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Crop yield modelling supporting the Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate

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Contents

Figures

Tables

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[1] **FAO (Food and Agriculture Organization of the United Nations).** 2020. *Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate*. Rome. https://www.fao.org/united-arab-emirates/projects/en/

Foreword

The Abu Dhabi Emirate faces significant challenges in achieving sustainable local food production because of its extremely dry climate, poor soil quality, and limited availability of high-quality water. Consequently, the country has become highly dependent on food imports. Addressing these challenges requires innovative and science-based strategies to enhance domestic agricultural production, optimize resource efficiency, and secure long-term food availability.

Recognizing the critical need for action, ADAFSA, in close partnership with FAO, initiated efforts to strengthen agriculture through improved data-driven decision-making. Under the "Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate", (hereafter, the Master Plan), this partnership has contributed to the development of a comprehensive decision support tool for evidence-based agricultural planning and management. The tool integrates the results from crop yield simulations and crop suitability mapping, providing essential guidance on optimal crop selection, resource allocation and farm management practices in the Abu Dhabi Emirate.

The process began with the compilation and analysis of data collected from various farms and research stations. Models were developed and integrated to assess the potential and attainable yields for various crops based on specific local conditions, including climate, soil properties and water availability. Accordingly, in preparing the Master Plan, simulations were conducted for 51 different crops – ranging from fruits and vegetables to annual crops and perennial grasses – across 181 representative sites in Abu Dhabi. The resulting insights formed the foundation for farm classification, regional agricultural zoning and informed economic planning.

Furthermore, through advanced modelling techniques, this initiative has contributed to identifying opportunities and critical constraints for each crop, providing robust, science-based recommendations for agricultural development. These insights support strategic decisions aimed at enhancing food production, reducing reliance on food imports, and promoting sustainable agricultural practices.

FAO and ADAFSA remain firmly committed to enhancing innovation, improving resource-use efficiency and promoting climate-resilient agricultural practices. We extend our gratitude to all stakeholders, particularly ICARDA and IIASA, as well as other contributors involved in this important work, and are confident that our collective efforts will contribute to a more productive, sustainable and food-secure future for Abu Dhabi.

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Abbreviations

ADAFSA	Abu Dhabi Agriculture and Food Safety Authority
Agron	agronomy
ANOVA	analysis of variance
APSIM	Agricultural Production Systems sIMulator
APSIMx	Agricultural Production Systems sIMulator (next generation)
AquaCrop	crop-water productivity model
Class	soil classification
DST	decision support tool
ECe	soil electrical conductivity
ECw	water electrical conductivity
ETc	crop evapotranspiration
FAO	the Food and Agriculture Organization of the United Nations
GDD	total length of crop cycle in growing degree days
GH	greenhouse
ICARDA	International Center for Agricultural Research in the Dry Areas
ICBA	International Center for Biosaline Agriculture
ID_AGR	unique ID corresponding to each farm
IIASA	International Institute for Applied Systems Analysis
Irrig	irrigation
Kc	crop coefficient
LAI	leaf area index
LF	leaching fraction
MC	soil moisture content
OF	open field
PAWC	plant available water content
Rad	radiation
RF	reduction factor
RH	air relative humidity
SCRUM	simple crop resource uptake model
SH	shade house

SN	scientific name
SNG	Sub-Regional Office for the Gulf Cooperation Council States and Yemen
SOM	surface organic matter
ST_Class	terrain class
T	temperature
TOC	total organic carbon
UN	United Nations
VPD	vapour pressure deficit
WP	water productivity
WUE	water use efficiency
Ya	actual yield
Yatt	attainable yield
Ycalib	calibrated yield
Yg	yield gap
Yp	potential yield

Executive summary

The Abu Dhabi Emirate faces significant agronomic challenges owing to its hyper-arid climate, poor soil fertility and limited water resources. Addressing these issues is essential to enhance food security and sustainable agriculture. Crop yield simulation and suitability mapping are essential tools for assessing agricultural potential, guiding resource allocation and supporting evidence-based land-use planning to optimize productivity and sustainability in the agricultural sector of the Abu Dhabi Emirate.

In collaboration with FAO, ICARDA, and IIASA, ADAFSA initiated the "Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate" (FAO, 2020)[2] to enhance agricultural planning. The project consists of several integrated modules, including yield simulation, farm typology classification, agroecological zoning, and economic modelling based on farm efficiency assessments, productivity frontier analyses and cost–benefit optimization. Together, these modules support the development of a comprehensive decision support tool (DST) for informed agricultural planning and management. One of the key components of a DST is crop yield modelling and crop suitability assessments. Accordingly, this study was initiated to provide an assessment of the attainable and potential yields of major crops by analysing crop responses to key growth limiting factors (reduction factor [RF]) under both open field (OF) conditions and controlled-environment conditions (greenhouse [GH] and shade house [SH]) at specific geographic locations.

The methodology consisted of the following key steps.

1. A total of 51 major crops were selected and evaluated across three production systems: OF, GH, and SH. Two research sites and 181 representative soil classifications across Abu Dhabi Emirate were identified for detailed yield assessments.
2. The Agricultural Production Systems sIMulator (next generation) (APSIMx) (APSIM Initiative, n.d.)[3] model simulated the potential and attainable yields for key vegetables (aubergine, cabbage, tomato, cucumber, marrow, sweet pepper, and lettuce) and date palm using detailed experimental data. The AquaCrop (FAO, n.d.)[4] model was employed for the remaining 43 crops with limited data.
3. Location-specific data was compiled, including farm, weather, soil, management, and crop-specific data.
4. The validated data were processed into compatible input files required for the models.
5. Yield simulations were conducted using the APSIMx and AquaCrop models estimated the potential and attainable yield and RF associated with critical growth-limiting factors.

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[2] **FAO (Food and Agriculture Organization of the United Nations).** 2020. *Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate*. Rome. https://www.fao.org/united-arab-emirates/projects/en/

[3] **APSIM (Agricultural Production Systems sIMulator) Initiative.** (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

[4] **FAO (Food and Agriculture Organization of the United Nations)**. (n.d.). *AquaCrop: FAO's crop water productivity model*. Rome. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

The results showed that farm-level potential and attainable yields varied across the 51 evaluated crops in Abu Dhabi, and were influenced primarily by crop type, climate and biophysical constraints. For tomatoes, the simulated potential yield ranged from 139 tonnes per hectare (t/ha) (OF) to 197 t/ha (GH), whereas the attainable yield declined dramatically under saline conditions, falling to 11 t/ha (OF) to 15 t/ha (GH). The RFs highlighted soil and water salinity as the most significant constraints, although other variables also influenced crop productivity. Among the assessed crops, strawberries exhibited high sensitivity to salinity, whereas date palms demonstrated strong tolerance.

The results from the selected simulation sites were extrapolated to all operational farms across Abu Dhabi Emirate through crop suitability analysis, creating a crop suitability mapping database. These findings contribute to the broader objective of designing a decision support tool for sustainable agriculture, enabling data-driven planning and the optimization of agricultural practices.

1. Introduction

The agricultural sector of the Abu Dhabi Emirate operates under challenging agroedaphic, climatic and environmental conditions, characterized by a hyper-arid climate, poor soil fertility and limited water resources of compromised quality. These constraints have limited local agricultural output, necessitating the import of over 90 percent of the country’s food supply (Abdelfattah, 2013). This dependence on imports not only strains economic resources, but also underscores the need to enhance domestic agricultural productivity. To address this challenge, the Government of Abu Dhabi – through initiatives such as the agricultural expansion plans detailed by the Abu Dhabi Agriculture and Food Safety Authority (ADAFSA) (ADAFSA, 2012) – have aimed to strengthen food security and self-sufficiency by adopting advanced and intensive agricultural methods.

The ADAFSA has undertaken a series of agronomic studies aimed at building a comprehensive soil, farm, crop, and water database, enhancing the understanding of crop water productivity and improving agricultural water management across numerous farms in the emirate. As part of this effort, soil survey data from 310 locations were collected and analysed, focusing on both the physical and chemical characteristics of the soil. In parallel, detailed farm surveys were conducted to gather information on operational practices, farm size, planted crop varieties, water sources, water quality, and management strategies.

To complement these surveys, experimental studies were carried out to evaluate the physiological responses of crops under diverse environmental and management conditions. These included field and controlled trials assessing crop performance, water use efficiency (WUE) and evapotranspiration (ET) in key crops, such as date palms, providing critical insights into how crops responded to the prevailing agricultural settings in the region.

With the objective of making better use of existing data and capacities and building upon past and ongoing efforts, ADAFSA requested technical support from the Food and Agriculture Organization of the United Nations (FAO) for the preparation of the “Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate” (hereafter, the Master Plan), implemented under Project GCP/UAE/013/AFS (FAO, 2020). This project aims to integrate scientific evidence into decision-making processes to optimize agricultural land use and resource allocation.

A central component of the initiative was the development of a decision support tool (DST) designed to assess crop suitability, guide investments in agricultural production systems and improve farm management efficiency. The development of the DST was based on the integration of multiple modules and data sources while following a structured workflow (Figure 1) and bringing together biophysical, climatic and farm-level data, along with their key variables and components (Table 1), to support evidence-based agricultural planning throughout the DST development process.

The integrated processes included:

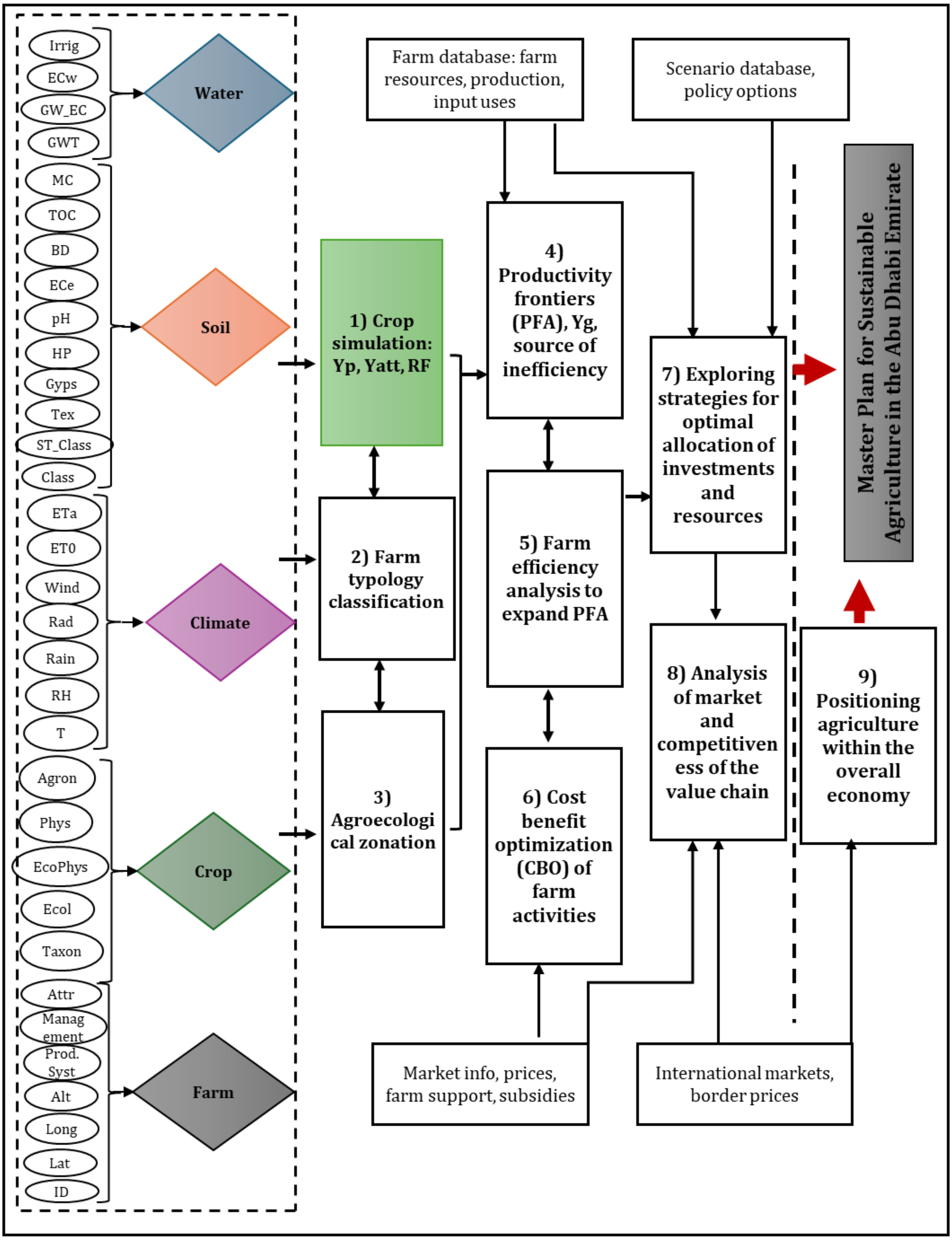
- a georeferenced agricultural database including data for 25 000 farms (encompassing more than 1 000 variables per farm) and 18 Geographic Information System (GIS)-based agroecological zone (AEZ) classes for sustainability analyses;
- sixteen farm typology classes and four productivity frontier analyses (to identify key inefficiencies and potential for sector and homogenous farm-type transformation);
- crop suitability estimates and yield modelling of 51 crops, resulting in crop suitability maps that show potential and attainable yields at the farm level; and
- cost–benefit optimization models covering analysis for scenarios and assessment of farmers' behaviours related to policy options and optimal crop mix at the farm level.

Special attention was paid to strategic resource allocation, exploring investment scenarios and policy options to maximize agricultural output while ensuring long-term sustainability. Additionally, the analysis of market conditions and value chain competitiveness ensured that agricultural production would remain both economically viable and competitive. Furthermore, complementary studies addressed the water–soil–energy nexus, subsidy, agricultural research and design (R&D), and agricultural extension strategic reforms.

Finally, the framework was supported by enabling environment assessment, stakeholder consultations and theories of change to ensure that agricultural policies would remain adaptive and resilient. This comprehensive and data-driven approach therefore establishes a sustainable agricultural system for Abu Dhabi Emirate, fostering food security, economic viability and environmental resilience.

Building on this strategic framework, the present report details the methodological approach applied to farm-level crop yield simulations. The approach utilized the Agricultural Production Systems sIMulator (next generation) (APSIMx) (APSIM Initiative, n.d.) and AquaCrop (FAO, n.d.), two well-established crop modelling tools to assess yield performance and reduction factors (RFs) for 51 major crops, including vegetables, annual crops, perennials, fruit trees, and grasses and shrubs, across three production systems: open field (OF), greenhouses (GH), and shade house (SH). The simulations were conducted using detailed experimental data from Al Salamat and the International Center for Biosaline Agriculture (ICBA) (EAD, 2018b, 2019; Al-Muaini *et al*., 2019a, 2019b, 2019c, 2019d) and were subsequently expanded to 181 representative sites across Abu Dhabi Emirate. The analysis concludes with recommendations for high-potential uncultivated crops suitable for the agroclimatic conditions of the region.

Figure 1. Workflow and key steps in the development of the decision support tool (DST) for the master plan for sustainable agriculture in Abu Dhabi Emirate



Note: See Table 1 for an explanation of the abbreviations.

Source: Authors' own elaboration.

Table 1. Definitions of abbreviations used in the workflow chart

No.	Category	Parameter	Abbreviation	Units
1	Farm	unique ID corresponding to each farm	**ID_AGR**	–
2	Farm	Latitude	**Lat**	Decimal degrees (DD)
3	Farm	Longitude	**Long**	DD
4	Farm	Altitude	**Alt**	m
5	Farm	Production system (OF, GH or SH)	**Prod.Syst**	–
6	Farm	Attributes: area (ha), crop variety and density, actual yield (kg/ha)	**Attr**	–
7	Crop	Taxonomy	**Taxon**	–
8	Crop	Agronomy	**Agron**	–
9	Crop	Ecology	**Ecol**	–
10	Crop	Physiology	**Phys**	–
11	Crop	Ecophysiology	**EcoPhys**	–
12	Climate	Radiation (daily)	**Rad**	MJ/m^2
13	Climate	Rain (daily)	**Rain**	mm
14	Climate	Temperature (daily)	**T**	°C
15	Climate	Air relative humidity (daily)	**RH**	%
16	Climate	Wind (daily)	**Wind**	m/s
17	Climate	Reference potential evapotranspiration (daily)	**ET0**	mm
18	Climate	actual evapotranspiration (daily)	**ETa**	mm
19	Soil	Soil classification (soil great group, soil subgroup, WRB soil type)	**Class**	–
20	Soil	Terrain class (such as calcids to psamments)	**ST_Class**	–
21	Soil	Hardpan	**HP**	–
22	Soil	Gypsum content	**Gyps**	%
23	Soil	Texture (clay, silt and sand)	**Tex**	%
24	Soil	moisture content	**MC**	%
25	Soil	bulk density	**BD**	g/cm^3
26	Soil	total organic carbon	**TOC**	%
27	Soil	soil salinity	**Ece**	dS/m
28	Soil	soil pH	**pH**	–
29	Water	Irrigation	**Irrig**	mm/day

No.	Category	Parameter	Abbreviation	Units
30	Water	Water electrical conductivity	**ECw**	dS/m
31	Water	Groundwater electrical conductivity	**GW_EC**	dS/m
32	Water	Ground water table	**GWT**	m
33	Management	Fertilizer schedule	**Fert_Sch**	kg/ha/day
34	Management	Irrigation schedule	**Irrig_Sch**	mm/day
35	Management	Leaching fraction	**LF**	%

Note: OF = open field, GH = greenhouse, and SH = shade house.

1.1. Objectives

This study aimed to assess crop suitability by simulating the potential and attainable yields and analysing crop responses to key growth-limiting factors across 51 crops at 181 sites (170 farms and 11 additional points) in Abu Dhabi Emirate. Crop suitability results are intended to be used to support land use optimization, enhance crop productivity and support sustainable agricultural planning.

The results from this process are reflected in the four appendices.

1.2. Data sources

The data required for this study were collected from multiple sources to ensure the comprehensive coverage of key variables. Soil mapping of the Abu Dhabi Emirate, including data from 310 soil surveys, formed the basis of this analysis (ADAFSA, personal communication, 2024). Meteorological data were obtained on a daily basis, corresponding to 310 soil survey locations across the emirate from 2011 to 2022 (C3S, n.d.). Additionally, local climatic data from national meteorological stations were collected for three sites representing the main regions of the Abu Dhabi Emirate (Abu Dhabi, Al Dhafra and Al Ain) under three production systems: OF, GH and SH (ADAFSA, personal communication, 2024). Data on farm surveys and attributes, water resources, and soil characteristics from 310 farms were provided by ADAFSA (2020) whereas AEZ data, including soil classification and terrain classes, were sourced from the International Institute for Applied Systems Analysis (IIASA) (personal communication, 2024) (unpublished data under MPSA project).

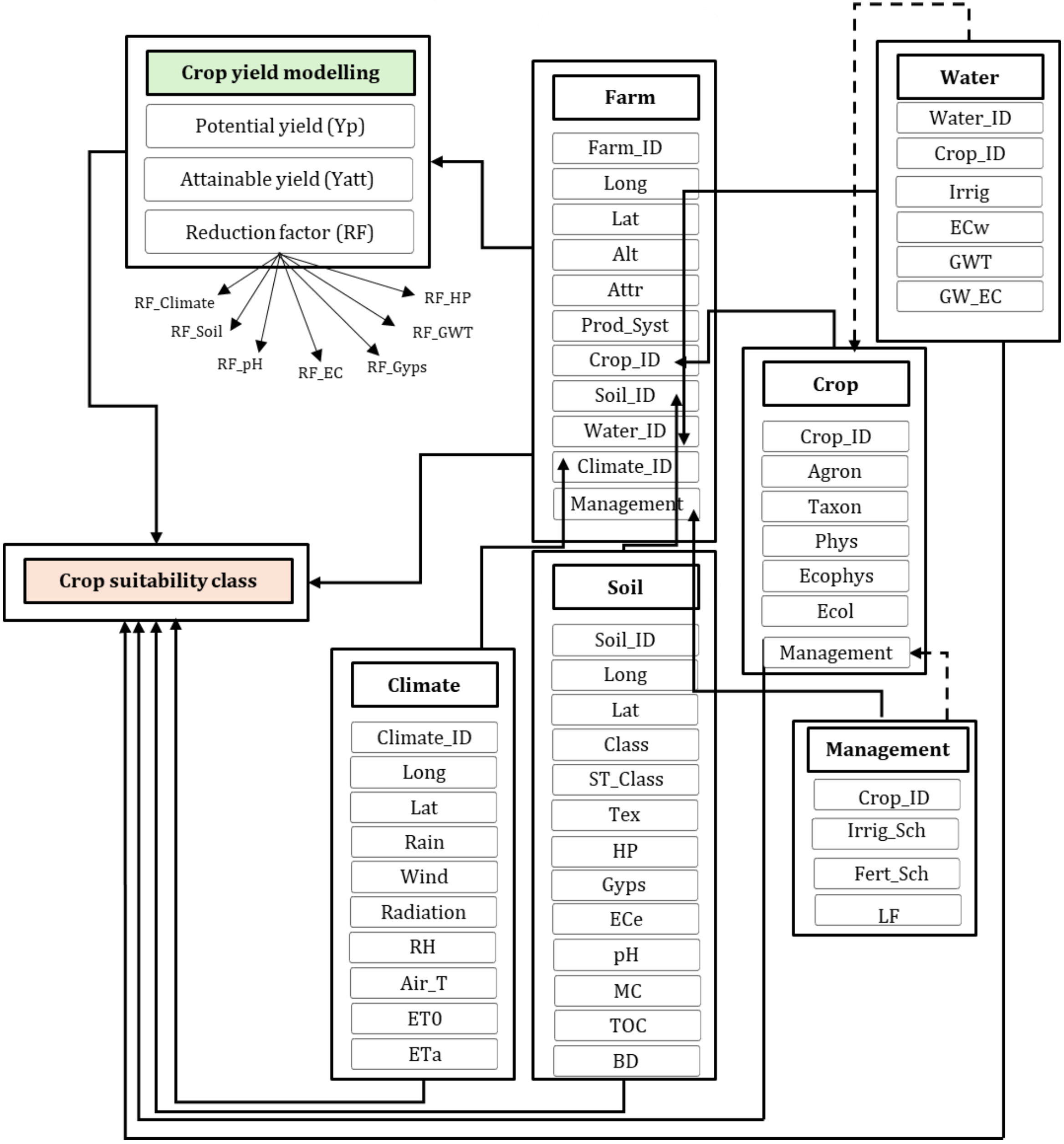
For seven vegetables, crop data were gathered from crop calculator reports (EAD, 2018b and 2019), date palm studies by Al-Muaini *et al.* (2019a, 2019b, 2019c, 2019d) and EAD (2018a). Additional sources include ADAFSA (2019, 2020), the ECOCROP database (FAO, 2022) and an intensive literature review. Relevant data collected from the literature review were cited alongside each parameter in the corresponding appendices.

