

Output file columns:	Variables to drag on	to grid:		
ear	Component filter:	Dar Alla Soil	>	✓ Search
20	Variable name nitrification nitrogenbalance no3 no3_min no3_transform_ne no3ppm num_fom_types oc org_c_pool org_n outflow_lat pond pond_evap profile_esw_depth profile_fesw	Yes No Yes Yes Yes No No	Units kg/ha kg/ha kg/ha % mm mm mm	Description Nitrogen moved by nitrification Nitrogen Balance Minimum allowable NO3 Net NO3 transformation Number of FOM types Organic carbon lateral flow out of the profile Surface ponding depth Evaporation from pond surface
	rock_p runoff	Yes No	mm	Runoff
	salb	No	0-1	bare soil albedo

Parentheses should appear when oc is listed in the output file column, as seen on the screenshot above. These parentheses have significance. In the variable listing under the Array column, you will see that the oc variable is listed as Yes. This means that APSIM simulates the oc percentage for each soil layer. In the case of Dar Alla Soil, we have 11 soil layers. What is needed is an average value taken from the 11 soils of the soil profile. For this reason, we put parentheses in the output file columns. If it is written as oc(3), It means APSIM will write out oc in the 3rd soil layer. Keep the reporting frequency as harvesting.

After all these steps click Save.

Now the Diversified scenario is complete.

<u>Collapse</u> the simulation tree of the entire Diversified scenario.

Now the user may create two replicas of this scenario and edit them to make different scenarios.

• **<u>Replicate</u>** the **Diversified** scenario twice (using the linked duplicates) modes. Refer to the previous chapters on how to do this.

Description	Value	
Fallow options		
Enter summer fallow name :	sf	
Enter summer fallow END date (dd-mmm)	23-aug	
Enter winter fallow name :	wf	
Enter winter fallow END date (dd-mmm) :	10-mar	
Crop rotation sequence		-
Enter 1st crop :	wheat	
Enter 2nd crop :	maize	
Enter 3rd crop :	wheat	
Enter 4th crop :	maize	
Enter 5th crop :	wheat	
Enter 6th crop :	maize	
Enter 7th crop :	wheat	
Enter 8th crop :	maize	
Enter 9th crop :	wheat	
Enter 10th crop :	maize	
Enter 11th crop :	wheat	
Enter 12th crop :	maize	continued
Enter 13th crop :	wheat	to
Enter 14th crop :	maize	200th crop
Enter 15th crop :	wheat	
Enter 16th crop :	maize	
Enter 17th crop :	wheat	
E + 401		v

Description	Value	
Fallow options		
Enter summer fallow name :	sf	
Enter summer fallow END date (dd-mmm) :	23-aug	
Enter winter fallow name :	wf	
Enter winter fallow END date (dd-mmm) :	10-mar	
Crop rotation sequence		
Enter 1st crop :	wheat	
Enter 2nd crop :	soybean	
Enter 3rd crop :	wheat	
Enter 4th crop :	soybean	
Enter 5th crop :	wheat	
Enter 6th crop :	soybean	
Enter 7th crop :	wheat	
Enter 8th crop :	soybean	
Enter 9th crop :	wheat	
Enter 10th crop :	soybean	
Enter 11th crop :	wheat	a a setting a set
Enter 12th crop :	soybean	continued
Enter 13th crop :	wheat	to
Enter 14th crop :	soybean	200th crop
Enter 15th crop :	wheat	
Enter 16th crop :	soybean	_
Enter 17th crop :	wheat	
E 1 101	- Y	

Change the default names of these two duplicates to Undiversified-Cereal-Cereal and Undiversified-Cereal-Legume.

As we already know, these three scenarios are linked and do the same things (although the names are different for the time).

- Unlink the Rotations manager in the two duplicate undiversified scenarios. Then customize each as shown on the previous page.
- Use the Excel sheet that was prepared earlier to fill in the necessary rotation definitions.

There is no need to remove any crop managers even if they are not used. For example in the **Undiversified-Cereal-Cereal** (wheatmaize) rotation scenario, crops such as soybean, chickpea, fababean and barley are not relevant. However, it won't affect the simulations because, in the **Rotation manager**, we instruct APSIM on which crop modules to use each season.

Now that we have prepared all three scenarios accurately, it is time to run APSIM for all three scenarios simultaneously.