1.3. Relational data architecture for yield simulation and crop suitability

The data architecture underpinning the crop yield simulation and crop suitability assessment components of the Master Plan was based on a relational database structure (Figure 2). This system organizes and links information across multiple domains – farm-level characteristics, soil and water attributes, climate data, and crop-specific parameters – to enable integrated and scalable analyses. At the centre is the farm table, which connects each farm to relevant biophysical and management data, including production systems, crop types, soil profiles, irrigation sources and quality, and localized climatic conditions.

Within this structure, detailed data on soil constraints, climatic variables, water quality, and crop physiology were systematically integrated and used to drive simulation models, such as APSIMx and AquaCrop. These models generated estimates of potential and attainable yields and RF, reflecting the key limiting conditions. The simulation outputs along with soil properties, water availability and quality, climate conditions, and crop-specific requirements were integrated to determine a crop suitability class for each crop under defined agrienvironmental settings (Figure 2) (the definitions of the variables used in Figure 2 are presented and discussed in Table 1).

Figure 2. Relational data structure supporting crop yield simulation and suitability assessment under the master plan of sustainable agriculture development of the Abu Dhabi Emirate



Source: Authors' own elaboration.

2. Methodological approach

2.1. Yield simulation

Yield simulation for 51 crops was conducted using the APSIMx and AquaCrop crop modelling tools, across three production systems: OF, GH, and SH at 181 sites (Table 2). Two different models were selected to meet the objectives of this assessment, considering data requirements and availability.

The APSIM model was initially created by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Queensland Government in Australia (Keating *et al*., 2003). It simulates biophysical processes in farming systems to predict the impacts of management practices on production under varying soil, climate and crop conditions (Holzworth *et al*., 2014). It has been widely applied to assess agricultural productivity, environmental sustainability, and economic viability of cropping practices in diverse climatic regions. The development of the APSIM (next generation) (APSIMx) introduced significant improvements in modularity and flexibility, enabling users to integrate crop-specific modules tailored to their research or operational needs (Holzworth *et al*., 2018). It includes a suite of biophysical modules that simulate crop physiological and phenological processes, soil-water dynamics, nutrient cycling, and pest and disease interactions (Moeller *et al*., 2014).

Because of its comprehensive nature, APSIMx was selected for simulations requiring detailed crop-specific datasets, providing an in-depth analysis of soil–plant interactions and climate responses. Conversely, AquaCrop, a water-driven model developed by FAO, focuses on water productivity and crop response to water stress. It is particularly effective in scenarios in which crop-specific data are limited, such as when assessing yield variations under different irrigation and salinity conditions. Together, APSIMx and AquaCrop provided complementary insights for simulating potential and attainable yields as well as for estimating RF for key growth-limiting variables.

The following key variables were assessed to evaluate crop yield performance and RFs:

- A crop’s calibrated yield: Crop yields were simulated and calibrated based on the reported actual yield from the Al Salamat and ICBA research sites (EAD, 2018b, 2019; Al-Muaini *et al*., 2019a, 2019b, 2019c, 2019d) for seven key vegetables (aubergine [*Solanum melongena*], cabbage [*Brassica oleracea*], tomato [*Solanum lycopersicum*], marrow [*Curcubita pepo*], sweet pepper, [*Capsicum annuum*] cucumber [*Cucumis sativus*], lettuce [*Lactuca sativa*]), and date palm [*Phoenix dactylifera*]), considering all environmental constraints and real-world conditions.

- A crop’s attainable yield: Crop yields were simulated, considering all farm-specific constraints and conditions under optimal management practices for all selected crops and sites.

- A crop’s potential yield: Crop yields were estimated to provide a baseline for maximum achievable yield by assessing the maximum yield potential for all the selected crops and sites, considering only farm-specific climatic data and without considering other growth-limiting factors.

- Analysing RFs: The RF (attainable yield divided by the potential yield) and the yield gap (attainable yield minus the actual yield) were calculated to understand the influence of suboptimal conditions compared to potential yield.

- Sensitivity analysis: The effects of variations in air temperature, soil salinity, soil pH, and water salinity on crop productivity were evaluated. For date palm, additional factors were considered, such as vapour pressure deficit (VPD), groundwater salinity, groundwater table depth, hardpan depth, plant-available water content, and fertilizer input.

The APSIMx model was used for the seven key vegetables and date palm because of the detailed experimental datasets available from the Al Salamat and ICBA research sites. It simulated potential and attainable yields, considering all input data except for soil and water salinity, due to it lacking the functionality to incorporate salinity effects. To address this limitation, AquaCrop was subsequently used to finalize the attainable yield simulations by integrating salinity inputs for the seven vegetables and date palm under different production systems (OF, GH and SH).

Appendix 1 complements the report by detailing the step-by-step approach used for yield calculations, specifically focusing on aubergine and cabbage under open-field production at Al Salamat Farm, Al Ain. It demonstrates how potential and attainable yields were estimated using crop modelling tools (APSIMx and Aquacrop), incorporating various input data such as phenology, irrigation schedules, fertilizer guidelines, water, and soil analysis, serving as an illustrative example for applying this methodology across all 181 targeted sites for other key vegetables. Overall, the assessment concluded that crop modelling effectively provided calibrated estimates of calibrated yield (reflecting the real world conditions), attainable yields (reflecting best management practices) and potential yields (indicating maximum achievable production under optimal agronomic conditions limited only by climate constraints).

Appendix 2 provides a detailed, step-by-step account of the methodology used to simulate date palm (*Phoenix dactylifera*) yields in the Abu Dhabi Emirate. The APSIMx model, which was originally developed for oil palm (Huth *et al*., 2014), was customized to simulate attainable and potential yields across 181 sites. Attainable yield is defined as the yield achieved by the top-performing 10 percent of farmers, while potential yield is defined as the maximum yield achievable under optimal agronomic conditions without limitations in water or nutrients. The simulations integrated local climate data, soil characteristics, irrigation, and nutrient management practices. Although APSIMx does not simulate the effects of salinity, the impact of soil pH (7.3 to 9) was minimal given the optimal range for date palms (pH 8 to 10). To differentiate attainable yields from potential yields, irrigation and fertilizer inputs were reduced in attainable yield simulations to reflect practical management constraints.

The APSIMx date palm model was validated by comparing simulated yields with measured yields at the ICBA station, which confirmed its accuracy in modelling crop growth, soil–water interactions and nutrient cycling. Sensitivity analyses were conducted to evaluate yield responses to variations in VPD, solar radiation, date palm varieties, and the optimization of water and nitrogen (N) fertilizer management. The results revealed a yield gap of approximately 6.5 tonnes per hectare (t/ha) between potential and attainable yields, indicating significant potential for enhancing productivity under arid conditions through improved agronomic practices.

AquaCrop was exclusively used to simulate potential and attainable yields for the remaining 43 crops, as follows:

- twenty-four annual crops (cherry tomato [*Solanum lycopersicum*], maize [*Zea mays*], cauliflower (*Brassica oleracea* var. *botrytis*], onion [*allium cepa*], broccoli [*Brassica oleracea* var. *italica*], potato [*Solanum tuberosum*], sweet melon [*Cucumis melo* var. *aegyptiacus L.*], watermelon [*Citrullus lanatus*], quinoa [*Chenopodium quinoa*], common bean (*Phaseolus vulgaris*), beetroot [*Beta vulgaris*], carrot [*Daucus carota*], pumpkin [*Cucurbita maxima*], sweet potato [*Ipomoea patatas*], jute mallow [*Corchorus olitorius*], okra [*Abelmoschus esculentus*], strawberry [*Fragaria x ananassa*], turnip [*Brassica rapa* subsp. *rapa*], parsley [*Petroselinum crispum*], raspberry [*Rubus idaeus*], butternut squash [*Curcurbita moschata*], cassava [*Manihot esculenta*], radish [*Raphanus sativus*], and blueberry [*Vaccinium corymbosum*]);

- eleven fruit tree crops (grape [*Vitis vinifera*], local almond [*Prunus amygdalus*], papaya [*Carica papaya*], banana [*Musa acuminata],* guava [*Psidium guajava*], lemon [*Citrus x lemon*], mango [*Mangifera indica*], pomegranate [*Punica granatum*], fig [*Ficus carica*], orange [*Citrus x sinensis*], and Ziziphus [*sidr*] [*Ziziphus spina-christi*]); and
- eight perennial grasses and shrubs used for fodder (leucaena (*Leucaena leucocephala],* alfalfa [*Medicago sativa],* panicum [*Panicum maximum]*, Rhodes grass [*Chloris gayana*], Napier grass [*Pennisetum purpureum*], buffel grass [*Cenchrus ciliaris*], sesbania [*Sesbania* sp.], and moringa [*Moringa oleifera*]).

Appendix 3 provides detailed methodological steps for three representative crops: cherry tomato, alfalfa and maize. However, since AquaCrop does not incorporate soil pH effects or air temperature sensitivity analyses, these factors were assessed through a literature review of 43 crops.

Table 2. List of simulated crops, corresponding crop models and production system type for each crop

No.	Crop	Crop type	OF	GH	SH	Model
1	Aubergine	Vegetable	x	–	–	APSIMx/AquaCrop
2	Cabbage	Vegetable	x	–	–	APSIMx/AquaCrop
3	Marrow	Vegetable	x	–	–	APSIMx/AquaCrop
4	Lettuce	Vegetable	x	–	–	APSIMx/AquaCrop
5	Tomato (round)	Vegetable	x	x	x	APSIMx/AquaCrop
6	Cucumber	Vegetable	–	x	x	APSIMx/AquaCrop
7	Sweet pepper	Vegetable	–	x	x	APSIMx/AquaCrop
8	Date palm (Khalas and LuLu varieties)	Fruit tree	x	–	–	APSIMx/AquaCrop
9	Cherry tomato	Vegetable	x	x	x	AquaCrop
10	Alfalfa	Fodder	x	–	–	AquaCrop
11	Maize	Field crop	x	x	x	AquaCrop
12	Cauliflower	Vegetable	x	–	–	AquaCrop
13	Onion	Root (bulb crop)	x	–	–	AquaCrop
14	Broccoli	Vegetable	x	–	–	AquaCrop
15	Potato	Root (bulb crop)	x	–	–	AquaCrop
16	Sweet melon	Vegetable	x	x	x	AquaCrop

No.	Crop	Crop type	OF	GH	SH	Model
17	Watermelon	Vegetable	x	x	x	AquaCrop
18	Quinoa	Field crop	x	–	–	AquaCrop
19	Tepary bean	Vegetable	x	x	x	AquaCrop
20	Beetroot	Root (bulb crop)	x	–	–	AquaCrop
21	Carrot	Root (bulb crop)	x	–	–	AquaCrop
22	Pumpkin	Vegetable	x	x	x	AquaCrop
23	Sweet potato	Root (bulb crop)	x	x	x	AquaCrop
24	Jute mallow	Vegetable	x	–	–	AquaCrop
25	Okra	Vegetable	x	x	x	AquaCrop
26	Strawberry	Fruit (berry)	–	x	x	AquaCrop
27	Turnip	Root (bulb crop)	x	–	–	AquaCrop
28	Parsley	Herb (green)	x	x	x	AquaCrop
29	Grape	Fruit tree	x	x	x	AquaCrop
30	Leucaena	Fodder	x	–	–	AquaCrop
31	Napier grass	Fodder	x	–	–	AquaCrop
32	Panicum	Fodder	x	–	–	AquaCrop
33	Raspberry	Fruit (berry)	–	x	x	AquaCrop
34	Buffel grass	Fodder	x	–	–	AquaCrop
35	Butternut squash	Vegetable	x	x	x	AquaCrop
36	Cassava	Field crop	x	–	–	AquaCrop
37	Radish	Root (bulb crop)	x	–	–	AquaCrop
38	Rhodes grass	Fodder	x	–	–	AquaCrop
39	Blueberry	Fruit (berry)	–	x	x	AquaCrop
40	Local almond	Fruit tree	x	–	–	AquaCrop
41	Papaya	Fruit tree	x	x	x	AquaCrop
42	Sispania	Fodder	x	–	–	AquaCrop
43	Banana	Fruit tree	x	x	x	AquaCrop

No.	Crop	Crop type	OF	GH	SH	Model
44	Guava	Fruit tree	x	x	x	AquaCrop
45	Lemon	Fruit tree	x	x	x	AquaCrop
46	Mango	Fruit tree	x	–	–	AquaCrop
47	Orange	Fruit tree	x	x	x	AquaCrop
48	Pomegranate	Fruit tree	x	x	x	AquaCrop
49	Fig	Fruit tree	x	x	x	AquaCrop
50	Moringa	Fodder	x	–	–	AquaCrop
51	Ziziphus (sidr)	Fruit tree	x	–	–	AquaCrop

Note: OF = open field, GH = greenhouse and SH = shade house.

2.2. Key input parameters for crop models

Each crop modelling tool requires specific key input data along with its own data formatting requirements. Nevertheless, certain key input parameters are essential for achieving accurate crop yield simulations. Table 3 provides a comprehensive list of these essential parameters required to simulate crop growth and productivity using APSIMx and AquaCrop. The parameters were organized into five main categories:

1. farm-specific attributes
2. climate variables
3. soil characteristics
4. water management factors
5. crop-specific parameters

Each parameter is presented with its abbreviation, unit of measurement, and an indicator of whether it is required by APSIMx or AquaCrop, represented numerically as 1 (required) or 0 (not required).

These parameters can be obtained from experimental studies or relevant published reference materials. Additionally, agricultural databases maintained by food and agriculture organizations can provide essential crop-specific input data. In the current study, key input parameters were derived from statistical yearbooks (ADAFSA, 2019, 2020), experimental research conducted by the Environment Agency – Abu Dhabi (EAD) (EAD, 2018, 2019), the FAO ECOCROP database (FAO, 2022), and an extensive review of existing scientific literature.

Table 3. List of key input parameters, units, and model applicability using the Agricultural Production Systems sIMulator (next generation) (APSIMx) and AquaCrop required for crop growth simulation

No.	Category	Parameter	Abbreviation	Units	APSIMx	AquaCrop
1	Farm	Unique ID corresponding to each farm	ID_AGR	–	1	1
2	Farm	Latitude	Lat	Decimal degrees	1	1
3	Farm	Longitude	Long	Decimal degrees	1	1
4	Farm	Altitude	Alt	m	1	1
5	Farm	Production system (OF, GH and SH)	Prod.Syst	–	1	1
6	Climate	Radiation (daily)	Rad	MJ/m^2	1	1
7	Climate	Rain (daily)	Rain	mm	1	1
8	Climate	Temperature (daily)	T	°C	1	1
9	Climate	Air relative humidity (daily)	RH	%	1	1
10	Climate	Wind (daily)	Wind	m/s	1	1
11	Climate	Reference potential evapotranspiration (daily)	ET0	mm	0	1
12	Climate	Actual evapotranspiration (daily)	ETa	mm	0	1
13	Soil	Texture (clay, silt and sand)	Tex	%	1	1
14	Soil	Moisture content	MC	%	1	1
15	Soil	Bulk density	BD	g/cm^3	1	1
16	Soil	Total organic carbon	TOC	%	1	1
17	Soil	Soil salinity	ECe	dS/m	1	1
18	Soil	Soil pH	pH	-	1	1
19	Soil	Fertilizer	Fert	kg/ha	1	1
20	Soil	Fertilizer schedule	Fert_Sch	Calendar days	1	0
21	Water	Water electrical conductivity	ECw	dS/m	1	1
22	Water	Irrigation	Irrig	mm/day	1	1
23	Water	Irrigation schedule	Irrig_Sch	Calendar days	1	0
24	Water	Irrigation method	Irrig_M	–	0	1
25	Crop	Scientific name	SN	–	1	1
26	Crop	Life form	LForm	–	1	1

No.	Category	Parameter	Abbreviation	Units	APSIMx	AquaCrop
27	Crop	Crop establishment (sowing or transplanting)	CE	–	1	1
28	Crop	Sowing date	SD	Calendar days	1	1
29	Crop	Planting density	PD	Plants/ha	1	1
30	Crop	Water requirement	WR	mm per day/month	1	1
31	Crop	Total length of crop cycle in growing degree-days	GDD	GDD	1	1
32	Crop	Leaf area index	LAI	Fraction or %	1	1
33	Crop	Rooting depth	RD	cm or m	1	1
34	Crop	Transpiration coefficient	TC	kg biomass/m³ water	1	1
35	Crop	Radiation use efficiency	RUE	g biomass/MJ photosynthetically active radiation (PAR)	1	0
36	Crop	Harvest index	HI	%	1	1
37	Crop	Crop coefficient	Kc	–	0	1
38	Crop	Water stress response	WSR	–	1	1
39	Crop	Yield response factor	Ky	–	0	1
40	Crop	Base temperature for growth	BT	°C	1	1
41	Crop	Upper temperature for growth	UT	°C	1	1
42	Crop	Soil water depletion	SWD	%	0	1
43	Crop	Electrical conductivity sensitivity	Ece	dS/m	0	1
44	Crop	Water productivity	WP	g/m²	0	1
45	Crop	Time from sowing to emergence	LT0	Calendar days	1	1
46	Crop	Time from sowing to maximum rooting depth	LT1	Calendar days	1	1
47	Crop	Time from sowing to maturity (length of crop cycle)	LT2	Calendar days	1	1
48	Crop	Time from sowing to flowering	LT3	Calendar days	1	1

No.	Category	Parameter	Abbreviation	Units	APSIMx	AquaCrop
49	Crop	Time from sowing to start senescence	LT4	Calendar days	1	1
50	Crop	Length of the flowering stage	LFS	Calendar days	1	1
51	Crop	Harvest duration	HD	Calendar days	1	1
52	Crop	Dry matter content of fresh yield	DMC	%	1	1
53	Crop	Potential yield	Yp	t/ha	1	1
54	Crop	Actual yield	Ya	t/ha	1	1

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
FAO (Food and Agriculture Organization of the United Nations). (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

2.3. Study area

The study area primarily focused on the Abu Dhabi Emirate, the largest emirate in the United Arab Emirates. The emirate is divided into three regions: Abu Dhabi on the coast, Al Ain in the east, and Al Dhafra in the west. To conduct farm-level yield simulations, a total of 181 sites were selected across the emirate, using the United Arab Emirates farm survey database (EAD, 2020), including two dedicated research locations (ICBA and Al Salamat), 170 farms and 11 additional points, as illustrated in Figure 3. The spatial distributions of the selected sites and their corresponding areas across different districts within Abu Dhabi Emirate are presented in Table 4.

A total of 181 sites were selected to ensure sufficient replication and capture diverse environmental, biophysical, and climatic conditions across the Abu Dhabi Emirate. The selected sites comprehensively represent most soil types and climatic variations within the region.

The dataset consisted of 181 sites (EAD, 2020) selected for farm-level yield simulations, representing a diverse range of soil types and terrain classes across the emirate. The sites were categorized based on their soil terrain class (ST_class), soil great group (soil_group), soil subgroup (subgroup), and World Reference Base (WRB) soil type (IUSS Working Group WRB, 2022).

Soil terrain classes (ST_class) range from calcids/gypsids with moderate constraints to psamments with severe constraints, highlighting variations in soil fertility, water retention capacity and drainage properties. In terms of soil taxonomy, the great soil groups (soil_group) included haplocalcids, torripsamments and petrocalcids, among others, indicating differences in soil structure, drainage and salinity levels.