Collapse all the simulation trees in the three scenarios. Then select all three scenarios using the Shift button and click Run.



Once the simulations have loaded to 100 per cent, the user can click on **outputfile** (not the subcomponents) to see the output file based on the configurations that we designed during the simulation set-up phase.

The user can plot this data using the procedure set out in chapter 2.

- Click the Graph button from the bottom panel.
- Select XY. Drag and drop it under the simulations folder.
- <u>Click</u> the + of the XY graph icon, you can see two child icons Plot and AspimFileReader. Through this, you can browse for your three output files. You will then be able to see these loaded into the Plot icon.

Diversified ou			
	Cereal-Cereal output of Cereal-Legume output		
indiversitieu.	Cereal-Legume output		
year	oc()	ApsimVersion	Title
-	oc() 1.247	ApsimVersion 7.10 r4158	Title Diversified output
2000	-		
2000 2001	1.247	7.10 r4158	Diversified output
2000 2001 2002	1.247 1.319	7.10 r4158 7.10 r4158	Diversified output
year 2000 2001 2002 2003 2004	1.247 1.319 1.456	7.10 r4158 7.10 r4158 7.10 r4158	Diversified output Diversified output Diversified output

- Click on the X variables to activate them (the background will turn pink) and click on the relevant year to list it in the pink area.
- <u>Click</u> on the Y variable to activate it (the background will turn pink) and <u>click</u> on yield so that it is listed in the Y variable box. Note that the X variable box will be white now.
- To visualize the graph, simply <u>click</u> on the XY icon.



D. Summary and conclusions of this exercise

A simulation of the long-term soil organic matter dynamics under the influence of a changing climate was carried out using the RICCAR data with various types of crop rotations. The investigation was done using three scenarios: (1) Undiversified crop rotation with a single cereal-legume system, (2) undiversified crop rotation with a single cereal-cereal system and (3) a fully diversified crop rotation with various crops considered in the rotation. While in all the scenarios the soil carbon initially increased and then slowly decreased with climate change, it was undoubtedly clear that a diversified crop rotation enhances soil carbon more than in an undiversified scenario. It was clear that wheat-legume rotation enhances soil carbon more than wheat-maize. Quantitatively, towards the end of the century, diversified cropping system will lead to a SOC level of around 2.2 per cent whereas the undiversified cropping system will have an average SOC level of around 1.8 per cent . The right step to climate smartness is hence to go for a more diversified crop rotation. RICCAR-based crop modelling activities are useful for exploring such adaptation/mitigation efforts.

7. SYNTHESIS AND CONCLUSIONS OF THIS TRAINING MANUAL

This training manual aimed to comprehensively train a non-expert user on how to use long-term location-specific climate data to drive a crop simulation model in order to understand the vulnerabilities under climate change. It also used a scenario-based approach to determine context-specific climate adaptation options. Comprehensive training material was developed for three solid test cases that are unique in terms of climate vulnerabilities, agroecosystem characteristics and climate adaptation interventions. Owing to its global popularity, the APSIM crop model was chosen to identify agricultural vulnerability under climate change and to identify the efficacy of the context-specific adaptation interventions. Starting with the characteristics of the RICCAR climate data at the outset, steps on how to develop input climate datasets using RICCAR in a format that the APSIM model requires were presented. Further to this, an elaborate discourse on how to create a soil profile or how to use an existing soil profile from the library of soil profiles and modify it to suit the modelling needs was provided. Furthermore, a walk-through of the APSIM UI was provided to familiarize the novice user with the main functionalities of the APSIM UI using an existing simulation example available in the APSIM interface software installation package. Here, an overview was provided on how to start a simulation, how to change the soil and management parameterizations, how to set up the output file and how to visualize the results. Following this, the simulation of crop responses to climate change was carried out using the RICCAR climate in three distinct contexts. Both conventional crop practices and "climate adaptation" practices were used as scenarios in these three cases. A step-by-step procedure was elaborated in the training material. The findings for the three contexts can be summarised as follows:

- In the rainfed context in Morocco, the study focused on how wheat yields could change under climate change in a rainfed scenario, taking Merchouche as an example. The modelling showed that rainfall in Morocco is significantly reducing under climate change and that this has an impact on the interannual wheat yields under the business-as-usual scenario (RCP 8.5) from 2020 onwards. Supplementary irrigation was projected to help reduce this effect dramatically from 2050 onwards. Therefore, if this climate adaptation is applied adequately, it's possible to maintain the current wheat productivity until 2080 without significant effects.
- 2. In the irrigated context in the lower Mesopotamian plains of Iraq, although temperature dramatically increases, modelling showed that the rainfall doesn't change substantially with climate change. This is consistent with other studies (CEOBS, 2021). As the system is irrigated, yield reduction is not critically affected if irrigated agriculture continues according to the current practices of using water from the Euphrates-Tigris river system. This, however, implies that the quantum of applied irrigated water keeps on increasing which has a toll on the water resources. This also creates secondary problems such as salinization. Thus, it is important to enhance water productivity as an apt climate adaptation intervention. Technologies such as drip irrigation should be applied in irrigated systems replacing the conventional flooding system.
- 3. In the irrigated Jordan valley, the mechanism of enhancing SOC was explored as a plausible pathway to climate mitigation and is also a good climate adaptation measure. Besides enhancing plant water relations and creating a conducive microclimate for plant growth, enhancing SOC has a multitude of benefits. RICCAR-based modelling studies showed that diversified crop rotation enhances SOC substantially unlike undiversified crop rotation practices. Diversified crop rotation significantly increases SOM. Relatively undiversified crop rotation with wheat-soybean was better than wheat-maize.

In the three case studies, three context-specific climate adaptations were evaluated against the conventional practices using an ex-ante analysis approach. In the rainfed scenario in Morocco, modelling showed that the scaling up of supplementary irrigation methods is a plausible and influential climate adaptation strategy that can sustain yields under a changing climate. In the case of irrigated agriculture, however, it was concluded that the scaling of techniques to enhance water productivity is the primary climate adaptation intervention in countries such as Iraq, the Sudan and Egypt where water is available through surface water resources. In Jordan, we identified that diversification of the crop rotation can facilitate enhanced SOC. These analyses were primarily conducted using yield as an indicator. However, other indicators such as soil organic matter, irrigation water applied, the impact of crop diversification, alternative crops and cultivars all could be examined further.

It should be acknowledged that the purpose of this manual is simply to train the non-expert user on how to use APSIM to test all these hypotheses to arrive at logical conclusions. We therefore encourage the user to test other scenarios more creatively. The climate adaptation measures examined here are not the only forms of climate adaptation. It is recommended that the user tests several climate-smart adaptation interventions and choose those that have the maximum benefits.

It is also suggested that applying these adaptation interventions should be done in a bundled form (not just one adaptation at a time) and that this bundled approach should be used as a context-specific package of practices while scaling out these technologies to adapt to a changing climate. In analysing the climate data and seeing the interannual yield variabilities, we stress the urgent need for context-specific climate adaptation and scaling out these packages using the enabling environments provided by the national policies. This is important to sustain the agrifood systems in these MENA countries under a changing climate. Table 8 provides a synthesis of what we learned from the three exercises and how such results could be interpreted for operational actions by the stakeholders.

This training material simply opens the doors to the novice user to explore the other immense possibilities that can be tested using the APSIM model. Thus, to gain expertise in this, it is highly recommended that the user further explores other aspects of APSIM.

TABLE 8: A synthesis of the findings made in the three test cases using RICCAR-based APSIM modelling