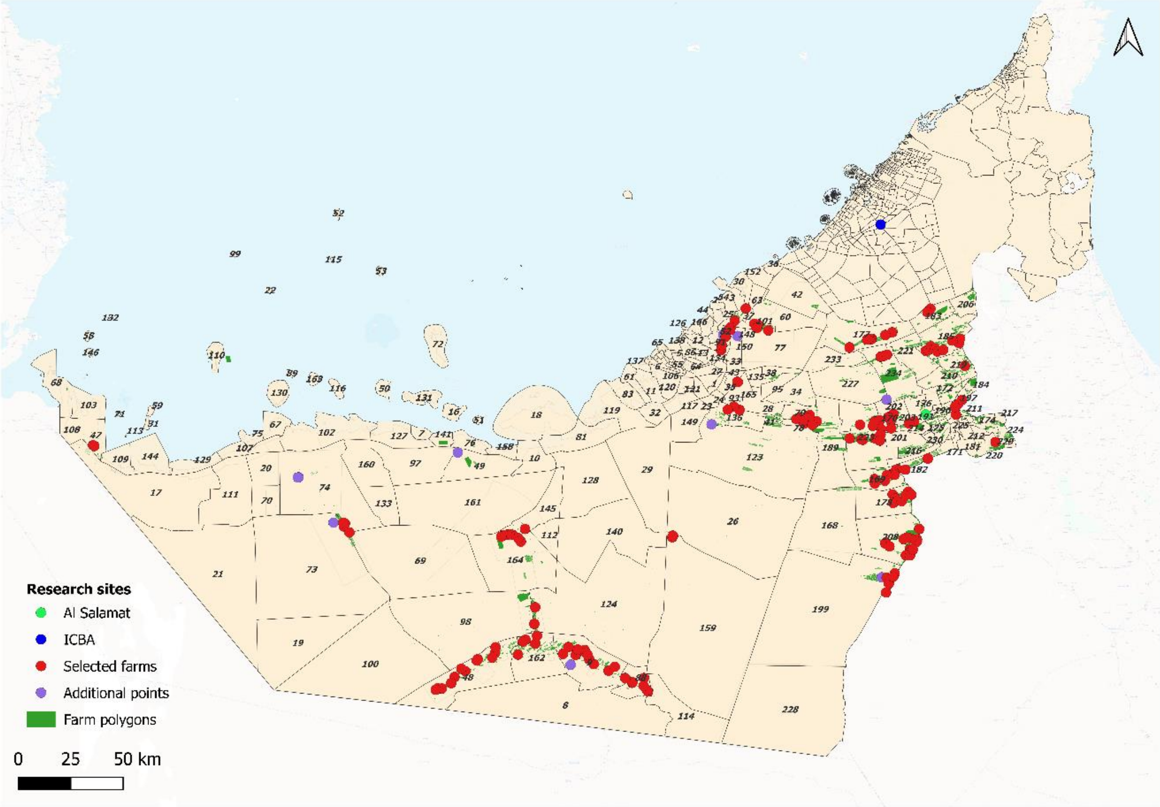
The soil subgroups (subgroup) further classified these units based on salinity, depth and parent material composition. The WRB soil types identified in this study include eutric arenosol, protic arenosol, aridic calcisol, and leptic gypsisol, which characterize the region's arid conditions, dominance of sandy textures and varying degrees of gypsum accumulation.

The number of selected sites in each category was determined based on two main variables: availability of data from 310 soil surveys and areas where the number of farms exceeded 100 (greater than 0.5 percent of total farms) for each category.

Based on a database of 310 soil surveys (EAD, 2020), soil biophysical parameters were collected from 181 sites, including the altitude of the site, total organic carbon (TOC), bulk density (BD), soil texture data (clay, silt and sand), and soil pH and salinity (soil electrical conductivity [ECe] in dS/m) at three depths (0–25 cm, 25–50 cm and 50–150 cm). In addition, the salinity of the irrigation water (water electrical conductivity [ECw] in (dS/m) was recorded for each site.

Table 5 presents a statistical summary of the biophysical parameters, providing insights into their variability across the 181 sites for the yield simulation. These parameters are essential for running yield simulations to extract soil hydraulic parameters, fertility and the effects of salinity conditions, which influence crop growth and productivity.

Figure 3. Map of the United Arab Emirates showing 181 target sites including two research sites (International Center for Biosaline Agriculture [ICBA] and Al Salamat), 170 selected farms, 11 additional points and farm polygons



Note: *Refer to the disclaimer on page ii for the names and boundaries used in this map.*

Source: **HDX (Humanitarian Data Exchange).** 2023. *United Arab Emirates Data Grid. United Arab Emirates – Subnational Administrative Boundaries. [Accessed on 3 June 2024]. https://data.humdata.org/dataset/cod-ab-sdn. Licence: CC-BY-IGO.*

Table 4. Distribution of selected sites and their corresponding area across districts in the Abu Dhabi Emirate

District number	District names	Number of selected farms	Number of additional points	Total land area (ha)	Cultivated land area (ha)
3	Al Wiqan	16	–	61 470	7 930
117	Western Mahadir	12	–	83 280	4 920
78	Eastern Mahadir	11	1	64 220	5 880
17	Rimah	11	–	69 910	9 760
233	Zayed City	9	–	106 840	3 600
34	Al' Ajban	9	–	54 070	4 180
32	Al Hiyar	9	–	37 750	6 640
157	Hameem	7	–	21 740	1 340
6	Al 'Arad	7	–	37 670	4 340
8	Al Dhahrah	7	–	9 370	3 500
148	Dihan	6	–	13 600	2 690
170	Muwaylih	5	–	6 040	2 430
231	Mzeer’ah	5	–	49 040	4 490
7	Bu Kirayyah	5	–	22 380	4 430
2	Al Qou'	5	2	282 950	3 590
20	Al Sad	5	1	16 460	1 950
173	Al Bahyah	4	1	6 770	2 060
30	Sweihan	4	–	42 580	7 210
143	Ghiyathi	3	2	135 080	1 100
151	Al Rahbah	3	–	1 760	600
33	Al Faqa'	3	–	18 400	2 430
106	Al Samhah	2	–	4 550	1 040
116	Al Sila'	2	–	18 200	300
193	Al 'Azeezah	2	–	252 890	2 070
205	Al Wathbah	2	1	25 900	1 920
228	Abu Qrayn	2	–	355 050	300
234	Madinat Al Riyad	2	–	9 890	130

District number	District names	Number of selected farms	Number of additional points	Total land area (ha)	Cultivated land area (ha)
24	Al Salamat	2	–	6 050	1 400
142	Ywaaw Al Nadhrah	1	–	270 880	1 590
147	Al Khatm	1	–	4 110	650
162	Al Nahdah	1	–	2 920	90
19	Abu Samrah	1	–	1 830	480
36	Al Jimi	1	–	1 140	120
16	Al Khaznah	1	–	66 130	5 080
63	Al Mu'tarid	1	–	600	50
39	Al Qattarah	1	–	460	150
58	Hili	1	–	3 310	410
28	Masakin	1	–	17 980	
118	Al Taf Al Gharbi	–	1	41 860	–
142	Yaw Al Nadhrah	–	1	27 090	–
12	Um Ghafah	1	–	6 620	470
217	Abu Mreikhah	–	1	3 600	–
Not applicable	Districts without sites (488)	–	–	4 139 730	–
TOTAL		–	–	6 329 640	104 050

Sources: **HDX (Humanitarian Data Exchange).** 2023. *United Arab Emirates Data Grid. United Arab Emirates – Subnational Administrative Boundaries*. [Accessed on 3 June 2024]. https://data.humdata.org/dataset/cod-ab-sdn. Licence: CC-BY-IGO. ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Table 5. Statistical summary of soil biophysical parameters for the 181 sites used in yield simulations

No.	Parameter	Abbreviation	Mean	Median	Min	Max	STD
1	Altitude (m)	ALT	141.5	137.5	4	360	67.0
2	Total organic carbon (%)	TOC	0.5	0.4	0.02	2.52	0.4
3	Bulk density (g/cm³)	BD	1.5	1.5	1.1	1.85	0.1
4	Clay content (%)	CLAY%	2.1	1.0	0	9	2.2

No.	Parameter	Abbreviation	Mean	Median	Min	Max	STD
5	Silt content (%)	SILT%	3.3	2.0	0	28	3.2
6	Sand content (%)	SAND%	91.9	93.0	59	100	6.3
7	Soil pH (0–25 cm)	PH_0-25	8.3	8.5	8	9	0.3
8	Soil pH (25–50 cm)	PH_25-50	8.4	8.5	8	9	0.3
9	Soil pH (50–150 cm)	PH_50-150	8.4	8.5	8	9	0.3
10	Maximum pH recorded	PH-MAX	8.4	8.5	7.3	9	0.3
11	Soil electrical conductivity (dS/m) at 0–25 cm	ECe_0-25	14.4	12.0	0	47.2	12.1
12	Soil electrical conductivity (dS/m) at 25–50 cm	ECe_25-50	9.7	6.0	0	28	8.0
13	Soil electrical conductivity (dS/m) at 50–150 cm	ECe_50-150	9.6	6.0	0	28	8.0
14	Electrical conductivity of irrigation water (dS/m)	ECw	9.7	8.1	0.5	25.7	7.3

Source: ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

2.4. Climatic data

The Abu Dhabi Emirate is divided into three distinct climatic zones: Abu Dhabi (coastal area), Al Ain and Al Dhafra. Each zone plays a critical role in agricultural and environmental studies, particularly in the context of this project, which focused on utilizing crop models to simulate growth and yield under different production systems. These systems included OF, GH and SH conditions, each of which hosts a variety of agricultural crops and agroforestry fruit trees.

2.4.1. Climate data source

Daily weather data for each location corresponding to the 310 soil survey sites from 2011 to 2022 were obtained from the AgERA5 gridded dataset (C3S, n.d.). The collected data were spatially interpolated to achieve a high-resolution format of 30 arc-seconds to ensure precise climate representation. The dataset included the following key meteorological variables:

- **Tmax-2m** (°C) (maxt): Daily maximum temperature at 2 m above the ground.
- **Tmin-2m** (°C) (mint): Daily minimum temperature at 2 m above ground.
- **Precip** (mm) (rain): Daily precipitation levels.
- **Srad** (MJ/m^2 /day) (radn): Incoming solar radiation.
- **Vapr** (kPa) (VPD): Vapour pressure (percentage of air relative humidity [rh2m] extracted from VPD data, using recorded air temperature [airT] values).
- **Wind-10m** (m/s) (wind): Average daily wind speed at 10 m above the ground.

For yield simulations using the APSIMx and AquaCrop models on 181 target sites, the nearest distance method was employed to match each site to the closest corresponding weather file. The assigned weather data for each farm were labelled using a unique site ID (ID_AGR) and incorporated into the simulations. To ensure compatibility of the extracted data from AgERA5 with both APSIMx and AquaCrop, multiple preprocessing steps were conducted with a Python script developed to automate the process. Sample weather files formatted for APSIMx and AquaCrop implementing Python code are shown in Figure 4.

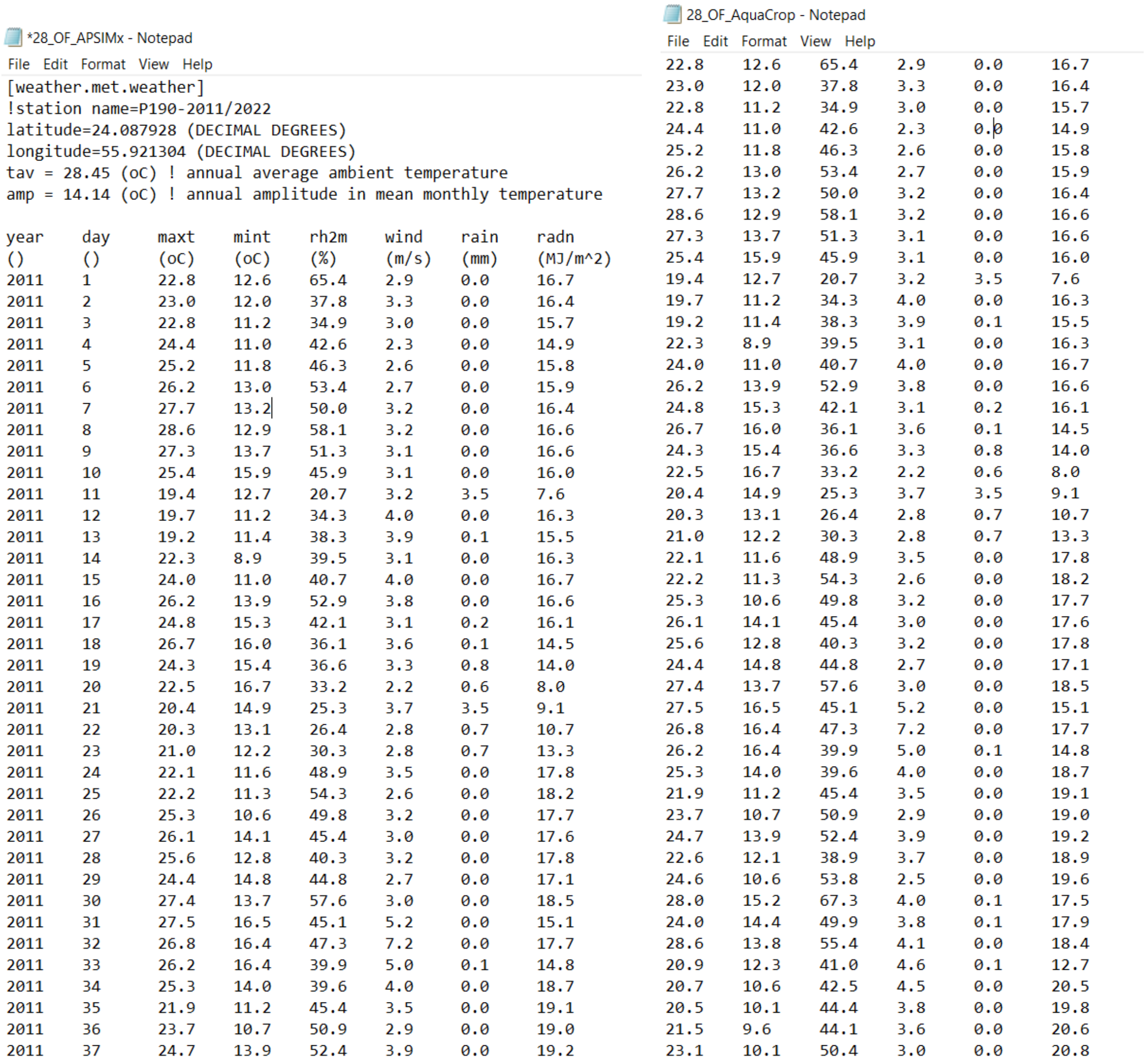
The time frame for the weather data was from 1 January 2011 to 1 January 2023. Both APSIMx and AquaCrop covered six main daily climate variables in the following order:

1. maximum temperature (maxt);
2. minimum temperature (mint);
3. relative humidity at 2 m (rh2m);
4. wind speed (wind);
5. rainfall (rain); and
6. radiation (radn).

Owing to the limitations of the AquaCrop model, data outside the acceptable range for AquaCrop were replaced with the maximum and minimum possible values within the reported range, as follows:

- Maximum temperature (maxt): The data were clipped to remain within a range of −15 °C to 45 °C.
- Minimum temperature (mint): Similar to maximum temperature, minimum temperature data were also clipped between −15 °C and 45 °C.
- Relative humidity at 2 m (rh2m): The relative humidity was adjusted to fall within 15 and 100 percent.
- Solar radiation (radn): Daily solar radiation values were restricted between 0 and 31.69 MJ/m².
- Wind speed (wind): Wind speed was clipped to a range of 0 to 8 m/s.
- Rainfall (rain): Rainfall data were maintained for up to 300 mm per event.

Figure 4. Sample weather data formats from farm ID_AGR: 28 under open field conditions (left: APSIMx and right: AquaCrop)



```
[weather.met.weather]
!station name=P190-2011/2022
latitude=24.087928 (DECIMAL DEGREES)
longitude=55.921304 (DECIMAL DEGREES)
tav = 28.45 (oC) ! annual average ambient temperature
amp = 14.14 (oC) ! annual amplitude in mean monthly temperature

year   day    maxt   mint   rh2m   wind   rain   radn
()     ()     (oC)   (oC)   (%)    (m/s)  (mm)   (MJ/m^2)
2011   1      22.8   12.6   65.4   2.9    0.0    16.7
2011   2      23.0   12.0   37.8   3.3    0.0    16.4
2011   3      22.8   11.2   34.9   3.0    0.0    15.7
2011   4      24.4   11.0   42.6   2.3    0.0    14.9
2011   5      25.2   11.8   46.3   2.6    0.0    15.8
2011   6      26.2   13.0   53.4   2.7    0.0    15.9
2011   7      27.7   13.2   50.0   3.2    0.0    16.4
2011   8      28.6   12.9   58.1   3.2    0.0    16.6
2011   9      27.3   13.7   51.3   3.1    0.0    16.6
2011   10     25.4   15.9   45.9   3.1    0.0    16.0
2011   11     19.4   12.7   20.7   3.2    3.5    7.6
2011   12     19.7   11.2   34.3   4.0    0.0    16.3
2011   13     19.2   11.4   38.3   3.9    0.1    15.5
2011   14     22.3   8.9    39.5   3.1    0.0    16.3
2011   15     24.0   11.0   40.7   4.0    0.0    16.7
2011   16     26.2   13.9   52.9   3.8    0.0    16.6
2011   17     24.8   15.3   42.1   3.1    0.2    16.1
2011   18     26.7   16.0   36.1   3.6    0.1    14.5
2011   19     24.3   15.4   36.6   3.3    0.8    14.0
2011   20     22.5   16.7   33.2   2.2    0.6    8.0
2011   21     20.4   14.9   25.3   3.7    3.5    9.1
2011   22     20.3   13.1   26.4   2.8    0.7    10.7
2011   23     21.0   12.2   30.3   2.8    0.7    13.3
2011   24     22.1   11.6   48.9   3.5    0.0    17.8
2011   25     22.2   11.3   54.3   2.6    0.0    18.2
2011   26     25.3   10.6   49.8   3.2    0.0    17.7
2011   27     26.1   14.1   45.4   3.0    0.0    17.6
2011   28     25.6   12.8   40.3   3.2    0.0    17.8
2011   29     24.4   14.8   44.8   2.7    0.0    17.1
2011   30     27.4   13.7   57.6   3.0    0.0    18.5
2011   31     27.5   16.5   45.1   5.2    0.0    15.1
2011   32     26.8   16.4   47.3   7.2    0.0    17.7
2011   33     26.2   16.4   39.9   5.0    0.1    14.8
2011   34     25.3   14.0   39.6   4.0    0.0    18.7
2011   35     21.9   11.2   45.4   3.5    0.0    19.1
2011   36     23.7   10.7   50.9   2.9    0.0    19.0
2011   37     24.7   13.9   52.4   3.9    0.0    19.2
```

```
22.8   12.6   65.4   2.9    0.0    16.7
23.0   12.0   37.8   3.3    0.0    16.4
22.8   11.2   34.9   3.0    0.0    15.7
24.4   11.0   42.6   2.3    0.0    14.9
25.2   11.8   46.3   2.6    0.0    15.8
26.2   13.0   53.4   2.7    0.0    15.9
27.7   13.2   50.0   3.2    0.0    16.4
28.6   12.9   58.1   3.2    0.0    16.6
27.3   13.7   51.3   3.1    0.0    16.6
25.4   15.9   45.9   3.1    0.0    16.0
19.4   12.7   20.7   3.2    3.5    7.6
19.7   11.2   34.3   4.0    0.0    16.3
19.2   11.4   38.3   3.9    0.1    15.5
22.3   8.9    39.5   3.1    0.0    16.3
24.0   11.0   40.7   4.0    0.0    16.7
26.2   13.9   52.9   3.8    0.0    16.6
24.8   15.3   42.1   3.1    0.2    16.1
26.7   16.0   36.1   3.6    0.1    14.5
24.3   15.4   36.6   3.3    0.8    14.0
22.5   16.7   33.2   2.2    0.6    8.0
20.4   14.9   25.3   3.7    3.5    9.1
20.3   13.1   26.4   2.8    0.7    10.7
21.0   12.2   30.3   2.8    0.7    13.3
22.1   11.6   48.9   3.5    0.0    17.8
22.2   11.3   54.3   2.6    0.0    18.2
25.3   10.6   49.8   3.2    0.0    17.7
26.1   14.1   45.4   3.0    0.0    17.6
25.6   12.8   40.3   3.2    0.0    17.8
24.4   14.8   44.8   2.7    0.0    17.1
27.4   13.7   57.6   3.0    0.0    18.5
27.5   16.5   45.1   5.2    0.0    15.1
26.8   16.4   47.3   7.2    0.0    17.7
26.2   16.4   39.9   5.0    0.1    14.8
25.3   14.0   39.6   4.0    0.0    18.7
21.9   11.2   45.4   3.5    0.0    19.1
23.7   10.7   50.9   2.9    0.0    19.0
24.7   13.9   52.4   3.9    0.0    19.2
22.6   12.1   38.9   3.7    0.0    18.9
24.6   10.6   53.8   2.5    0.0    19.6
28.0   15.2   67.3   4.0    0.1    17.5
24.0   14.4   49.9   3.8    0.1    17.9
28.6   13.8   55.4   4.1    0.0    18.4
20.9   12.3   41.0   4.6    0.1    12.7
20.7   10.6   42.5   4.5    0.0    20.5
20.5   10.1   44.4   3.8    0.0    19.8
21.5   9.6    44.1   3.6    0.0    20.6
23.1   10.1   50.4   3.0    0.0    20.8
```

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

FAO (Food and Agriculture Organization of the United Nations). (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

2.4.2. Statistical analysis of climatic data

To gain a comprehensive understanding of the climatic conditions in the three regions (Abu Dhabi, Al Ain and Al Dhafra), climatic data were statistically analysed. These are presented in the three following sections.

Monthly average comparison

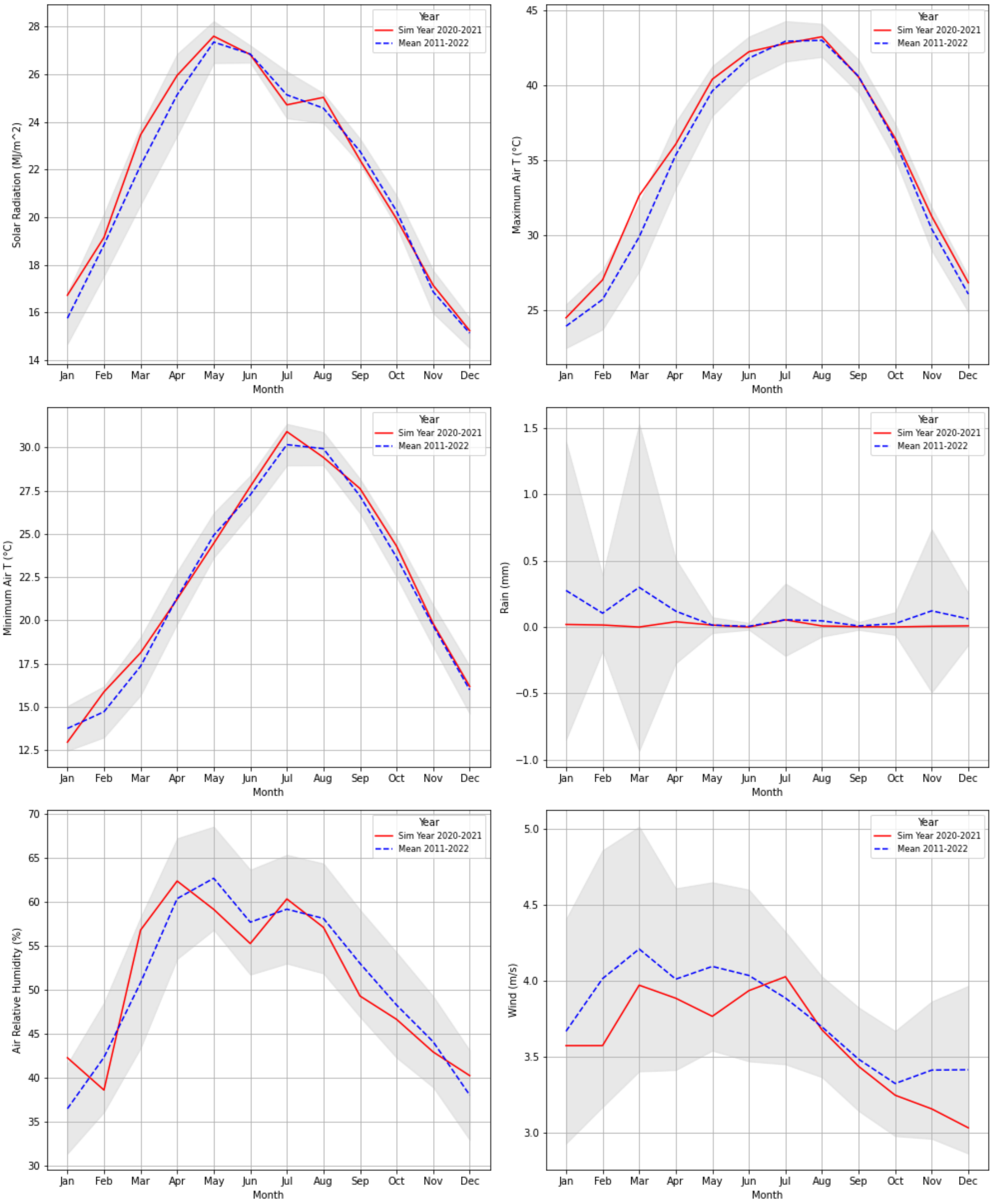
This section compares the monthly averages of each climatic variable between the simulated year (e.g. data for 43 crops from to 2020 to 2021) and the mean of all available data from 2011 to 2022.

Figure 5, Figure 6 and Figure 7 illustrate the monthly mean values of key climatic variables in Abu Dhabi, Al Ain and Al Dhafra from 2011 to 2022 compared with the simulated year (2020/21) for 43 crop categories.

Rainfall exhibited the highest variability in all three regions, with Al Ain showing slightly more pronounced fluctuations than Abu Dhabi and Al Dhafra. Wind speed varied significantly, with Al Dhafra experiencing higher variability than the other regions. Relative humidity showed slight variations across all regions, with Al Ain exhibiting greater deviations in the simulated year. Solar radiation and air temperatures (maximum and minimum) were consistent across all regions, with minimal interannual variability, indicating stable, long-term trends.

These findings highlight the necessity of considering regional climate variability in future studies assessing the agricultural and ecological conditions in the Abu Dhabi Emirate. Given the observed fluctuations in rainfall, wind speed and humidity, long-term yield simulations are crucial for improving crop modelling accuracy and decision-making.

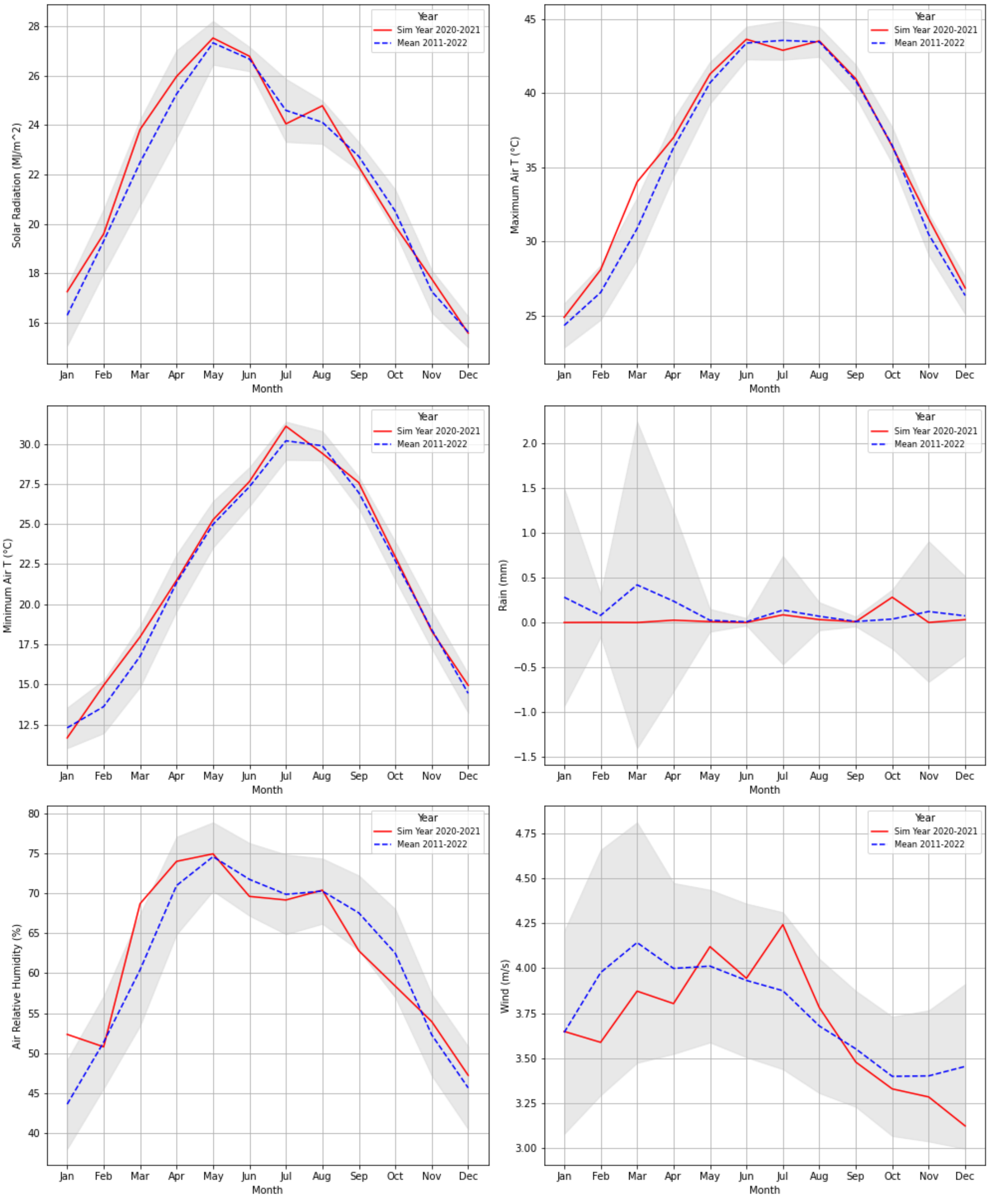
Figure 5. Monthly mean of climatic variables with 95 percent confidence intervals for 2011 to 2022 compared to the simulation year (2020–2021) for 43 crops in the Abu Dhabi Emirate



Note: The blue dashed line indicates the overall mean for all years (2011–2022), with 95 percent confidence intervals shaded in grey. The red line highlights the data for the simulated year, designated as the "Sim Year 2020-2021". This comparison helps to identify any significant deviations in the simulated year from the historical averages.

Source: **C3S (Copernicus Climate Change Service).** n.d. *Climate Data Store: Datasets – AgERA5*. [Accessed on 10 January 2024]. https://cds.climate.copernicus.eu/datasets?q=AgERA5. Licence: CC-BY-4.0.

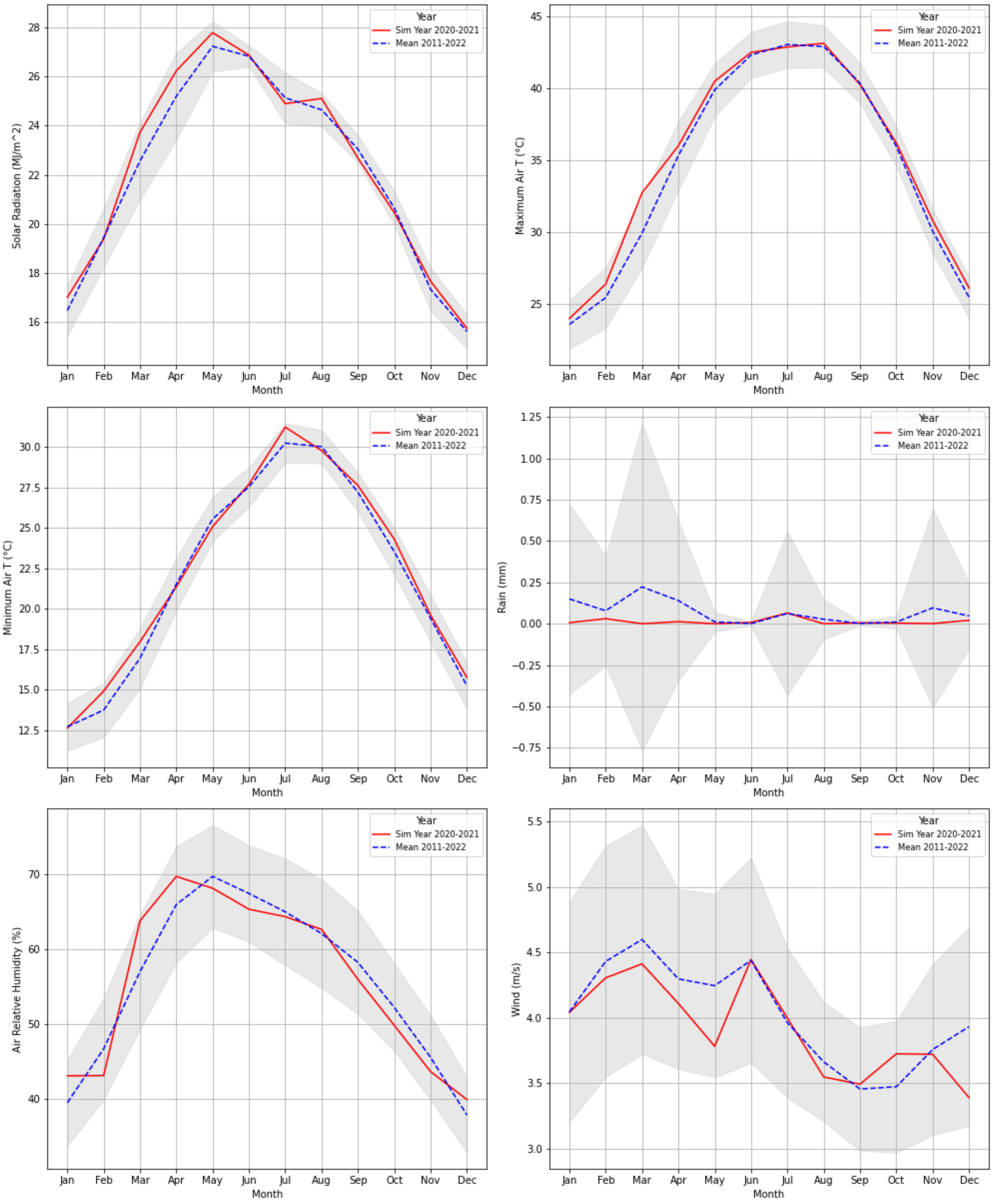
Figure 6. Monthly mean of climatic variables with 95 percent confidence intervals for 2011 to 2022 compared to the simulation year (2020–2021) for 43 crops in Al Ain, Abu Dhabi Emirate



Note: The blue dashed line indicates the overall mean for all years (2011–2022), with 95 percent confidence intervals shaded in grey. The red line highlights the data for the simulated year, designated as the "Sim Year 2020-2021". This comparison helps to identify any significant deviations in the simulated year from the historical averages.

Source: **C3S (Copernicus Climate Change Service).** n.d. *Climate Data Store: Datasets – AgERA5*. [Accessed on 10 January 2024]. https://cds.climate.copernicus.eu/datasets?q=AgERA5. Licence: CC-BY-4.0.

Figure 7. Monthly mean of climatic variables with 95 percent confidence intervals for 2011 to 2022 compared to the simulation year (2020–2021) for 43 crops in Al Dhafra, Abu Dhabi Emirate



Note: The blue dashed line indicates the overall mean for all years (2011–2022), with 95 percent confidence intervals shaded in grey. The red line highlights the data for the simulated year, designated as the "Sim Year 2020-2021". This comparison helps to identify any significant deviations in the simulated year from the historical averages.

Source: **C3S (Copernicus Climate Change Service).** n.d. *Climate Data Store: Datasets – AgERA5*. [Accessed on 10 January 2024]. https://cds.climate.copernicus.eu/datasets?q=AgERA5. Licence: CC-BY-4.0.

Statistical summary

A detailed statistical summary is provided for each climatic variable for each year (Table 6). The summary includes essential statistical measures such as mean, median, minimum, maximum, and standard deviation. These metrics offer insights into the central tendency and variability of climatic data, allowing for a nuanced understanding of annual variations.

Table 6. Statistical summary of the climatic variables across the three regions (Abu Dhabi, Al Ain and Al Dhafra) of the Abu Dhabi Emirate from 2011 to 2022

No.	Var.	year	Abu Dhabi				Al Ain				Al Dhafra			
			Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum
1	radn	2011	21.7	23	9	29	22	23	7	29	22	23	6	29
2	radn	2012	21.8	23	10	29	22	23	11	29	22	23	10	29
3	radn	2013	21.6	22	8	29	22	22	8	29	22	23	8	29
4	radn	2014	21.9	23	8	29	22	22	6	29	22	23	6	29
5	radn	2015	21.9	23	6	29	22	23	5	29	22	23	3	29
6	radn	2016	21.5	22	8	29	22	22	6	29	22	22	8	29
7	radn	2017	21.6	23	8	29	22	23	8	29	22	23	7	29
8	radn	2018	21.9	23	7	28	22	23	9	28	22	23	11	29
9	radn	2019	21.6	22	8	29	22	22	8	29	22	22	7	29
10	radn	2020	21.7	23	6	29	22	23	3	29	22	23	5	29
11	radn	2021	22	23	10	29	22	23	4	30	22	23	12	29
12	radn	2022	21.9	23	8	29	22	23	6	29	22	23	7	29
13	maxt	2011	34.5	36	20	48	35	36	19	47	34	36	18	47
14	maxt	2012	34.8	35	17	47	35	36	17	48	35	36	14	48
15	maxt	2013	33.7	35	19	47	34	35	19	46	34	34	18	47
16	maxt	2014	34.1	36	18	47	35	37	18	47	34	36	17	47
17	maxt	2015	35	36	17	48	36	37	17	48	35	36	17	47
18	maxt	2016	34.3	35	18	47	35	35	18	47	34	35	15	47
19	maxt	2017	35.1	37	15	48	36	39	15	48	35	37	13	48
20	maxt	2018	35	36	20	48	36	37	20	48	35	36	19	48
21	maxt	2019	34.6	37	20	48	35	37	20	48	35	36	18	48
22	maxt	2020	34.5	36	16	47	35	36	15	48	34	35	15	47

No.	Var.	year	Abu Dhabi				Al Ain				Al Dhafra			
			Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum
23	maxt	2021	35.4	37	21	48	36	37	21	48	35	37	18	48
24	maxt	2022	35.1	37	19	48	36	37	19	48	35	36	16	48
25	mint	2011	22.1	23	9	34	21	22	7	33	22	23	8	35
26	mint	2012	21.8	22	7	35	21	22	6	34	22	22	5	35
27	mint	2013	21.6	22	7	34	21	21	5	35	21	22	6	35
28	mint	2014	21.7	23	9	34	21	23	9	34	22	23	7	34
29	mint	2015	22	23	9	35	21	22	8	34	22	23	7	35
30	mint	2016	22.3	22	9	35	22	22	9	35	22	22	7	36
31	mint	2017	22.5	23	9	35	22	23	6	35	22	23	6	35
32	mint	2018	22.6	24	10	35	22	23	9	34	22	24	6	34
33	mint	2019	22.5	23	10	35	22	23	9	34	22	23	9	35
34	mint	2020	22.5	23	9	35	22	22	8	35	22	23	7	35
35	mint	2021	22.4	23	8	35	22	22	6	34	22	23	7	34
36	mint	2022	22.4	22	9	35	22	22	9	34	22	23	8	34
37	rain	2011	0	0	0	3	0	0	0	5	0	0	0	4
38	rain	2012	0	0	0	3	0	0	0	3	0	0	0	2
39	rain	2013	0.2	0	0	21	0	0	0	45	0	0	0	35
40	rain	2014	0.1	0	0	23	0	0	0	24	0	0	0	26
41	rain	2015	0.1	0	0	8	0	0	0	8	0	0	0	10
42	rain	2016	0.2	0	0	41	0	0	0	54	0	0	0	43
43	rain	2017	0.1	0	0	17	0	0	0	20	0	0	0	17
44	rain	2018	0	0	0	5	0	0	0	3	0	0	0	16
45	rain	2019	0.1	0	0	12	0	0	0	14	0	0	0	9
46	rain	2020	0.2	0	0	33	0	0	0	39	0	0	0	20
47	rain	2021	0	0	0	1	0	0	0	20	0	0	0	2
48	rain	2022	0.1	0	0	15	0	0	0	19	0	0	0	31
49	rh2m	2011	51	50	16	84	62	64	16	88	56	56	12	88
50	rh2m	2012	51.9	51	21	86	64	67	27	90	57	56	10	90
51	rh2m	2013	48.5	48	17	83	59	60	20	88	54	55	15	87

No.	Var.	year	Abu Dhabi				Al Ain				Al Dhafra			
			Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum	Mean	Median	Minimum	Maximum
52	rh2m	2014	49.7	50	20	87	60	63	22	91	55	56	13	87
53	rh2m	2015	52.6	52	18	87	63	64	14	91	57	57	14	89
54	rh2m	2016	48.8	48	18	85	60	61	19	86	53	53	11	86
55	rh2m	2017	51.2	51	15	85	63	66	20	90	55	54	11	87
56	rh2m	2018	52.3	52	17	82	64	66	29	88	57	57	15	88
57	rh2m	2019	52.2	51	20	85	62	63	20	90	56	56	17	89
58	rh2m	2020	51.6	50	20	87	62	64	15	92	55	55	16	86
59	rh2m	2021	51	50	22	82	63	64	28	87	56	55	14	91
60	rh2m	2022	50.7	50	23	84	61	64	18	89	56	56	18	89
61	wind	2011	3.9	4	2	10	4	4	2	9	4	4	2	9
62	wind	2012	3.8	4	2	10	4	4	2	9	4	4	1	11
63	wind	2013	3.7	4	1	9	4	4	2	9	4	4	1	11
64	wind	2014	3.7	4	2	9	4	4	2	8	4	4	1	9
65	wind	2015	3.9	4	2	10	4	4	2	10	4	4	2	10
66	wind	2016	3.7	4	2	9	4	4	2	7	4	4	1	10
67	wind	2017	3.8	4	2	11	4	4	2	9	4	4	1	11
68	wind	2018	3.7	4	2	8	4	4	2	8	4	4	2	8
69	wind	2019	3.9	4	2	9	4	4	2	9	4	4	2	10
70	wind	2020	3.8	4	2	9	4	4	2	9	4	4	1	10
71	wind	2021	3.6	4	2	7	4	4	2	7	4	4	1	9
72	wind	2022	3.8	4	2	11	4	4	2	8	4	4	2	11

Note: rh2m = percentage of air relative humidity, maxt = maximum temperature, mint = minimum temperature, and radn = radiation.

Source: **C3S (Copernicus Climate Change Service).** n.d. *Climate Data Store: Datasets – AgERA5*. [Accessed on 10 January 2024]. https://cds.climate.copernicus.eu/datasets?q=AgERA5. Licence: CC-BY-4.0.