	Case study and context	Findings from RICCAR-based modelling	Message to scientists	Message to small-holder farmers	Message to policy makers
Climate adaptation	Morocco roi: Rabat-Salé-Ké- nitra - Rainfed system	Annual rainfall in Morocco significantly reduces under climate change. This pattern is expected to have a great impact on wheat yield or on rainfed agriculture in general from the year 2050 onwards to the extent that wheat yields may decline by as much as 50 per cent from the current yield value (4.2t/ha may reduce to as little as 1.3t/ha). Supplementary irrigation helps reduce this effect dramatically. If this climate adaptation measure is applied correctly, it's possible to maintain the current wheat productivity until 2080 without significant effects.	 Develop agronomic research on planning and implementing supplementary irrigation. Identify crop-specific supplementary irrigation needs and engage in capacity building in this area. Also, identify deficit irrigation strategies to protect a crop in the event of adverse drought conditions. 	 Select short duration crop varieties that can make use of the short rainy season. Early identification of plant water needs should be based on discussions with extension agents. Consider the consumptive water use for various crops based on the model outputs under the business-as-usual climate scenario. 	 Develop early warning systems and agroclimatic weather services to help farmers do proper planning. Invest in research and development on drought-tolerant varieties and market mechanisms for climate risks insurance. Adopt soil and land-use planning practices. Promote the capacity building of farmers and extension workers in the use of early warning systems and advisories on the application of supplementary/ deficit irrigation.
Climate adaptation	Iraq roi: Lower Mesopotamian plain - Irrigated system	In the LMP study location, modelling showed that the annual rainfall in Iraq doesn't change substantially with climate change (there is a slight increase in precipitation), but temperature dramatically increases. As the agricultural system is irrigated, yield reduction may not be evident as agriculture continues with water used from the Euphrates-Tigris river system. RICCAR-based analysis showed that the quantity of irrigation water increases with climate change. This means more water will be needed to have the same levels of food production. This has a great toll on the water resources of Iraq along with the rising population and also creates secondary problems such as salinization. Thus, it is important to enhance water productivity as a climate adaptation intervention. Technologies such as drip irrigated systems. Modelling showed that drip irrigation enhances water productivity as much as 10 times compared to the conventional irrigation methods. This is a significant gain of yield for a given amount of water applied.	 Develop cost- effective and low energy consuming drip irrigation systems running on solar power. Research alternative irrigation systems that enhance water productivity. 	 Adopt drip irrigation facilities. Avoid over- irrigation. Adopt agronomic interventions (such as using the ICARDA mechanized raised bed planter*) to enhance water productivity by 30 per cent . 	 Create enabling environments to foster water productivity as a theme of National Action/Adaptation Plans (NAPs). Facilitate access to financing mechanisms and loans to adopt drip irrigation facilities. Promote capacity building on water productivity under climate change. Transboundary water sharing needs to be planned in advance (20 years in advance) based on the projected climate scenarios optimizing it with each country's sectorial water requirements.

72

	Case study and context	Findings from RIC- CAR-based modelling	Message to scientists	Message to small-holders farmers	Message to policy makers
Climate adaptation	Jordan roi: Jordan val- ley - Irrigated system	Enhancing SOC offers pathways to climate mitigation. It is also a good climate adapta- tion measure. Besides enhancing plant water relations and creating a conducive microcli- mate for plant growth, enhancing SOC has a multitude of benefits. RICCAR-based mod- elling studies showed that diversified crop rotation enhances SOC substantially unlike undiversified crop rotation practices. In the case of undiver- sified crop rotation, it was found that continu- ous wheat-soybean is better than continuous wheat-maize. But this greatly depends on the cultivars used in the rotation and the amount of residue left in the soil after each crop. Conservation tillage is the solution if undiversified crop rotation is followed. This study also has relevance for adaptation-mitigation co-benefits. This is because enhanced SOC while fostering climate mitigation also helps the system to adapt to a changing climate by enhancing water conservation in the soil. It also favours soil nutrient conservation in the long run.	 Identify the best crop sequence for each location that optimizes SOC along with yield and farm income. Identify a crop sequence that enhances SOC but also soil nitrogen. Identify methods to enhance SOC in rainfed contexts and in saline soils of MENA. 	 Introduce legumes and maize in the crop rotation. Adopt conservation agriculture occasionally. Conduct occasional soil testing for nutrients and SOC with the help of extension agents. 	 Include SOC as an important factor in NAPs. Create carbon credits and carbon finance to encourage farmers. Reduce taxes to farmers growing diversified crops. Adopt policies on combating agricultural land degradation.

*The mechanized raised bed is an improved surface irrigation technique from ICARDA, which offers farmers a practical and more sustainable alternative to conventional irrigation systems. The technology has transformed irrigated wheat-based producing systems across Egypt, the Sudan and beyond, achieving significantly higher crop yields of 20-30 per cent while ensuring 25 per cent savings in irrigation water and reducing farming costs by about 20 per cent . For more information on this technique, see: ICARDA, "Mechanized raised bed technology for better wheat", n.d. For more information on carbon credits, see: BBC, "The regenerative revolution in food", 22 October 2021.