Analysis of variance (ANOVA) test

An analysis of variance (ANOVA) test was conducted to compare the variations in each climatic variable between years. The ANOVA test helped determine whether there were statistically significant differences in climatic conditions over the years. The results of the ANOVA test provided a robust statistical foundation for assessing the impact of annual climatic variations.

Table 7 provides the ANOVA results for the different climatic variables in the three main regions. Significant F-values and p-values indicated notable year-to-year variability in some climatic variables within each region. For instance, the highest variability was in air relative humidity (rh2m) in Al Ain (F = 19 and p = 9.49E-38), and wind speed showed significant differences in all regions, with Abu Dhabi showing the highest F-value of 11.6 (p = 6.43E-22).

sum_sq (sum of squares) = a measure of the total variability for each source. Higher values indicate greater variability.

df (degrees of freedom) = the number of values that are free to vary. For year, it is the number of years minus one. The residuals are the total number of observations minus the number of groups.

F(F-value) = the ratio of the variability between the group means to the variability within the groups. Higher F-values indicate a greater degree of variation between groups than within groups.

PR(>F) (p-value) = the probability of obtaining an F-value at least as extreme as that observed, assuming that the null hypothesis is true. Lower p-values (typically less than 0.05) indicate that the observed variability between the groups was statistically significant.

Var = The climatic variable being analysed.

Statistical analysis of weather data underscores the importance of multiyear yield simulations rather than relying on a single selected year, as a single year cannot statistically represent all historical climatic conditions. In the current study, both the APSIMx and AquaCrop models were run for a single year. To conduct simulations over multiple years, historical yield data and management practices are required for each crop and year.

Table 7. An analysis of variance (ANOVA) results for climatic variables across the three regions (Abu Dhabi, Al Ain and Al Dhafra) of the Abu Dhabi Emirate

No	Var	Abu Dhabi				Al Ain				Al Dhafra			
		sum_sq	**df**	**F**	**PR(>F)**	**sum_sq**	**df**	**F**	**PR(>F)**	**sum_sq**	**df**	**F**	**PR(>F)**
1	radn	459	11	2.1	0.020	530	11	3	3E-03	515	11	3	3E-03
2	maxt	3752	11	6.2	2E-10	3627	11	6	6E-10	3209	11	5	1E-07
3	mint	2091	11	5.2	3E-08	1197	11	3	3E-03	2032	11	4	2E-06
4	rain	63	11	6.1	4E-10	138	11	7	3E-11	33	11	5	9E-08
5	rh2m	28713	11	13.9	5E-27	39903	11	19	9E-38	22872	11	8	7E-15
6	wind	140	11	11.6	6E-22	82	11	10	5E-18	130	11	7	3E-12

Notes: rh2m = percentage of air relative humidity, maxt = maximum temperature, mint = minimum temperature, and radn = radiation.

2.4.3. Shade house and greenhouse climate data

In this project, because SH and GH climatic data was lacking for the 181 sites, specific formulas were required to convert OF data to SH and GH conditions for each region and each variable. The Crop Calculator Report-Year 2 (EAD, 2019), provided correlation equations between air temperature (airT), VPD and solar radiation. However, the correlation, particularly for air temperature, was not applicable because of its polynomial nature and yielded unreasonable results. Additionally, it is important to note that the source data for these correlations originated from the ICBA research site and not the other site at Al Salamat.

To develop appropriate correlation equations for each region, ADAFSA shared a daily climatic database (ADAFSA, personal communication, 2024). This database included only the minimum, maximum and average air temperature (airT) and air relative humidity (RH) values. The file contained OF, GH and SH climatic data for each region of Abu Dhabi, Al Ain and Al Dhafra. For Abu Dhabi, the dataset included OF data from 2021 to 2023, Plastic-GH-High-tech[5] from 2021 to 2023, Plastic-GH-Med-tech[6] from 2021 to 2023, Plastic-GH-Low-tech[7] from 2021 to 2023, Plastic-GH (only for 2023), and SH (only for 2023). For Al Ain and Al Dhafra, the datasets covered OF, Plastic-GH and SH for the year 2023.

To ensure harmonization across the three regions, 2023 was selected as the common reference year for conducting correlation analyses. Consequently, correlations were only performed for air temperature (airT) and relative humidity (RH). For both the SH and GH, the rainfall was assumed to be 0 percent rainfall. For SH, a 20 percent wind speed relative to the OF conditions was assumed, whereas GH assumed 0 percent wind. Using correlations of solar radiation from OF to SH and GH (EAD, 2019) (Figure 8 and Figure 9), along with regression results for airT and RH, the climatic data for SH and GH were finalized. All correlation coefficients for the variables across the three regions are presented in Table 8.

The results indicate that compared to the outside environment, SH exhibits a significantly greater reduction in solar radiation than GH. This reduction is nonlinear, with more pronounced decreases at lower sun angles following the order OF >GH >SH. The correlation analysis showed high accuracy for airT, with R^2 values exceeding 85 percent across all scenarios. The RH correlations also demonstrated high accuracy, with R^2 values above 75 percent, except for Abu Dhabi GH, where it dropped to 55 percent. The observed trends for airT and RH across OF, GH and SH were consistent with expectations, validating the findings (airT: OF >SH >GH and RH: OF <SH <GH).

For future studies, it is recommended that solar radiation data sources are established under OF, SH and GH conditions across the three regions of the Abu Dhabi Emirate to improve the correlation accuracy. Additionally, the evaluation should account for different net houses and greenhouse materials, as these affect radiation transmission. To illustrate the systematic error introduced by incorrect correlation equations, an APSIMx simulation was conducted for cucumber under SH conditions, replacing SH solar radiation data with GH radiation data. This resulted in a yield reduction of 10 t/ha (from 84 to 74 t/ha), emphasizing the necessity of accurate solar radiation correlations for yield simulations.

In the current study, owing to the inaccuracy in radiation correlation equations, solar radiation data for the SH were replaced with GH data.

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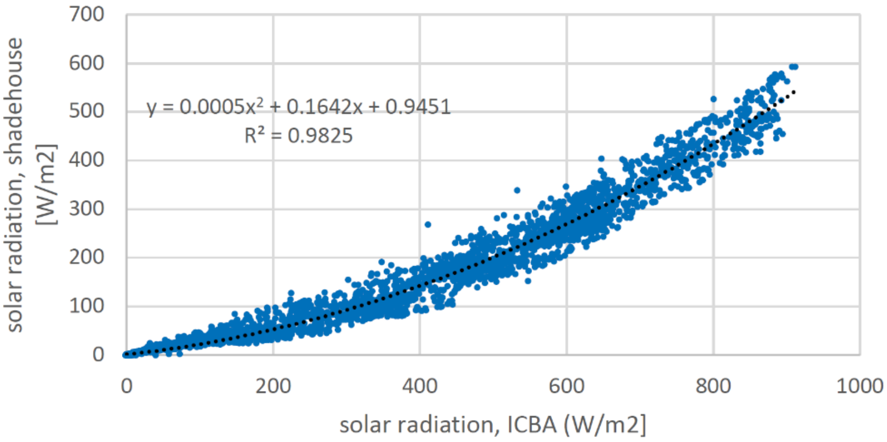
[5] Greenhouse covered with plastic roof, equipped with advanced or high technology systems.

[6] Greenhouse covered with plastic roof, equipped with moderate or intermediate technology systems.

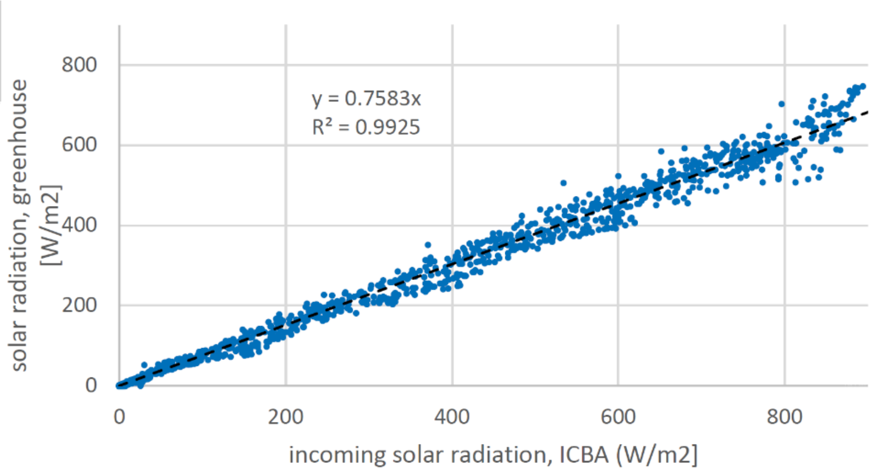
[7] Greenhouse covered with plastic roof, equipped with basic or low technology systems

Figure 8. Correlation analysis of solar radiation between open field (OF) and shade house (SH)



Source: **EAD (Environment Agency – Abu Dhabi)**. 2019. *Crop calculator Year 2 field experiments*. Abu Dhabi.

Figure 9. Correlation analysis of solar radiation between open field (OF) and greenhouse (GH)



Source: **EAD (Environment Agency – Abu Dhabi)**. 2019. *Crop calculator Year 2 field experiments*. Abu Dhabi.

Table 8. Results of the correlation analysis for the conversion of open field (OF) climate data to shade house (S)H and greenhouse (GH) climate data

Region	**System**	**airT (mx + b)**		**RH (mx + b)**		**Rain (mx)**	**Wind (mx)**	**Radiation (mx^2 + bx + c)**		
		m	***b***	***m***	***b***	***m***	***m***	***m***	***b***	***c***
Abu Dhabi	SH	**0.9**	**1.9**	**0.72**	**25.69**	**0**	**0.2**	**0.0005**	**0.164**	**0.945**
Al Ain	SH	**0.87**	**2.3**	**0.99**	**15.64**	**0**	**0.2**	**0.0005**	**0.164**	**0.945**

Region	**System**	**airT (mx + b)**		**RH (mx + b)**		**Rain (mx)**	**Wind (mx)**	**Radiation (mx^2 + bx + c)**		
		m	***b***	***m***	***b***	***m***	***m***	***m***	***b***	***c***
Al Dhafra	SH	**0.9**	**2.83**	**0.7**	**23.82**	**0**	**0.2**	**0.0005**	**0.164**	**0.945**
Abu Dhabi	GH	**0.67**	**5.73**	**0.38**	**58.69**	**0**	**0**	**0**	**0.76**	**0**
Al Ain	GH	**0.56**	**6.59**	**0.46**	**59.30**	**0**	**0**	**0**	**0.76**	**0**
Al Dhafra	GH	**0.58**	**6.80**	**0.41**	**59.50**	**0**	**0**	**0**	**0.76**	**0**

Note: "x" is the corresponding value for each climatic variable under open field (OF) conditions.

3. Results and discussion

3.1. Crop yield modelling output

The average yields from all simulation sites under OF, SH and GH conditions for 51 crops are summarized in Table 9. For the first seven vegetables and date palm, APSIMx was utilized to simulate the climate-specific potential yield (Yp_APSIMx) and attainable yield (Yatt_APSIMx), excluding soil and water salinity inputs. Additionally, AquaCrop was employed to simulate the attainable yield (Yatt_Aquacrop), considering the impact of salinity. For the remaining crops, both the climate-specific potential yield (Yp_Aquacrop) and the attainable yield (Yatt_Aquacrop) were simulated using AquaCrop. All yield values are expressed in t/ha and represent the fresh yield. Detailed tables with yield results are included in Appendix 1 and Appendix 2 for the seven key vegetables and date palm and Appendix 3 for the remaining 43 crops.

Table 9. Summary of average yields for 51 crops under open field (OF), shade house (SH) and greenhouse (GH) conditions simulated using the Agricultural Production Systems sIMulator (next generation) (APSIMx) and AquaCrop

No	**Crop**	**Code**	**Yield_model**	**OF**	**SH**	**GH**
1	Aubergine	Egg	Yp_APSIMx	81.2	–	–
2	Aubergine	Egg	Yatt_APSIMx	68.3	–	–
3	Aubergine	Egg	Yatt_Aquacrop	8.8	–	–
4	Cabbage	Cabb	Yp_APSIMx	79.0	–	–
5	Cabbage	Cabb	Yatt_APSIMx	65.7	–	–
6	Cabbage	Cabb	Yatt_Aquacrop	6.9	–	–
7	Courgette	Zuc	Yp_APSIMx	56.8	–	–
8	Courgette	Zuc	Yatt_APSIMx	41.5	–	–
9	Courgette	Zuc	Yatt_Aquacrop	7.2	–	–

No	Crop	Code	Yield_model	OF	SH	GH
10	Lettuce	Let	Yp_APSIMx	56.5	–	–
11	Lettuce	Let	Yatt_APSIMx	39.5	–	–
12	Lettuce	Let	Yatt_Aquacrop	3.1	–	–
13	Tomato (round)	Tom	Yp_APSIMx	139.0	163.8	196.8
14	Tomato (round)	Tom	Yatt_APSIMx	109.4	139.4	169.6
15	Tomato (round)	Tom	Yatt_Aquacrop	11.2	1.5	15.4
16	Cucumber	Cuc	Yp_APSIMx	–	98.0	115.1
17	Cucumber	Cuc	Yatt_APSIMx	–	84.9	99.8
18	Cucumber	Cuc	Yatt_Aquacrop	–	7.9	9.6
19	Sweet pepper	Cap	Yp_APSIMx	–	115.8	135.3
20	Sweet pepper	Cap	Yatt_APSIMx	–	100.7	118.3
21	Sweet pepper	Cap	Yatt_Aquacrop	–	6.3	7.7
22	Date palm	date-lulu-	Yp_APSIMx	25.2	–	–
23	Date palm	date-lulu	Yatt_APSIMx	18.7	–	–
24	Date palm	date-lulu	Yatt_Aquacrop	9.6	–	–
25	Date palm	date-khalas	Yp_APSIMx	15.3	–	–
26	Date palm	date-khalas	Yatt_APSIMx	10.7	–	–
27	Date palm	date-khalas	Yatt_Aquacrop	5.4	–	–
28	Cherry tomato	CherTom	Yp_Aquacrop	14.5	16	15.3
29	Cherry tomato	CherTom	Yatt_Aquacrop	2.4	1.6	1.3
30	Alfalfa	Alfa	Yp_Aquacrop	19.9	–	–
31	Alfalfa	Alfa	Yatt_Aquacrop	0.5	–	–
32	Maize	SwCrn	Yp_Aquacrop	15.3	–	–
33	Maize	SwCrn	Yatt_Aquacrop	4.2	–	–
34	Cauliflower	Clflwr	Yp_Aquacrop	19.2	–	–
35	Cauliflower	Clflwr	Yatt_Aquacrop	5.2	–	–
36	Watermelon	WtrMln	Yp_Aquacrop	28.6	27.7	26.6
37	Watermelon	WtrMln	Yatt_Aquacrop	5.8	5.8	4.8
38	Potato	Pot	Yp_Aquacrop	73.6	–	–
39	Potato	Pot	Yatt_Aquacrop	9.1	–	–

No	Crop	Code	Yield_model	OF	SH	GH
40	Onion	Onn	Yp_Aquacrop	36.4	–	–
41	Onion	Onn	Yatt_Aquacrop	5.5	–	–
42	Broccoli	Brcl	Yp_Aquacrop	21.4	–	–
43	Broccoli	Brcl	Yatt_Aquacrop	6.6	–	–
44	Sweet melon	SwtMln	Yp_Aquacrop	33.5	33.4	31
45	Sweet melon	SwtMln	Yatt_Aquacrop	5.8	7	5.7
46	Quinoa	Qin	Yp_Aquacrop	3.3	–	–
47	Quinoa	Qin	Yatt_Aquacrop	2	–	–
48	Parsley	Prsly	Yp_Aquacrop	10.9	11.2	9.3
49	Parsley	Prsly	Yatt_Aquacrop	2.2	1.7	1.4
50	Sweet potato	SwtPot	Yp_Aquacrop	19.3	19.5	19.4
51	Sweet potato	SwtPot	Yatt_Aquacrop	3.5	2.6	2.1
52	Carrot	Car	Yp_Aquacrop	31.6	–	–
53	Carrot	Car	Yatt_Aquacrop	4.7	–	–
54	Pumpkin	Pmkn	Yp_Aquacrop	25.5	26.4	23.4
55	Pumpkin	Pmkn	Yatt_Aquacrop	6.7	2.7	3.1
56	Turnip	Tnp	Yp_Aquacrop	16.1	–	–
57	Turnip	Tnp	Yatt_Aquacrop	3	–	–
58	Common bean	Bean	Yp_Aquacrop	4.8	4	3
59	Common bean	Bean	Yatt_Aquacrop	0.5	0.4	0.3
60	Jute mallow	Mlky	Yp_Aquacrop	7.6	–	–
61	Jute mallow	Mlky	Yatt_Aquacrop	1.7	–	–
62	Beetroot	BtRoot	Yp_Aquacrop	16.9	–	–
63	Beetroot	BtRoot	Yatt_Aquacrop	4.3	–	–
64	Okra	Okr	Yp_Aquacrop	10.4	10.4	9.9
65	Okra	Okr	Yatt_Aquacrop	3	2	1.8
66	Banana	Bna	Yp_Aquacrop	19.7	19.8	19.3
67	Banana	Bna	Yatt_Aquacrop	5.8	3.7	3.6
68	Papaya	Ppya	Yp_Aquacrop	29.6	29.8	29
69	Papaya	Ppya	Yatt_Aquacrop	9.1	5.3	5.1

No	**Crop**	**Code**	**Yield_model**	**OF**	**SH**	**GH**
70	Leucaena	Lcna	Yp_Aquacrop	24.4	–	–
71	Leucaena	Lcna	Yatt_Aquacrop	6.9	–	–
72	Fig	Fig	Yp_Aquacrop	14.4	14.5	14.1
73	Fig	Fig	Yatt_Aquacrop	5.7	1	1.9
74	Pomegranate	Pmgrnt	Yp_Aquacrop	14.8	14.9	14.5
75	Pomegranate	Pmgrnt	Yatt_Aquacrop	7.3	2.4	2.6
76	Butternut squash	BttNt	Yp_Aquacrop	28.7	28.5	26.6
77	Butternut squash	BttNt	Yatt_Aquacrop	6.9	5.5	6.1
78	Buffel grass	Buffl	Yp_Aquacrop	44.7	–	–
79	Buffel grass	Buffl	Yatt_Aquacrop	12.1	–	–
80	Orange	Orng	Yp_Aquacrop	49.2	49.5	48.2
81	Orange	Orng	Yatt_Aquacrop	12.1	9	9.4
82	Cassava	Kasf	Yp_Aquacrop	27.2	–	–
83	Cassava	Kasf	Yatt_Aquacrop	4.1	–	–
84	Grape	Grp	Yp_Aquacrop	42.4	36.2	35.1
85	Grape	Grp	Yatt_Aquacrop	10.2	7.9	22.8
86	Moringa	Mrnga	Yp_Aquacrop	24.4	–	–
87	Moringa	Mrnga	Yatt_Aquacrop	6.5	–	–
88	Rhodes grass	RhdGrs	Yp_Aquacrop	41.8	–	–
89	Rhodes grass	RhdGrs	Yatt_Aquacrop	14.6	–	–
90	Radish	Rad	Yp_Aquacrop	35.5	–	–
91	Radish	Rad	Yatt_Aquacrop	13.4	–	–
92	Ziziphus (sidr)	sider	Yp_Aquacrop	24.5	–	–
93	Ziziphus (sidr)	sider	Yatt_Aquacrop	6	–	–
94	Lemon	Lmn	Yp_Aquacrop	11.7	11.8	11.3
95	Lemon	Lmn	Yatt_Aquacrop	0.8	0.2	0.4
96	Sesbania	Ssbnia	Yp_Aquacrop	19.4	–	–
97	Sesbania	Ssbnia	Yatt_Aquacrop	5.8	–	–
98	Guava	Gva	Yp_Aquacrop	14.8	14.8	14.4
99	Guava	Gva	Yatt_Aquacrop	2.4	2.2	2.9

No	Crop	Code	Yield_model	OF	SH	GH
100	Mango	Mang	Yp_Aquacrop	16.3	–	–
101	Mango	Mang	Yatt_Aquacrop	3.8	–	–
102	Napier grass	Napr	Yp_Aquacrop	43.5	–	–
103	Napier grass	Napr	Yatt_Aquacrop	10.6	–	–
104	Local almond	LclAlmnd	Yp_Aquacrop	19.3	–	–
105	Local almond	LclAlmnd	Yatt_Aquacrop	6.8	–	–
106	Panicum	Pncm	Yp_Aquacrop	48.7	–	–
107	Panicum	Pncm	Yatt_Aquacrop	12.4	–	–
108	Strawberry	Strwb	Yp_Aquacrop	–	13.9	12.9
109	Strawberry	Strwb	Yatt_Aquacrop	–	2.4	2.1
110	Raspberry	Rspbry	Yp_Aquacrop	–	23.5	22.5
111	Raspberry	Rspbry	Yatt_Aquacrop	–	4.9	4.3
112	Blueberry	Blbry	Yp_Aquacrop	–	14.6	14
113	Blueberry	Blbry	Yatt_Aquacrop	–	3.4	2.7

3.2. Crop sensitivity analysis

The common variables used for the sensitivity analysis of 51 crops, including optimal and absolute values for soil salinity in dS/m of the extract (ECe-opt and ECe-abs) and irrigation water salinity in dS/m (ECw-opt and ECw-abs), as well as minimum and maximum optimal and absolute seasonal average air temperatures (T-min-opt, T-max-opt, T-min-abs, and T-max-abs), are summarized in Table 10. As AquaCrop does not include a pH input, the sensitivity to pH was only analysed using APSIMx for the seven vegetables and date palm.

A review of the pH range for various crops shows that date palm has an optimal pH range of 6 to 8, with an absolute pH tolerance of 3 to 12. In contrast, the average pH range for vegetable crops, which include aubergine, cabbage, tomato, lettuce, marrow, cucumber and sweet pepper, shows an optimal pH range of 5.07 to 8.43 and an absolute pH tolerance of 4.36 to 9. This information highlights the broader pH adaptability of date palms compared to the more specific requirements of vegetable crops.

Sensitivity analysis of the extra key limiting factors for date palms using APSIMx and AquaCrop was conducted because of its significance in the Abu Dhabi Emirate. The results indicate that date palm thrives at a VPD above 0.9 kPa, with a plant-available water content (PAWC) of 30 percent, ensuring sufficient moisture retention. The N requirement was 150 kg/ha to support optimal growth. Deep rooting requires a minimum hardpan depth of 2 m, and since date palms do not tolerate root submersion, the optimal groundwater table should be above 2 m. The crop exhibits moderate tolerance to groundwater salinity, with an optimal electrical conductivity (EC) threshold below 5 dS/m, whereas absolute tolerance extends up to 30 dS/m before significant physiological stress or yield reduction occurs.

Although both APSIMx and AquaCrop were used to attempt soil-type sensitivity analysis, the models were limited in showing reasonable results. This limitation is mainly due to the fact that under conditions of high nutrient and water availability, soil type and texture do not play a significant role. However, under stress conditions, the plant response is influenced by a combination of factors, such as water limitation and the role of soil type in providing PAWC.

Table 10. Summary of common variables for sensitivity analysis of 51 crops

No.	Crop	ECe-opt	ECe-abs	ECw-opt	ECw-abs	T-min-opt	T-max-opt	T-min-abs	T-max-abs
1	Aubergine	<1.5	13.7	<1	8.31	15	35	10	35
2	Cabbage	<2.5	12.2	<1	8.67	20	32	10	32
3	Tomato	<2	12	<1	8.2	25	32	15	35
4	Lettuce	<0.2	9	<0.5	7.84	15	35	10	35
5	Courgette	<4	14	<2	11	20	32	15	35
6	Cucumber	<2.5	10	<1	7.78	20	32	10	35
7	Sweet pepper	<1	9	<0.5	6.04	25	32	15	35
8	Date palm	<4	32	<2.7	21	30	38	9	45
9	Cherry tomato	3	13	2	8	20	28	7	35
10	Alfalfa	2	16	1	10	21	27	5	45
11	Maize	2	10	1	7	16	24	12	38
12	Sweet melon	3	10	2	7	18	30	9	35
13	Watermelon	1	12	1	8	9	35	15	40
14	Broccoli	4	14	4	9	10	25	5	30
15	Cauliflower	4	14	4	9	10	25	5	30
16	Potato	2	10	1	7	15	25	7	30
17	Onion	1	7	1	5	12	25	4	30
18	Quinoa	15	52	8	50	14	18	2	35
19	Common bean	1	6	1	5	16	28	13	34
20	Beet	4	15	3	10	14	25	4	35
21	Carrot	1	6	1	5	15	24	3	30
22	Pumpkin	2	10	5	8	17	30	6	40
23	Sweet potato	2	11	1	7	18	28	10	38
24	Jute mallow	8	27	5	18	20	37	13	45
25	Okra	8	27	5	18	20	30	12	35
26	Strawberry	1	5	1	5	11	24	8	26
27	Turnip	1	12	1	8	15	25	7	26
28	Parsley	1	5	1	10	11	20	7	28

No.	Crop	ECe-opt	ECe-abs	ECw-opt	ECw-abs	T-min-opt	T-max-opt	T-min-abs	T-max-abs
29	Grape	2	8	1	5	18	30	10	38
30	Leucaena	3	16	2	11	20	32	10	42
31	Napier grass	3	16	2	11	21	40	15	45
32	Panicum	6	24	3	16	4	30	10	35
33	Raspberry	2	6	1	5	17	23	5	28
34	Buffel grass	3	16	2	11	22	37	5	42
35	Butternut squash	5	15	3	10	17	30	6	40
36	Cassava	3	16	2	11	20	29	10	35
37	Radish	1	9	1	6	12	25	3	30
38	Rhodes grass	6	24	3	16	20	37	5	50
39	Blueberry	2	6	1	5	13	20	4	30
40	Local almond	2	7	1	5	12	35	10	40
41	Papaya	6	24	2	16	21	30	12	44
42	Sesbania	2	17	2	11	18	30	10	34
43	Banana	2	7	1	5	22	32	13	38
44	Guava	3	16	2	11	20	28	12	32
45	Lemon	2	8	1	5	15	28	12	36
46	Mango	2	8	1	5	24	30	8	48
47	Orange	2	8	1	5	20	30	13	38
48	Pomegranate	3	16	2	11	23	32	8	40
49	Fig	3	16	2	11	20	30	10	36
50	Moringa	2	12	1	8	20	35	7	48
51	Ziziphus (sidr)	2	8	1	5	15	30	10	40

3.3. Recommendations for high suitability but uncultivated crops in the Abu Dhabi Emirate

The report concludes by recommending high-value crop species with high suitability potential that are currently uncultivated in the Abu Dhabi Emirate. These recommendations, detailed in Appendix 4, consider the emirate's geographical and biophysical characteristics along with the economic value of the crops, including a detailed analysis of each crop's suitability and specific recommendations for their potential integration into the agriculture of the Abu Dhabi Emirate. Given the arid climate, high temperatures, and saline soils of the emirate, conventional agriculture faces significant challenges. To enhance food security and sustainability, this assessment evaluated 11 underutilized crops with promising adaptability and economic benefits. These crops – jatropha (*Jatropha curcas*), castor bean (*Ricinus communis*), camelina (*Camelina sativa*), teff (*Eragrostis tef*), purslane (*Portulaca oleracea*), safflower (*Carthamus tinctorius*), jojoba (*Simmondsia chinensis*), guayule (*Parthenium argentatum*), sweet sorghum (*Sorghum bicolor*), prickly pear (*Opuntia ficus-indica*), and coconut (*Cocos nucifera*) – were assessed based on temperature tolerance, water requirements, salinity tolerance, and overall suitability to the region's environmental conditions.

Among the evaluated crops, purslane, prickly pear, jatropha, and jojoba demonstrated the highest adaptability because of their resilience to extreme temperatures, low water requirements, and strong salinity tolerance. Moderately suitable crops include guayule, sweet sorghum, safflower, and castor bean, which require moderate water and salinity. In contrast, teff and coconut exhibited limited suitability owing to higher water and humidity demands, making them less viable for large-scale cultivation in the Abu Dhabi Emirate.

4. Conclusion

This assessment provides an in-depth analysis of yield simulations for 51 crops, including annuals, perennials, and fruit trees, under different growing conditions, such as OF, SH, and GH. Using the APSIMx and AquaCrop modelling tools, this report highlights the effects of environmental and biophysical variables on crop yields, including climatic conditions, soil pH, and soil and water salinity. Different models were used owing to data availability and to capitalize on the strengths and limitations of each model to meet the objectives of this study. The results provided RFs for the key growth drivers for each crop at each site. These results were integrated into a crop suitability rating by upscaling the RFs across all operational farms in the Abu Dhabi Emirate. Finally, the results of the crop suitability assessment can be used extensively in decision support tool to improve agricultural productivity and sustainability.

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Appendix A 1. Methodological approach for yield simulation using the Agricultural Production Systems sIMulator (next generation) (APSIMx) and AquaCrop models for aubergine and cabbage

A1.1. The Agricultural Production Systems sIMulator (next generation) (APSIMx)-Simple Crop Resource Uptake Model (SCRUM)

In yield simulation models, such as APSIMx, the input data on cultivars is crucial because it influences the accuracy of predictions related to yield, root stover and phenology. Each cultivar possesses unique genetic characteristics that determine its responses to various environmental conditions. These responses included growth rates, yield potential, root biomass production, and developmental phases (phenology). By incorporating specific cultivar data, APSIMx can simulate these aspects more accurately in different scenarios. This precision is vital for farmers and researchers in planning and optimizing agricultural practices, such as selecting the most suitable cultivar for a given environment, understanding the timing of planting and harvesting, and estimating the potential yield and biomass production under varying climate and soil conditions. Therefore, detailed cultivar data enable APSIMx to provide more tailored and realistic predictions, thus enhancing the decision-making processes in agriculture.

In the context of vegetable crop modelling, the Simple Crop Resource Uptake Model (SCRUM) package, as a simple crop resource uptake model, may be used as a tool to provide and manage cultivar information. This model was built using the Plant Modelling Framework (PMF) (Brown *et al.*, 2014) to simulate a range of different crops where water and N balances are of interest.

The SCRUM model utilizes sigmoidal functions to estimate daily changes in plant cover and biomass, thereby providing a realistic assessment of water and N demands for crops. Unlike models that directly simulate potential yield, SCRUM requires potential yield as an input, focusing instead on the impact of environmental factors on yield. This highlights that actual yields may fall below the potential yield if soil resources, particularly N and water, are insufficient to meet crop demands. This approach is essential for understanding and managing crop growth under varying environmental conditions, making it a valuable tool for precision agriculture.

The SCRUM model has a simple phenology model that divides crop growth into three main phases: a vegetative phase when the canopy is expanding, a reproductive phase when the product is being formed, and a senescing phase when the canopy is contracting (Table A1.1). The phenology growing degree days (GDD) formula is shown by Equation 1, as follows:

$GDD = \Sigma ni = 1\ [(Tmax + Tmin)/2] - Tbase$ *Equation 1* where Tmax is the maximum temperature, Tmin is the minimum temperature and Tbase is the minimum temperature below which the crop stops developing.

The model has multiple organ classes to represent different biomass components, and the real biomass components of these classes represent changes from crop to crop:

- A simple leaf class, called *stover*, represents the unharvested parts of the plant. Generally, this represents the leaf and stem components of the crop, but for crops where stems and leaves are part of the harvested product (such as forages and leafy vegetables), stover is the residual fraction of leaves and stems that are not harvested.
- A generic organ class called a plant *product* represents the plant parts that are harvested and removed from the field. This could represent grain, fruits, tubers, leaves, or stems, depending on the type of crop being represented.
- A *root* is a plant organ class that extracts water and N from the soil for plant growth and returns biomass to the soil during harvest.
- A *nodule* is a plant organ class which is activated and fixes N in leguminous crops.
- An *arbitrator* is also included, which determines the allocation of dry matter and N biomass between each of these organs.

Table A1.1. Phenology stages in the Agricultural Production Systems sIMulator (next generation) (APSIMx)

Phase number	Phase name	Initial stage	Final stage
1	Germinating	Sowing	Germination
2	Emerging	Germination	Emergence
3	CanopyExpanding	Emergence	StartReproductive
4	YieldIncreasing	StartReproductive	StartSenescence
5	Senescing	StartSenescence	EndReproductive
6	Mature	EndReproductive	Maturity
7	ReadyForHarvesting	Maturity	Unused

Source: **APSIM (Agricultural Production Systems sIMulator) Initiative.** (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

A1.2. Methodological approach

A1.2.1. General data overview

The key agronomic and environmental parameters for the two sample crops, aubergine and cabbage, cultivated in an open-field system at the Al Salamat site in Al Ain during the 2017/18 growing season are presented in Table A1.2. The data were primarily derived from experimental studies conducted under lysimeter-equipped conditions to monitor water use and crop performance for key vegetables (EAD, 2018b; Al-Tamimi *et al*., 2022; ADAFSA, personal communication, 2023).

Table A1.2. General data overview for aubergine and cabbage

Parameter	**Aubergine**	**Cabbage**	**Unit**
Location	AL Salamat, Al Ain	AL Salamat, Al Ain	–
Coordinate	24°12'56" N, 55°35'57" E	24°12'56" N, 55°35'57" E	–
Production system	Open field	Open field	–
Year	2017/18	2017/18	–
Sowing date	16 Oct 2017	16 Oct 2017	–
End sowing	26 Oct 2017	23 Oct 2017	–
Harvest date	19 Feb 2018	19 Feb 2018	–
End of harvesting	29 Feb 2018	23 Feb 2018	–
Planting type	Seedling	Seedling	–
Sowing depth	50	50	mm
Plant space area	1 m × 0.5 m = 0.5	1 m × 0.5 m = 0.5	m^2
Density	20 000	20 000	plants/ha
Root depth	0.7	0.7	m
Soil	Top layer (15 cm) from a mix of one part sand + one part compost + one part potting mix only for the crops equipped with lysimeters	Top layer (15 cm) from a mix of one part sand + one part compost + one part potting mix only for the crops equipped with lysimeters	–
Original soil type	Sandy	Sandy	–
pH	8	8	–
Dry bulk density of original soil	1.28	1.28	kg/L

Parameter	Aubergine	Cabbage	Unit
Soil water content for topsoil	34	36	%
Crop duration	16	18	weeks
Total irrigation	162	185	L/plant
Total drainage	47	48	L/plant
Total crop ETc	115	136	L/plant
Leaching fraction	29	26	%
Crop yield	3.21	3.28	kg/plant
Yield (ADAFSA)	64	66	t/ha
Efficient irrigation (150% ETc)	172.5	204	L/plant
Actual WUE	19.8	17.7	kg crop/m^3 water
Efficient WUE	20.1	16.9	kg crop/m^3 water
Total urea	20	20	kg/donum
Total NPK	–	–	kg/donum
Total potassium nitrate	54	35	kg/donum
Total magnesium sulphate	12	6	kg/donum
Total calcium nitrate	25	–	kg/donum
Total ammonium sulphate	15	50	kg/donum
Total chelated iron (Fe-EDDHA)*	2	1.8	kg/donum
Total potassium sulphate	–	–	kg/donum
Total trace element mix	–	1.8	kg/donum

* Fe-EDDHA = ethylenediamine-N,N′-bis(2-hydroxyphenylacetic acid).

Note: ETC = crop evapotranspiration, WUE = water use efficiency, NPK = nitrogen, phosphorus and potassium. A donum is the equivalent of 1 000 m^2 or a tenth of a hectare.

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

A1.2.2. Phenology

The key crop growth stage parameters for the two sample crops, aubergine and cabbage, used in the APSIMx model are presented in Table A1.3. These include the duration of each growth phase (initial, developmental, mid-season, and late season) and their corresponding crop coefficient (Kc) values. For instance, the initial phase duration was 30 days for aubergine and 40 days for cabbage, each with a Kc of 0.15.

The key cultivar-specific parameters for aubergine and cabbage used in the APSIMx-SCRUM model are listed in Table A1.4. These parameters covered various modules within the model, including phenology, product, root, and stover. Each setting, such as CanopyExpanding.Target.FixedValue or Root.MaximumRootDepth.FixedValue, is designated as calibrated, user-defined or maintained as a default value. In the absence of detailed cultivar information, the data were primarily derived from experimental trials and APSIMx-SCRUM model calibration exercises and were essential for accurately simulating the growth dynamics and yield potential of the selected cultivars under local conditions (Brown *et al.*, 2014).

Table A1.3. Duration of growing phases under crop development and corresponding crop factors for aubergine

Parameter	Aubergine	Cabbage	Unit
Length of initial phase	30	40	day
Length of developing phase	40	60	day
Length of mid-season	50	50	day
Length of end phase	20	15	day
Crop factor_Kc initial	0.15	0.15	n/a
Crop factor_Kc mid	1	0.95	n/a
Crop factor_Kc end	0.8	0.85	n/a

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

Table A1.4. The Agricultural Production Systems sIMulator (next generation) (APSIMx)-Simple Crop Resource Uptake Model (SCRUM) model specifics for aubergine and cabbage cultivar characteristics

Aubergine	Cabbage
[Phenology].CanopyExpanding.Target.FixedValue **= 1 186 (calculated using GDD equation)** **[Phenology].Senescing.Target.FixedValue** **= 750 (calibrated)** **[Phenology].YieldIncreasing.Target.FixedValue** **= 914.0 (calibrated)** **[Product].DryMatterContent.FixedValue** **= 0.10 (calibrated)** **[Product].ExpectedYield.FixedValue** **= 6 500 (user-specified)** **[Product].HarvestIndex.FixedValue** **= 0.6 (calibrated)** **[Root].KLModifier.XYPairs.Y** **= 1,1,1,1,1,1,1,0.472,0.223,0.105,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0 (default)** **[Root].MaximumNConc.FixedValue** **= 0.01 (default)** **[Root].MaximumRootDepth.FixedValue** **= 700 (default)** **[Root].MinimumNConc.FixedValue** **= 0.01 (default)** **[Root].RootProportion.FixedValue** **= 0.1 (default)** **[Stover].Cover.Expanding.SigCoverFunction.Xo.FixedValue** **= 690 (default)** **[Stover].Cover.Expanding.SigCoverFunction.Ymax.FixedValue** **= 0.96 (default)** **[Stover].Cover.Expanding.SigCoverFunction.b.FixedValue** **= 120 (default)** **[Stover].MaximumNConc.FixedValue** **= 0.02 (default)** **[Stover].MinimumNConc.FixedValue** **= 0.02 (default)** **[Stover].XoBiomass.FixedValue** **= 1350.0 (default)** **[Stover].bBiomass.FixedValue** **= 255.0 (calibrated)**	[Nodule].FixationMetabolicCost.FixedValue = 0 (not used) [Nodule].FixationRate.FixedValue = 0 (not used) [Phenology].CanopyExpanding.Target.FixedValue = 550 (calibrated) [Phenology].Senescing.Target.FixedValue = 800 (calibrated) [Phenology].YieldIncreasing.Target.FixedValue = 1 210 (calculated using GDD equation) [Product].DryMatterContent.FixedValue = 0.10 (calibrated) [Product].ExpectedYield.FixedValue = 7 000 (user-specified) [Product].HarvestIndex.FixedValue = 0.80 (calibrated) [Product].MaximumNConc.FixedValue = 0.026 (default) [Product].MinimumNConc.FixedValue = 0.0182 (default) [Root].KLModifier.XYPairs.Y = 1,1,1,1,1,1,1,0.472,0.223,0.105,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0 (default) [Root].MaximumNConc.FixedValue = 0.009 (default) [Root].MaximumRootDepth.FixedValue = 500 (default) [Root].MinimumNConc.FixedValue = 0.009 (default) [Root].RootProportion.FixedValue = 0.1 (default) [Stover].Cover.Expanding.SigCoverFunction.Xo.FixedValue = 360 (default) [Stover].Cover.Expanding.SigCoverFunction.Ymax.FixedValue = 0.8 (default) [Stover].Cover.Expanding.SigCoverFunction.b.FixedValue = 120 (default) [Stover].MaximumNConc.FixedValue = 0.03 (default)

Aubergine	**Cabbage**
	[Stover].MinimumNConc.FixedValue = 0.03 (default) [Stover].XoBiomass.FixedValue = 1 500 (default) [Stover].bBiomass.FixedValue = 295 (default)

Source: **APSIM (Agricultural Production Systems sIMulator) Initiative.** (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

A1.2.3. Irrigation schedule

The key parameters used to characterize the irrigation schedules for aubergine and cabbage are presented in Table A1.5 and Table A1.6. These included the daily irrigation time per plant (in minutes), recorded on a weekly basis, with a fixed flow rate of 4 L/h (EAD, 2018). As required by the APSIMx platform, irrigation values were converted to millimetres (mm) using the daily irrigation time and plant spacing area. The conversion was performed using the following equation:

Daily irrigation (mm) = irrigation time (mins/plant) × flow rate (L/hr) × 1 000 000/plant spacing area (mm^2/plant)

In accordance with local irrigation practices, no irrigation was applied on Fridays. Instead, the scheduled irrigation time for Friday was split evenly and added to the irrigation times for the preceding and following days, resulting in an irrigation value of 0 mm for Fridays (EAD, 2018).

The APSIMx format irrigation schedule was organized based on the amount of irrigation, expressed in mm, and an efficiency index. The efficiency was calculated by dividing the ETc (L/plant/day) by the values shown in the irrigation column (L/plant/day) (Figure A1.1).