APPENDIX 1

A code written in R-language to extract climate data as a time series from the **RICCAR** format

library(ncdf4) # package for netcdf manipulation library(raster) # package for raster manipulation library(rgdal) # package for geospatial analysis library(ggplot2) # package for plotting library(RColorBrewer)

outputFile <- "E:\\ICARDA\\APSIM\\IQ_escwa_TMAX85.txt" #vear loop to go through each NETCDF file year <-seq(from=1999, to=2100, by=1) for(j in seq_along(year)) {

```
##
 PPT RCP 45
    ##
#
```

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP4.5\\CNRM\\pr_MNA-44_CNRM-CERFACS-CNRM-CM5_ historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP4.5\\EC-EARTH\\pr_MNA-44_ICHEC-EC-EARTH_</pre> historicalandrcp45_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP4.5\\GFDL\\pr_MNA-44_NOAA-GFDL-GFDL-ESM2M_</pre> historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

```
# nc_data1 <- nc_open(ncfile1)</pre>
# nc_data2 <- nc_open(ncfile2)</pre>
# nc_data3 <- nc_open(ncfile3)</pre>
# lon <- ncvar_get(nc_data1, "lon")</pre>
# lat <- ncvar_get(nc_data1, "lat", verbose = F)</pre>
# if (year[i] %% 4== 0) dn=366 else dn=365
# day=(1:dn)
# pr.array1 <- ncvar_get(nc_data1, "pr")</pre>
# pr.array2 <- ncvar_get(nc_data2, "pr")</pre>
# pr.array3 <- ncvar_get(nc_data3, "pr")</pre>
```

##

```
##
          PPT RCP 85
```

```
**********
```

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP8.5\\CNRM\\pr_MNA-44_CNRM-CERFACS-CNRM-CM5_ historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP8.5\\EC-EARTH\\pr_MNA-44_ICHEC-EC-EARTH_</pre> historicalandrcp85_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\PPT\\RCP8.5\\GFDL\\pr_MNA-44_NOAA-GFDL-GFDL-ESM2M_</pre> historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

nc_data1 <- nc_open(ncfile1)</pre>

nc_data2 <- nc_open(ncfile2)</pre>

nc_data3 <- nc_open(ncfile3)</pre>

```
# lon <- ncvar_get(nc_data1, "lon")</pre>
```

lat <- ncvar_get(nc_data1, "lat", verbose = F)</pre>

if (year[j] %% 4== 0) dn=366 else dn=365

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMIN\\RCP4.5\\CNRM\\tasmin_MNA-44_CNRM-CERFACS-CNRM-CM5_ historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMIN\\RCP4.5\\EC-EARTH\\tasmin_MNA-44_ICHEC-EC-EARTH_ historicalandrcp45_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMIN\\RCP4.5\\GFDL\\tasmin_MNA-44_NOAA-GFDL-GFDL-ESM2M_ historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

```
# nc_data1 <- nc_open(ncfile1)
# nc_data2 <- nc_open(ncfile2)
# nc_data3 <- nc_open(ncfile3)
# lon <- ncvar_get(nc_data1, "lon")
# lat <- ncvar_get(nc_data1, "lat", verbose = F)
# if (year[j] %% 4== 0) dn=366 else dn=365
# day=(1:dn)
# pr.array1 <- ncvar_get(nc_data1, "tasmin")
# pr.array2 <- ncvar_get(nc_data2, "tasmin")
# pr.array3 <- ncvar_get(nc_data3, "tasmin")
# #</pre>
```


#

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMIN\\RCP8.5\\CNRM\\tasmin_MNA-44_CNRM-CERFACS-CNRM-CM5_ historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMIN\\RCP8.5\\EC-EARTH\\tasmin_MNA-44_ICHEC-EC-EARTH_ historicalandrcp85_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMIN\\RCP8.5\\GFDL\\tasmin_MNA-44_NOAA-GFDL-GFDL-ESM2M_ historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

```
# nc_datal <- nc_open(ncfile1)
# nc_data2 <- nc_open(ncfile2)
# nc_data3 <- nc_open(ncfile3)
# lon <- ncvar_get(nc_data1, "lon")
# lat <- ncvar_get(nc_data1, "lat", verbose = F)
# if (year[j] %% 4== 0) dn=366 else dn=365
# day=(1:dn)
# pr.array1 <- ncvar_get(nc_data1, "tasmin")
# pr.array2 <- ncvar_get(nc_data2, "tasmin")
# pr.array3 <- ncvar_get(nc_data3, "tasmin")</pre>
```