Table A1.5. Daily irrigation schedule for aubergine

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
1	16/10/2017	12	0.80	1.6	0.73	0.91
2	17/10/2017	12	0.80	1.6	0.73	0.91
3	18/10/2017	12	0.80	1.6	0.73	0.91
4	19/10/2017	18	1.20	2.4	0.73	0.61
5	20/10/2017	0	0.00	0.0	0.73	
6	21/10/2017	18	1.20	2.4	0.73	0.61
7	22/10/2017	12	0.80	1.6	0.73	0.91

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
8	23/10/2017	15	1.00	2.0	0.89	0.89
9	24/10/2017	15	1.00	2.0	0.89	0.89
10	25/10/2017	15	1.00	2.0	0.89	0.89
11	26/10/2017	22.5	1.50	3.0	0.89	0.59
12	27/10/2017	0	0.00	0.0	0.89	
13	28/10/2017	22.5	1.50	3.0	0.89	0.59
14	29/10/2017	15	1.00	2.0	0.89	0.89
15	30/10/2017	17	1.13	2.3	1.01	0.89
16	31/10/2017	17	1.13	2.3	1.01	0.89
17	1/11/1/2017	17	1.13	2.3	1.01	0.89
18	2/11/2/2017	25.5	1.70	3.4	1.01	0.59
19	3/11/3/2017	0	0.00	0.0	1.01	
20	4/11/4/2017	25.5	1.70	3.4	1.01	0.59
21	5/11/5/2017	17	1.13	2.3	1.01	0.89
22	6/11/6/2017	18	1.20	2.4	1.09	0.91
23	7/11/7/2017	18	1.20	2.4	1.09	0.91
24	8/11/8/2017	18	1.20	2.4	1.09	0.91
25	9/11/9/2017	27	1.80	3.6	1.09	0.61
26	10/11/2017	0	0.00	0.0	1.09	
27	11/11/2017	27	1.80	3.6	1.09	0.61
28	12/11/2017	18	1.20	2.4	1.09	0.91
29	13/11/2017	19	1.27	2.5	1.17	0.92
30	14/11/2017	19	1.27	2.5	1.17	0.92
31	15/11/2017	19	1.27	2.5	1.17	0.92
32	16/11/2017	28.5	1.90	3.8	1.17	0.62
33	17/11/2017	0	0.00	0.0	1.17	
34	18/11/2017	28.5	1.90	3.8	1.17	0.62
35	19/11/2017	19	1.27	2.5	1.17	0.92
36	20/11/2017	20	1.33	2.7	1.23	0.92
37	21/11/2017	20	1.33	2.7	1.23	0.92
38	22/11/2017	20	1.33	2.7	1.23	0.92

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
39	23/11/2017	30	2.00	4.0	1.23	0.62
40	24/11/2017	0	0.00	0.0	1.23	
41	25/11/2017	30	2.00	4.0	1.23	0.62
42	26/11/2017	20	1.33	2.7	1.23	0.92
43	27/11/2017	20	1.33	2.7	1.21	0.91
44	28/11/2017	20	1.33	2.7	1.21	0.91
45	29/11/2017	20	1.33	2.7	1.21	0.91
46	30/11/2017	30	2.00	4.0	1.21	0.61
47	1/12/2017	0	0.00	0.0	1.21	
48	2/12/2017	30	2.00	4.0	1.21	0.61
49	3/12/2017	20	1.33	2.7	1.21	0.91
50	4/12/2017	19	1.27	2.5	1.17	0.92
51	5/12/2017	19	1.27	2.5	1.17	0.92
52	6/12/2017	19	1.27	2.5	1.17	0.92
53	7/12/2017	28.5	1.90	3.8	1.17	0.62
54	8/12/2017	0	0.00	0.0	1.17	
55	9/12/2017	28.5	1.90	3.8	1.17	0.62
56	10/12/2017	19	1.27	2.5	1.17	0.92
57	11/12/2017	19	1.27	2.5	1.14	0.90
58	12/12/2017	19	1.27	2.5	1.14	0.90
59	13/12/2017	19	1.27	2.5	1.14	0.90
60	14/12/2017	28.5	1.90	3.8	1.14	0.60
61	15/12/2017	0	0.00	0.0	1.14	
62	16/12/2017	28.5	1.90	3.8	1.14	0.60
63	17/12/2017	19	1.27	2.5	1.14	0.90
64	18/12/2017	19	1.27	2.5	1.17	0.92
65	19/12/2017	19	1.27	2.5	1.17	0.92
66	20/12/2017	19	1.27	2.5	1.17	0.92
67	21/12/2017	28.5	1.90	3.8	1.17	0.62
68	22/12/2017	0	0.00	0.0	1.17	
69	23/12/2017	28.5	1.90	3.8	1.17	0.62

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
70	24/12/2017	19	1.27	2.5	1.17	0.92
71	25/12/2017	20	1.33	2.7	1.21	0.91
72	26/12/2017	20	1.33	2.7	1.21	0.91
73	27/12/2017	20	1.33	2.7	1.21	0.91
74	28/12/2017	30	2.00	4.0	1.21	0.61
75	29/12/2017	0	0.00	0.0	1.21	
76	30/12/2017	30	2.00	4.0	1.21	0.61
77	31/12/2017	20	1.33	2.7	1.21	0.91
78	1/1/2018	21	1.40	2.8	1.27	0.91
79	2/1/2018	21	1.40	2.8	1.27	0.91
80	3/1/2018	21	1.40	2.8	1.27	0.91
81	4/1/2018	31.5	2.10	4.2	1.27	0.60
82	5/1/2018	0	0.00	0.0	1.27	
83	6/1/2018	31.5	2.10	4.2	1.27	0.60
84	7/1/2018	21	1.40	2.8	1.27	0.91
85	8/1/2018	20	1.33	2.7	1.35	1.01
86	9/1/2018	20	1.33	2.7	1.35	1.01
87	10/1/2018	20	1.33	2.7	1.35	1.01
88	11/1/2018	30	2.00	4.0	1.35	0.68
89	12/1/2018	0	0.00	0.0	1.35	
90	13/1/2018	30	2.00	4.0	1.35	0.68
91	14/1/2018	20	1.33	2.7	1.35	1.01
92	15/1/2018	22	1.47	2.9	1.38	0.94
93	16/1/2018	22	1.47	2.9	1.38	0.94
94	17/1/2018	22	1.47	2.9	1.38	0.94
95	18/1/2018	33	2.20	4.4	1.38	0.63
96	19/1/2018	0	0.00	0.0	1.38	
97	20/1/2018	33	2.20	4.4	1.38	0.63
98	21/1/2018	22	1.47	2.9	1.38	0.94
99	22/1/2018	22	1.47	2.9	1.40	0.95
100	23/1/2018	22	1.47	2.9	1.40	0.95

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
101	24/1/2018	22	1.47	2.9	1.40	0.95
102	25/1/2018	33	2.20	4.4	1.40	0.64
103	26/1/2018	0	0.00	0.0	1.40	
104	27/1/2018	33	2.20	4.4	1.40	0.64
105	28/1/2018	22	1.47	2.9	1.40	0.95
106	29/1/2018	23	1.53	3.1	1.40	0.91
107	30/1/2018	23	1.53	3.1	1.40	0.91
108	31/1/2018	23	1.53	3.1	1.40	0.91
109	1/2/2018	34.5	2.30	4.6	1.40	0.61
110	2/2/2018	0	0.00	0.0	1.40	
111	3/2/2018	34.5	2.30	4.6	1.40	0.61
112	4/2/2018	23	1.53	3.1	1.40	0.91
113	5/2/2018	23	1.53	3.1	1.39	0.91
114	6/2/2018	23	1.53	3.1	1.39	0.91
115	7/2/2018	23	1.53	3.1	1.39	0.91
116	8/2/2018	34.5	2.30	4.6	1.39	0.60
117	9/2/2018	0	0.00	0.0	1.39	
118	10/2/2018	34.5	2.30	4.6	1.39	0.60
119	11/2/2018	23	1.53	3.1	1.39	0.91
120	12/2/2018	22	1.47	2.9	1.38	0.94
121	13/2/2018	22	1.47	2.9	1.38	0.94
122	14/2/2018	22	1.47	2.9	1.38	0.94
123	15/2/2018	33	2.20	4.4	1.38	0.63
124	16/2/2018	0	0.00	0.0	1.38	
125	17/2/2018	33	2.20	4.4	1.38	0.63
126	18/2/2018	22	1.47	2.9	1.38	0.94

Note: ET = evapotranspiration.

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

Table A1.6. Daily irrigation schedule for cabbage

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
0	16/10/2017	9.00	0.60	1.20	0.51	0.85
1	17/10/2017	9.00	0.60	1.20	0.51	0.85
2	18/10/2017	9.00	0.60	1.20	0.51	0.85
3	19/10/2017	13.50	0.90	1.80	0.51	0.57
4	20/10/2017	0.00	0.00	0.00	0.51	
5	21/10/2017	13.50	0.90	1.80	0.51	0.57
6	22/10/2017	9.00	0.60	1.20	0.51	0.85
7	23/10/2017	10.00	0.67	1.33	0.57	0.86
8	24/10/2017	10.00	0.67	1.33	0.57	0.86
9	25/10/2017	10.00	0.67	1.33	0.57	0.86
10	26/10/2017	15.00	1.00	2.00	0.57	0.57
11	27/10/2017	0.00	0.00	0.00	0.57	
12	28/10/2017	15.00	1.00	2.00	0.57	0.57
13	29/10/2017	10.00	0.67	1.33	0.57	0.86
14	30/10/2017	10.00	0.67	1.33	0.6	0.90
15	31/10/2017	10.00	0.67	1.33	0.6	0.90
16	1/11/1/2017	10.00	0.67	1.33	0.6	0.90
17	2/11/2/2017	15.00	1.00	2.00	0.6	0.60
18	3/11/3/2017	0.00	0.00	0.00	0.6	
19	4/11/4/2017	15.00	1.00	2.00	0.6	0.60
20	5/11/5/2017	10.00	0.67	1.33	0.6	0.90
21	6/11/6/2017	11.00	0.73	1.47	0.61	0.83
22	7/11/7/2017	11.00	0.73	1.47	0.61	0.83
23	8/11/8/2017	11.00	0.73	1.47	0.61	0.83
24	9/11/9/2017	16.50	1.10	2.20	0.61	0.55
25	10/11/2017	0.00	0.00	0.00	0.61	
26	11/11/2017	16.50	1.10	2.20	0.61	0.55
27	12/11/2017	11.00	0.73	1.47	0.61	0.83
28	13/11/2017	11.00	0.73	1.47	0.62	0.85
29	14/11/2017	11.00	0.73	1.47	0.62	0.85

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
30	15/11/2017	11.00	0.73	1.47	0.62	0.85
31	16/11/2017	16.50	1.10	2.20	0.62	0.56
32	17/11/2017	0.00	0.00	0.00	0.62	
33	18/11/2017	16.50	1.10	2.20	0.62	0.56
34	19/11/2017	11.00	0.73	1.47	0.62	0.85
35	20/11/2017	11.00	0.73	1.47	0.64	0.87
36	21/11/2017	11.00	0.73	1.47	0.64	0.87
37	22/11/2017	11.00	0.73	1.47	0.64	0.87
38	23/11/2017	16.50	1.10	2.20	0.64	0.58
39	24/11/2017	0.00	0.00	0.00	0.64	
40	25/11/2017	16.50	1.10	2.20	0.64	0.58
41	26/11/2017	11.00	0.73	1.47	0.64	0.87
42	27/11/2017	11.00	0.73	1.47	0.66	0.90
43	28/11/2017	11.00	0.73	1.47	0.66	0.90
44	29/11/2017	11.00	0.73	1.47	0.66	0.90
45	30/11/2017	16.50	1.10	2.20	0.66	0.60
46	1/12/2017	0.00	0.00	0.00	0.66	
47	2/12/2017	16.50	1.10	2.20	0.66	0.60
48	3/12/2017	11.00	0.73	1.47	0.66	0.90
49	4/12/2017	12.00	0.80	1.60	0.69	0.86
50	5/12/2017	12.00	0.80	1.60	0.69	0.86
51	6/12/2017	12.00	0.80	1.60	0.69	0.86
52	7/12/2017	18.00	1.20	2.40	0.69	0.58
53	8/12/2017	0.00	0.00	0.00	0.69	
54	9/12/2017	18.00	1.20	2.40	0.69	0.58
55	10/12/2017	12.00	0.80	1.60	0.69	0.86
56	11/12/2017	12.00	0.80	1.60	0.73	0.91
57	12/12/2017	12.00	0.80	1.60	0.73	0.91
58	13/12/2017	12.00	0.80	1.60	0.73	0.91
59	14/12/2017	18.00	1.20	2.40	0.73	0.61
60	15/12/2017	0.00	0.00	0.00	0.73	

Day after planting	**Date**	**Irrigation duration (mins/plant)**	**Irrigation (L/plant)**	**Irrigation (mm/plant)**	**Crop ET (L/plant)**	**Efficiency**
61	16/12/2017	18.00	1.20	2.40	0.73	0.61
62	17/12/2017	12.00	0.80	1.60	0.73	0.91
63	18/12/2017	13.00	0.87	1.73	0.74	0.85
64	19/12/2017	13.00	0.87	1.73	0.74	0.85
65	20/12/2017	13.00	0.87	1.73	0.74	0.85
66	21/12/2017	19.50	1.30	2.60	0.74	0.57
67	22/12/2017	0.00	0.00	0.00	0.74	
68	23/12/2017	19.50	1.30	2.60	0.74	0.57
69	24/12/2017	13.00	0.87	1.73	0.74	0.85
70	25/12/2017	13.00	0.87	1.73	0.77	0.89
71	26/12/2017	13.00	0.87	1.73	0.77	0.89
72	27/12/2017	13.00	0.87	1.73	0.77	0.89
73	28/12/2017	19.50	1.30	2.60	0.77	0.59
74	29/12/2017	0.00	0.00	0.00	0.77	
75	30/12/2017	19.50	1.30	2.60	0.77	0.59
76	31/12/2017	13.00	0.87	1.73	0.77	0.89
77	1/1/2018	14.00	0.93	1.87	0.61	0.65
78	2/1/2018	14.00	0.93	1.87	0.61	0.65
79	3/1/2018	14.00	0.93	1.87	0.61	0.65
80	4/1/2018	21.00	1.40	2.80	0.61	0.44
81	5/1/2018	0.00	0.00	0.00	0.61	
82	6/1/2018	21.00	1.40	2.80	0.61	0.44
83	7/1/2018	14.00	0.93	1.87	0.61	0.65
84	8/1/2018	14.00	0.93	1.87	0.86	0.92
85	9/1/2018	14.00	0.93	1.87	0.86	0.92
86	10/1/2018	14.00	0.93	1.87	0.86	0.92
87	11/1/2018	21.00	1.40	2.80	0.86	0.61
88	12/1/2018	0.00	0.00	0.00	0.86	
89	13/1/2018	21.00	1.40	2.80	0.86	0.61
90	14/1/2018	14.00	0.93	1.87	0.86	0.92
91	15/1/2018	15.00	1.00	2.00	0.93	0.93

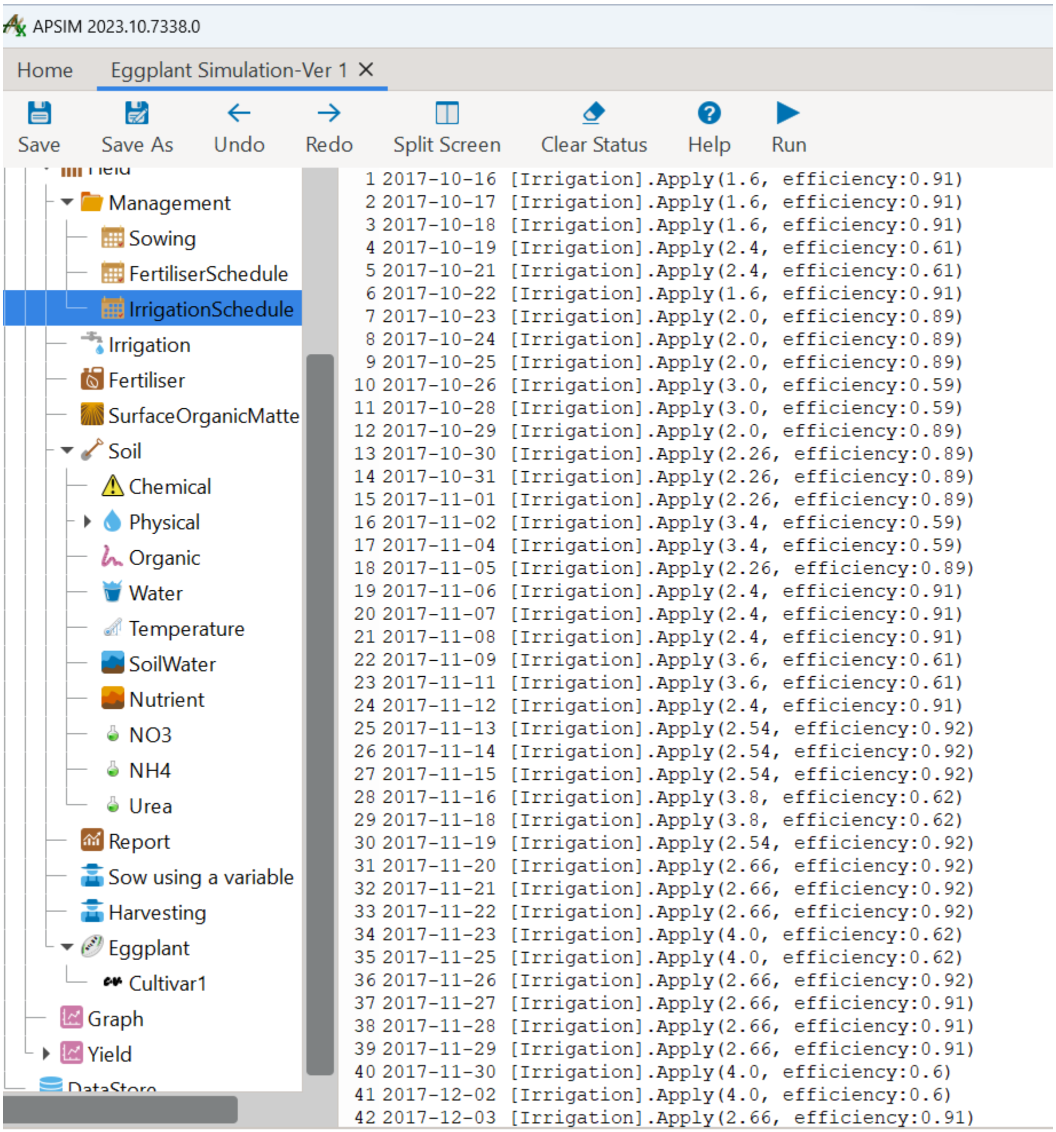
Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
92	16/1/2018	15.00	1.00	2.00	0.93	0.93
93	17/1/2018	15.00	1.00	2.00	0.93	0.93
94	18/1/2018	22.50	1.50	3.00	0.93	0.62
95	19/1/2018	0.00	0.00	0.00	0.93	
96	20/1/2018	22.50	1.50	3.00	0.93	0.62
97	21/1/2018	15.00	1.00	2.00	0.93	0.93
98	22/1/2018	17.00	1.13	2.27	1	0.88
99	23/1/2018	17.00	1.13	2.27	1	0.88
100	24/1/2018	17.00	1.13	2.27	1	0.88
101	25/1/2018	25.50	1.70	3.40	1	0.59
102	26/1/2018	0.00	0.00	0.00	1	
103	27/1/2018	25.50	1.70	3.40	1	0.59
104	28/1/2018	17.00	1.13	2.27	1	0.88
105	29/1/2018	17.00	1.13	2.27	1.05	0.93
106	30/1/2018	17.00	1.13	2.27	1.05	0.93
107	31/1/2018	17.00	1.13	2.27	1.05	0.93
108	1/2/2018	25.50	1.70	3.40	1.05	0.62
109	2/2/2018	0.00	0.00	0.00	1.05	
110	3/2/2018	25.50	1.70	3.40	1.05	0.62
111	4/2/2018	17.00	1.13	2.27	1.05	0.93
112	5/2/2018	18.00	1.20	2.40	1.08	0.90
113	6/2/2018	18.00	1.20	2.40	1.08	0.90
114	7/2/2018	18.00	1.20	2.40	1.08	0.90
115	8/2/2018	27.00	1.80	3.60	1.08	0.60
116	9/2/2018	0.00	0.00	0.00	1.08	
117	10/2/2018	27.00	1.80	3.60	1.08	0.60
118	11/2/2018	18.00	1.20	2.40	1.08	0.90
119	12/2/2018	18.00	1.20	2.40	1.1	0.92
120	13/2/2018	18.00	1.20	2.40	1.1	0.92
121	14/2/2018	18.00	1.20	2.40	1.1	0.92
122	15/2/2018	27.00	1.80	3.60	1.1	0.61

Day after planting	Date	Irrigation duration (mins/plant)	Irrigation (L/plant)	Irrigation (mm/plant)	Crop ET (L/plant)	Efficiency
123	16/2/2018	0.00	0.00	0.00	1.1	
124	17/2/2018	27.00	1.80	3.60	1.1	0.61
125	18/2/2018	18.00	1.20	2.40	1.1	0.92

Note: ET = evapotranspiration.