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMAX\\RCP4.5\\CNRM\\tasmax_MNA-44_CNRM-CERFACS-CNRM-CM5_historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMAX\\RCP4.5\\EC-EARTH\\tasmax_MNA-44_ICHEC-EC-EARTH_
historicalandrcp45_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming
input netcdf file with year loop</pre>

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMAX\\RCP4.5\\GFDL\\tasmax_MNA-44_NOAA-GFDL-GFDL-ESM2M_ historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

```
# nc_data1 <- nc_open(ncfile1)
# nc_data2 <- nc_open(ncfile2)
# nc_data3 <- nc_open(ncfile3)
# lon <- ncvar_get(nc_data1, "lon")
# lat <- ncvar_get(nc_data1, "lat", verbose = F)
# if (year[j] %% 4== 0) dn=366 else dn=365
# day=(1:dn)
# pr.array1 <- ncvar_get(nc_data1, "tasmax")
# pr.array2 <- ncvar_get(nc_data2, "tasmax")</pre>
```

pr.array2 < noval_get(nc_data2, 'tasmax')
pr.array3 <- ncvar_get(nc_data3, "tasmax")</pre>

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMAX\\RCP8.5\\CNRM\\tasmax_MNA-44_CNRM-CERFACS-CNRM-CM5_ historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMAX\\RCP8.5\\EC-EARTH\\tasmax_MNA-44_ICHEC-EC-EARTH_ historicalandrcp85_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TMAX\\RCP8.5\\GFDL\\tasmax_MNA-44_NOAA-GFDL-GFDL-ESM2M_ historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

```
nc_data1 <- nc_open(ncfile1)
nc_data2 <- nc_open(ncfile2)
nc_data3 <- nc_open(ncfile3)
lon <- ncvar_get(nc_data1, "lon")
lat <- ncvar_get(nc_data1, "lat", verbose = F)
if (year[j] %% 4== 0) dn=366 else dn=365
day=(1:dn)
pr.array1 <- ncvar_get(nc_data1, "tasmax")
pr.array2 <- ncvar_get(nc_data2, "tasmax")
```

```
pr.array3 <- ncvar_get(nc_data3, "tasmax")
```

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TAS\\RCP4.5\\CNRM\\tas_MNA-44_CNRM-CERFACS-CNRM-CM5_ historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TAS\\RCP4.5\\EC-EARTH\\tas_MNA-44_ICHEC-EC-EARTH_
historicalandrcp45_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming
input netcdf file with year loop</pre>

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TAS\\RCP4.5\\GFDL\\tas_MNA-44_NOAA-GFDL-GFDL-ESM2M_ historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

nc_data1 <- nc_open(ncfile1)</pre>

nc_data2 <- nc_open(ncfile2)</pre>

```
# nc_data3 <- nc_open(ncfile3)</pre>
```

- # lon <- ncvar_get(nc_data1, "lon")</pre>
- # lat <- ncvar_get(nc_data1, "lat", verbose = F)</pre>
- # if (year[j] %% 4== 0) dn=366 else dn=365
- # day=(1:dn)
- # pr.array1 <- ncvar_get(nc_data1, "tas")</pre>
- # pr.array2 <- ncvar_get(nc_data2, "tas")</pre>
- # pr.array3 <- ncvar_get(nc_data3, "tas")</pre>

```
# outputfilepath_mn <- "E:\\ICARDA\\RICCAR_processing\\IRAQ\\0.43\\TAS45\\TAS_RCP45_AVG_"
```

outputfilepath_sd <- "E:\\ICARDA\\RICCAR_processing\\IRAQ\\0.43\\TAS45\\TAS_RCP45_SD_"</p>

ncfile1 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TAS\\RCP8.5\\CNRM\\tas_MNA-44_CNRM-CERFACS-CNRM-CM5_ historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile2 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TAS\\RCP8.5\\EC-EARTH\\tas_MNA-44_ICHEC-EC-EARTH_ historicalandrcp85_r12i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

ncfile3 <- file.path(paste("E:\\ICARDA\\RICCAR_data\\TAS\\RCP8.5\\GFDL\\tas_MNA-44_NOAA-GFDL-GFDL-ESM2M_ historicalandrcp85_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_",year[j],"_", year[j],".nc",sep="")) #renaming input netcdf file with year loop

nc_data1 <- nc_open(ncfile1)</pre>

nc_data2 <- nc_open(ncfile2)</pre>

nc_data3 <- nc_open(ncfile3)</pre>

lon <- ncvar_get(nc_data1, "lon")</pre>

lat <- ncvar_get(nc_data1, "lat", verbose = F)</pre>

if (year[j] %% 4== 0) dn=366 else dn=365

day=(1:dn) #day loop within a single netcdf file

pr.array1 <- ncvar_get(nc_data1, "tas")</pre>

pr.array2 <- ncvar_get(nc_data2, "tas")</pre>

```
# pr.array3 <- ncvar_get(nc_data3, "tas")</pre>
```

outputfilepath_mn <- "E:\\ICARDA\\IRAQ-ETBasin\\TAS85\\TAS_RCP45_AVG_"

```
# outputfilepath_sd <- "E:\\ICARDA\\RICCAR_processing\\IRAQ\\0.43\\TAS85\\TAS_RCP85_SD_"
```

##^^^^^^^^

```
for(i in seq_along(day)) {
    pr.slice1 <- pr.array1[, , i]
    pr.slice2 <- pr.array2[, , i]
    pr.slice3 <- pr.array3[, , i]</pre>
```

```
conne1 <- file.path(paste(outputfilepath_mn,year[j], "_", day[i],".bin",sep=""))
conne2 <- file.path(paste(outputfilepath_sd, year[j], "_", day[i],".bin",sep=""))</pre>
```

r1 <- raster(t(pr.slice1), xmn=min(lon), xmx=max(lon), ymn=min(lat), ymx=max(lat), crs=CRS("+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs+ towgs84=0,0,0"))

r2 <- raster(t(pr.slice2), xmn=min(lon), xmx=max(lon), ymn=min(lat), ymx=max(lat), crs=CRS("+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs+ towgs84=0,0,0"))

r3 <- raster(t(pr.slice3), xmn=min(lon), xmx=max(lon), ymn=min(lat), ymx=max(lat), crs=CRS("+proj=longlat +ellps=WGS84 +datum=WGS84 +no_defs+ towgs84=0,0,0"))

r1 <- flip(r1, direction='y') r2 <- flip(r2, direction='y') r3 <- flip(r3, direction='y') meanxx <- (r1+r2+r3)/3

For REGIONAL AOI DEFINITION

ss <- extent(42.441635608457545,45.86715593581527,32.37278315907344,35.165326904202024) # writeRaster(meanxx, filename =conne1, datatype='FLT4S', format="raster",overwrite=TRUE) roundDigits <- 3

For LOCAL pixel extraction #alpha <- extract(meanxx, SpatialPoints(cbind(45.398, 31.593)))

For REGIONAL AOI extraction
alpha <- mean(extract(meanxx, ss))
alpha <- extract(meanxx, ss, fun = mean, na.rm = TRUE)</pre>

write.table(alpha, outputFile, append=TRUE, row.names=FALSE,col.names=FALSE)

}

nc_close(nc_data1) nc_close(nc_data2) nc_close(nc_data3)

}

APPENDIX 2

Calculation of surface radiation using basic climate data

When no estimates of solar radiation are available to run the simulations, the only possibility is to model the solar radiation, as it is an essential input to run most of the crop simulation or hydrological models. The basic idea is to first simulate the extraterrestrial radiation above the atmosphere assuming that the sunspot cycles are not affecting the solar irradiance. The extraterrestrial radiation (Ra) for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year, using the following formula:

$$R_a = \frac{24*60}{\pi} G_{sc} \cdot d_r \cdot \left[\omega \cdot Sin(\varphi) \cdot Sin(\delta) + Cos(\varphi) \cdot Cos(\delta) \cdot Sin(\omega)\right]$$

- Ra extraterrestrial radiation (MJ m-2 day-1).
- Gsc solar constant = 0.0820 (MJ m-2 min-1).
- dr inverse relative distance Earth-Sun.
- ω sunset hour angle (rad).
- φ latitude (rad).
- δ solar declination (rad).
- J Julien day of the year.

The inverse relative Earth-Sun distance (dr) can be calculated as a function of the day of the year (J) as:

$$d_r = 1 + 0.033$$
. Cos $\left[\frac{2\pi}{365}J\right]$

The Solar declination angle (δ) can be calculated as a function of day of the year (J) as:

$$\delta = 0.409$$
. Sin $\left[\frac{2\pi}{365}J - 1.39\right]$

The sunset hour angle (ω) can be approximated as a function of declination angle and latitude of the location as:

$$\omega = \frac{\pi}{2} - Arctan \left[\frac{-Tan(\varphi) \cdot Tan(\delta)}{\sqrt{\left[1 - \left[Tan(\varphi)\right]^{2} \left[Tan(\varphi)\right]^{2}\right]}} \right]$$

All the angles are expressed in Radians (rad) and can be calculated in degrees as:

$$Radians = \frac{\pi}{180} Degrees$$

After calculating the extraterrestrial radiation, we calculate the surface incoming radiation following the method of Hargreaves and Samani (1982):

$$R_{s} = \left(k_{Rs}\left[T_{max} - T_{min}\right]^{0.5}\right) \cdot R_{a}$$

APPENDIX 3

A code to generate the required instructions for modifying the APSIM Rotation Manager

This code may be compiled in any C compiler to generate a text file that contains the necessary code that can be replaced in the yellow highlighted area in the Rotation manager of chapter 5.

```
#include "stdio.h"
#include "stdlib.h"
main()
{
FILE *fout;
fout=fopen("E:\\ Rotation_Looper.txt","wt");
int year;
for(year=1; year<=200;year++) //year loop
{
fprintf(fout,"elseif (NextCropIndex =%d ) then\n", year);
fprintf(fout,"NextCrop = '[crop%d]'\n", year);
}
fclose(fout);
}</pre>
```

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ENDNOTES

- 1. For more information about RICCAR, see: United Nations Economic and Social Commission for Western Asia (ESCWA) et al. 2017. Arab Climate Change Assessment Report Main Report. Beirut, E/ESCWA/SDPD/2017/RICCAR/Report.
- 2. For more details, see: Tomaszkiewicz, Marlene (2021). RICCAR Climate Modelling Updates: Mashreq Domain. ArabCOF June 2021.
- 3. In computing, endianness is the order or sequence of bytes of a word of digital data in computer memory. Endianness is primarily expressed as big-endian (BE) or little-endian (LE). A big-endian system stores the most significant byte of a word at the smallest memory address and the least significant byte at the largest. A little-endian system, in contrast, stores the least-significant byte at the smallest address.
- 4. Supplementary irrigation is a simple but highly effective technology that allows farmers to plant and manage crops at the optimal time without having to wait for unpredictable rainfall.

Although several downscaled and bias-corrected climate datasets are available, their operational use is too challenging for non-expert users. To make the data meaningful, it must be used as inputs into crop models to identify and analyse context-specific climate-smart agriculture (CSA) solutions. This often presents technical challenges for the users. To overcome user challenges, and to support increased utilization of the data, a training manual on the use of the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) data in a common crop simulation model is presented.

The main objective of the present training manual is to develop step-by-step instructional materials for agriculture extension agents on how to integrate and utilize long-term climate data in a typical and commonly used crop model such as the Agricultural Production Systems Simulator (APSIM) and identify a Context-Based Climate Adaptation Option (CBCAO), in three unique circumstances. Firstly, taking Morocco as an example, the manual demonstrates yield gap evolution under climate change in a rainfed agroecosystem and the relative effects of two Intergovernmental Panel on Climate Change (IPCC) scenarios, representative concentration pathways (RCPs) 8.5 and 4.5. Additionally, supplementary irrigation is applied as a key climate adaptation measure in a location suffering from increasing droughts to augment water supply in arid weather conditions. Secondly, taking Irag as an example, the manual demonstrates changes in water productivity and yield dynamics in an arid but irrigated agroecosystem to show how judicious irrigation techniques, as opposed to conventional irrigation as a climate adaptation measure, can enhance water productivity while also maintaining and possibly maximizing yield. Thirdly, taking Jordan as an example of a semi-arid agroecosystem, the of alternate resilient crops) as a key climate adaptation measure and assesses impacts on soil carbon sequestration.