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi. **Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B**. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

Figure A1.1. The Agricultural Production Systems sIMulator (next generation) (APSIMx) format irrigation schedule for aubergine



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2017-10-16 [Irrigation].Apply(1.6, efficiency:0.91)
2017-10-17 [Irrigation].Apply(1.6, efficiency:0.91)
2017-10-18 [Irrigation].Apply(1.6, efficiency:0.91)
2017-10-19 [Irrigation].Apply(2.4, efficiency:0.61)
2017-10-21 [Irrigation].Apply(2.4, efficiency:0.61)
2017-10-22 [Irrigation].Apply(1.6, efficiency:0.91)
2017-10-23 [Irrigation].Apply(2.0, efficiency:0.89)
2017-10-24 [Irrigation].Apply(2.0, efficiency:0.89)
2017-10-25 [Irrigation].Apply(2.0, efficiency:0.89)
2017-10-26 [Irrigation].Apply(3.0, efficiency:0.59)
2017-10-28 [Irrigation].Apply(3.0, efficiency:0.59)
2017-10-29 [Irrigation].Apply(2.0, efficiency:0.89)
2017-10-30 [Irrigation].Apply(2.26, efficiency:0.89)
2017-10-31 [Irrigation].Apply(2.26, efficiency:0.89)
2017-11-01 [Irrigation].Apply(2.26, efficiency:0.89)
2017-11-02 [Irrigation].Apply(3.4, efficiency:0.59)
2017-11-04 [Irrigation].Apply(3.4, efficiency:0.59)
2017-11-05 [Irrigation].Apply(2.26, efficiency:0.89)
2017-11-06 [Irrigation].Apply(2.4, efficiency:0.91)
2017-11-07 [Irrigation].Apply(2.4, efficiency:0.91)
2017-11-08 [Irrigation].Apply(2.4, efficiency:0.91)
2017-11-09 [Irrigation].Apply(3.6, efficiency:0.61)
2017-11-11 [Irrigation].Apply(3.6, efficiency:0.61)
2017-11-12 [Irrigation].Apply(2.4, efficiency:0.91)
2017-11-13 [Irrigation].Apply(2.54, efficiency:0.92)
2017-11-14 [Irrigation].Apply(2.54, efficiency:0.92)
2017-11-15 [Irrigation].Apply(2.54, efficiency:0.92)
2017-11-16 [Irrigation].Apply(3.8, efficiency:0.62)
2017-11-18 [Irrigation].Apply(3.8, efficiency:0.62)
2017-11-19 [Irrigation].Apply(2.54, efficiency:0.92)
2017-11-20 [Irrigation].Apply(2.66, efficiency:0.92)
2017-11-21 [Irrigation].Apply(2.66, efficiency:0.92)
2017-11-22 [Irrigation].Apply(2.66, efficiency:0.92)
2017-11-23 [Irrigation].Apply(4.0, efficiency:0.62)
2017-11-25 [Irrigation].Apply(4.0, efficiency:0.62)
2017-11-26 [Irrigation].Apply(2.66, efficiency:0.92)
2017-11-27 [Irrigation].Apply(2.66, efficiency:0.91)
2017-11-28 [Irrigation].Apply(2.66, efficiency:0.91)
2017-11-29 [Irrigation].Apply(2.66, efficiency:0.91)
2017-11-30 [Irrigation].Apply(4.0, efficiency:0.6)
2017-12-02 [Irrigation].Apply(4.0, efficiency:0.6)
2017-12-03 [Irrigation].Apply(2.66, efficiency:0.91)
```

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

EAD (Environment Agency – Abu Dhabi). 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.

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A1.2.4. Fertilizer guidelines

A range of fertilizers, each with specific chemical compositions essential for plant nutrition, were applied to support the growth of both aubergine and cabbage (EAD, 2018). The key parameters used to characterize the fertilizer schedules for these two crops are presented (Table A1.7 and Table A1.8). Originally reported in units of kg/dunum in the EAD (2018) report, application rates were converted to APSIMx-compatible units of kg/ha by applying a conversion factor of 10. It should be noted that APSIMx does not support all fertilizer types, by default. Therefore, while some fertilizers are directly compatible and can be entered as is, others require approximation using the equivalent components available in the model.

For instance, in the case of calcium nitrate ($Ca[NO_3]_2$), which was applied in the experimental setup, its chemical composition (calcium [Ca] at 24.42 percent, N at 17.07 percent and oxygen [O] at 58.5 percent) was used to determine an equivalent representation in APSIMx. Accordingly, 25 percent of the total $Ca(NO_3)_2$ amount was represented as CalciteFine, and 60 percent as nitrate. The APSIMx-format fertilizer schedule table was organized by the chemical component labels recognized by the model, with the quantities expressed in kg/ha. Additionally, each application was linked to the corresponding soil depth in mm (Figure A1.2).

The total amount of fertilizer applied (measured in kg/ha) is presented in Table A1.9 and Table A1.10 for aubergine and cabbage, respectively.

The EAD (2018) report contains typographical errors in the fertilizer tables, specifically in the fractional values reported for $Ca(NO_3)_2$ and magnesium sulphate ($MgSO_4$). Following confirmation from the data received through ADAFSA (personal communication, 2024), these values were corrected by excluding the fractional components, resulting in a more accurate representation of total fertilizer application.

Table A1.7. Fertilizer application schedule for aubergine

Date	Fertilizer	Chemical formula	Amount (kg/ha)
30/10/2017	Urea	$CO(NH_2)_2$	50
6/11/2017	Urea	$CO(NH_2)_2$	50
13/11/2017	Urea	$CO(NH_2)_2$	50
20/11/2017	Urea	$CO(NH_2)_2$	50
30/10/2017	Magnesium sulphate	$MgSO_4$	10
6/11/2017	Magnesium sulphate	$MgSO_4$	20

Date	Fertilizer	Chemical formula	Amount (kg/ha)
13/11/2017	Magnesium sulphate	$MgSO_4$	20
20/11/2017	Magnesium sulphate	$MgSO_4$	20
27/11/2017	Magnesium sulphate	$MgSO_4$	10
4/12/2017	Magnesium sulphate	$MgSO_4$	10
11/12/2017	Magnesium sulphate	$MgSO_4$	10
18/12/2017	Magnesium sulphate	$MgSO_4$	10
25/12/2017	Magnesium sulphate	$MgSO_4$	10
6/11/2017	Potassium nitrate	KNO_3	40
13/11/2017	Potassium nitrate	KNO_3	50
20/11/2017	Potassium nitrate	KNO_3	70
27/11/2017	Potassium nitrate	KNO_3	70
4/12/2017	Potassium nitrate	KNO_3	20
11/12/2017	Potassium nitrate	KNO_3	20
18/12/2017	Potassium nitrate	KNO_3	30
25/12/2017	Potassium nitrate	KNO_3	30
1/1/2018	Potassium nitrate	KNO_3	30
8/1/2018	Potassium nitrate	KNO_3	30
15/1/2018	Potassium nitrate	KNO_3	30
22/1/2018	Potassium nitrate	KNO_3	30
29/1/2018	Potassium nitrate	KNO_3	30
5/2/5/2018	Potassium nitrate	KNO_3	30
12/2/2018	Potassium nitrate	KNO_3	30
30/10/2017	Chelated iron	Fe-EDDHA	2
6/11/2017	Chelated iron	Fe-EDDHA	2
13/11/2017	Chelated iron	Fe-EDDHA	2
20/11/2017	Chelated iron	Fe-EDDHA	2
27/11/2017	Chelated iron	Fe-EDDHA	1
4/12/2017	Chelated iron	Fe-EDDHA	1
11/12/2017	Chelated iron	Fe-EDDHA	1
18/12/2017	Chelated iron	Fe-EDDHA	1
25/12/2017	Chelated iron	Fe-EDDHA	1
1/1/2018	Chelated iron	Fe-EDDHA	1

Date	Fertilizer	Chemical formula	Amount (kg/ha)
8/1/2018	Chelated iron	Fe-EDDHA	1
15/1/2018	Chelated iron	Fe-EDDHA	1
22/1/2018	Chelated iron	Fe-EDDHA	1
29/1/2018	Chelated iron	Fe-EDDHA	1
5/2/2018	Chelated iron	Fe-EDDHA	1
12/2/2018	Chelated iron	Fe-EDDHA	1
13/11/2017	Calcium nitrate	$Ca(NO_3)_2$	20
20/11/2017	Calcium nitrate	$Ca(NO_3)_2$	20
27/11/2017	Calcium nitrate	$Ca(NO_3)_2$	20
4/12/2017	Calcium nitrate	$Ca(NO_3)_2$	20
11/12/2017	Calcium nitrate	$Ca(NO_3)_2$	20
18/12/2017	Calcium nitrate	$Ca(NO_3)_2$	20
25/12/2017	Calcium nitrate	$Ca(NO_3)_2$	20
1/1/2018	Calcium nitrate	$Ca(NO_3)_2$	20
8/1/2018	Calcium nitrate	$Ca(NO_3)_2$	20
15/1/2018	Calcium nitrate	$Ca(NO_3)_2$	20
22/1/2018	Calcium nitrate	$Ca(NO_3)_2$	20
29/1/2018	Calcium nitrate	$Ca(NO_3)_2$	20
5/2/2018	Calcium nitrate	$Ca(NO_3)_2$	10
27/11/2017	Ammonium sulphate	$(NH_4)_2SO_4$	50
4/12/2017	Ammonium sulphate	$(NH_4)_2SO_4$	50
11/12/2017	Ammonium sulphate	$(NH_4)_2SO_4$	50

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

Table A1.8. Fertilizer application schedule for cabbage

Date	Fertilizer	Chemical formula/element	Amount (kg/ha)
23/10/2017	Ammonium sulphate	$(NH_4)_2SO_4$	30
30/10/2017	Ammonium sulphate	$(NH_4)_2SO_4$	30
6/11/2017	Ammonium sulphate	$(NH_4)_2SO_4$	30
13/11/2017	Ammonium sulphate	$(NH_4)_2SO_4$	40

Date	Fertilizer	Chemical formula/element	Amount (kg/ha)
20/11/2017	Ammonium sulphate	$(NH_4)_2SO_4$	70
27/11/2017	Ammonium sulphate	$(NH_4)_2SO_4$	70
4/12/2017	Ammonium sulphate	$(NH_4)_2SO_4$	70
11/12/2017	Ammonium sulphate	$(NH_4)_2SO_4$	70
18/12/2017	Ammonium sulphate	$(NH_4)_2SO_4$	70
25/12/2017	Ammonium sulphate	$(NH_4)_2SO_4$	20
30/10/2017	Potassium nitrate	KNO_3	30
6/11/2017	Potassium nitrate	KNO_3	30
13/11/2017	Potassium nitrate	KNO_3	30
20/11/2017	Potassium nitrate	KNO_3	50
27/11/2017	Potassium nitrate	KNO_3	50
4/12/2017	Potassium nitrate	KNO_3	50
11/12/2017	Potassium nitrate	KNO_3	50
18/12/2017	Potassium nitrate	KNO_3	50
25/12/2017	Potassium nitrate	KNO_3	10
30/10/2017	Magnesium sulphate	$MgSO_4$	5
6/11/2017	Magnesium sulphate	$MgSO_4$	10
13/11/2017	Magnesium sulphate	$MgSO_4$	10
20/11/2017	Magnesium sulphate	$MgSO_4$	10
27/11/2017	Magnesium sulphate	$MgSO_4$	10
4/12/2017	Magnesium sulphate	$MgSO_4$	10
11/12/2017	Magnesium sulphate	$MgSO_4$	5
23/10/2017	Chelated iron	Fe-EDDHA	2
30/10/2017	Chelated iron	Fe-EDDHA	2
6/11/2017	Chelated iron	Fe-EDDHA	2
13/11/2017	Chelated iron	Fe-EDDHA	2
20/11/2017	Chelated iron	Fe-EDDHA	2
27/11/2017	Chelated iron	Fe-EDDHA	2
4/12/2017	Chelated iron	Fe-EDDHA	2
11/12/2017	Chelated iron	Fe-EDDHA	2
18/12/2017	Chelated iron	Fe-EDDHA	2

Date	Fertilizer	Chemical formula/element	Amount (kg/ha)
23/10/2017	Trace element mix	Boron (B), molybdenum (Mo), manganese (Mn), copper (Cu), zinc (Zn) and iron (Fe)	2
30/10/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2
6/11/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2
13/11/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2
20/11/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2
27/11/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2
4/12/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2
11/12/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2
18/12/2017	Trace element mix	Boron, Mo, Mn, Cu, Zn and Fe	2

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

Table A1.9. Summary of total fertilizer application for aubergine

Type	$Ca(NO_3)_2$	Fe	KNO_3	$MgSO_4$	$(NH_4)_2SO_4$	Urea
Total amount (kg/ha)	250	20	540	120	150	200

Note: $Ca(NO_3)_2$ = calcium nitrate, Fe = iron, KNO_3 = potassium nitrate, $MgSO_4$ = magnesium sulphate, and $(NH_4)_2SO_4$ = ammonium sulphate.

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

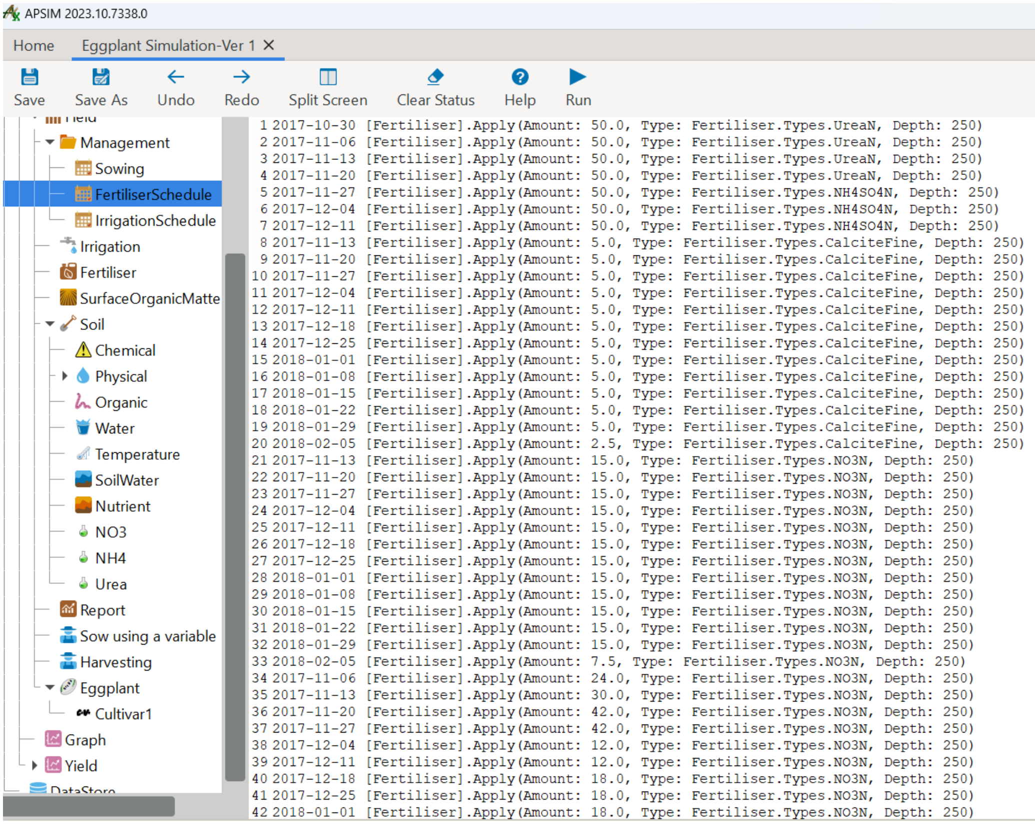
Table A1.10. Summary of total fertilizer application for cabbage

Type	Fe	KNO_3	$MgSO_4$	$(NH_4)_2SO_4$	Trace element mix
Total amount (kg/ha)	18	350	60	500	18

Note: Fe = iron, KNO_3 = potassium nitrate, $MgSO_4$ = magnesium sulphate, and $(NH_4)_2SO_4$ = ammonium sulphate.

Sources: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

Figure A1.2. The Agricultural Production Systems sIMulator (APSIMx) format fertilizer schedule for aubergine



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2017-11-20 [Fertiliser].Apply(Amount: 50.0, Type: Fertiliser.Types.UreaN, Depth: 250)
2017-11-27 [Fertiliser].Apply(Amount: 50.0, Type: Fertiliser.Types.NH4SO4N, Depth: 250)
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2017-11-20 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2017-11-27 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2017-12-04 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2017-12-11 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2017-12-18 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2017-12-25 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2018-01-01 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2018-01-08 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2018-01-15 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
2018-01-22 [Fertiliser].Apply(Amount: 5.0, Type: Fertiliser.Types.CalciteFine, Depth: 250)
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2017-12-04 [Fertiliser].Apply(Amount: 15.0, Type: Fertiliser.Types.NO3N, Depth: 250)
2017-12-11 [Fertiliser].Apply(Amount: 15.0, Type: Fertiliser.Types.NO3N, Depth: 250)
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2018-01-01 [Fertiliser].Apply(Amount: 18.0, Type: Fertiliser.Types.NO3N, Depth: 250)
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Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
EAD (Environment Agency – Abu Dhabi). 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.
Tamimi, M.Al, Green, S., Hammami, Z., Ammar, K., Al Ketbi, M., Al-Shrouf, A. M., Dawoud, M., Kennedy, L. & Clothier, B. 2022. Evapotranspiration and crop coefficients using lysimeter measurements for food crops in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 272: 107826. https://doi.org/10.1016/j.agwat.2022.107826

A1.2.5. Water analysis

Water, nutrient, and chemical analyses were conducted using samples collected from the inflow (representing irrigation water characteristics) and outflow (reflecting drainage water properties) over a six-week period during the mid-season (during the crop development phase). Sampling was carried out exclusively on plants equipped with lysimeter systems to ensure precise measurement of water and nutrient dynamics. These findings provide detailed data relevant to the cultivation of aubergine and cabbage under the monitored field conditions (Table A1.11 and Table A1.12). In addition to the tables provided, the report also highlights that irrigation water – supplied as desalinated water with an EC of 1 dS/m – was used in the experiment, and this value was utilized for modelling purposes.

Table A1.11. Inflow and outflow water, nutrient, and chemical analyses for aubergine

Date	Water sample	pH	EC (dS/m)	TDS (g/L)	SAR	Ca (g/L)	Mg (g/L)	Na (g/L)	K (mg/L)	CO_3 (mg/L)	HCO_3 (g/L)	Cl (g/L)	SO_4 (g/L)
15/12/2017	Inflow	8.5	3.5	2.28	7.43	0.09	0.18	0.45	17	17	0.05	0.73	0.61
	Outflow	8.18	6.55	4.59	6.2	0.41	0.33	0.74	40.25	40.25	0.53	1.28	1.12
21/12/2017	Inflow	8	3.56	2.31	7.68	0.09	0.18	0.46	18	18	0.15	0.7	0.67
	Outflow	7.91	7.87	5.51	6.76	0.5	0.41	0.95	44.5	44.5	0.41	1.46	1.54
27/12/2017	Inflow	7.95	3.65	2.37	8.31	0.09	0.16	0.37	17	17	0.15	0.74	0.39
	Outflow	7.9	9.51	6.65	8.37	0.59	0.49	1.13	45.33	45.33	0.65	2.13	1.37
3/1/2017	Inflow	7.8	3.65	2.37	7.91	0.09	0.19	0.46	21	21	0.15	0.48	0.65
	Outflow	8.4	9.25	6.48	8.72	0.53	0.47	1.13	46.75	46.75	0.58	1.63	1.73
10/1/2017	Inflow	7.8	3.67	2.39	9.01	1	0.18	0.45	21	21	0.15	0.71	0.63
	Outflow	8.34	9.64	6.75	7.94	0.54	0.48	1.15	42.5	42.5	0.56	2.01	1.8
17/1/2017	Inflow	8.3	3.73	2.43	9.67	0.09	0.18	0.43	16	16	0.2	0.74	0.64
	Outflow	8.35	10.9	7.63	9.07	0.57	0.54	1.29	46.25	46.25	0.56	2.38	2.1

Note: EC = electrical conductivity, TDS = total dissolved solids, SAR = sodium adsorption ratio, Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, CO_3 = carbonate, HCO_3 = bicarbonate, Cl = chloride, and SO_4 = sulphate.

Source: ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Table A1.12. Inflow and outflow water, nutrient, and chemical analyses for cabbage

Date	**Water sample**	**PH**	**EC (dS/m)**	**TDS (g/L)**	**SAR**	**Ca (g/L)**	**Mg (g/L)**	**Na (g/L)**	**K (mg/L)**	**CO_3 (mg/L)**	**HCO_3 (g/L)**	**Cl (g/L)**	**SO_4 (g/L)**
15/12/2017	Inflow	8.5	3.5	2.28	7.43	0.09	o.18	0.45	17	17	0.05	0.73	0.61
	Outflow	8.24	5.5	3.74	6.04	0.29	0.31	0.62	27.25	27.25	0.43	1.14	0.84
21/12/2017	Inflow	8	3.56	2.31	7.68	0.09	0.18	0.46	18	18	0.15	0.7	0.67
	Outflow	8.13	5.81	4.01	6.63	0.28	0.33	0.7	30	30	0.36	1.12	0.95
27/12/2017	Inflow	7.95	3.65	2.37	8.31	0.09	0.16	0.37	17	17	0.15	0.74	0.39
	Outflow	8.33	6.3	4.41	7.38	0.31	0.34	0.8	29.67	29.67	0.6	1.27	0.86
3/1/2017	Inflow	7.8	3.65	2.37	7.91	0.09	0.19	0.46	21	21	0.15	0.48	0.65
	Outflow	8.5	6.96	4.87	7.54	0.31	0.38	0.85	33	33	0.6	1.27	1.14
10/1/2017	Inflow	7.8	3.67	2.39	9.01	1	0.18	0.45	21	21	0.15	0.71	0.63
	Outflow	8.59	7.36	5.15	7.36	0.34	0.41	0.87	29.5	29.5	0.63	1.5	1.21
17/1/2017	Inflow	8.3	3.73	2.43	9.67	0.09	0.18	0.43	16	16	0.2	0.74	0.64
	Outflow	8.35	8.45	5.95	8.46	0.31	0.48	1.02	32	32	0.5	1.77	1.46

Notes: Note: EC = electrical conductivity, TDS = total dissolved solids, SAR = sodium adsorption ratio, Ca = calcium, Mg = magnesium, Na = sodium, K = potassium, CO_3 = carbonate, HCO_3 = bicarbonate, Cl = chloride, and SO_4 = sulphate

Source: ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A1.2.6. Soil analysis

Soil samples were collected exclusively from plants equipped with a lysimeter system. The analysis results are presented for aubergine and cabbage (Table A1.13 and Table A1.14). Soil sampling was conducted at a depth of 0–30 cm on 27 March 2018 (ADAFSA, personal communication, 2024). For accurate input into the APSIMx model, EC values were divided by 2.5. A sample input format for the soil parameters in APSIMx is provided for reference in Figure A1.3.

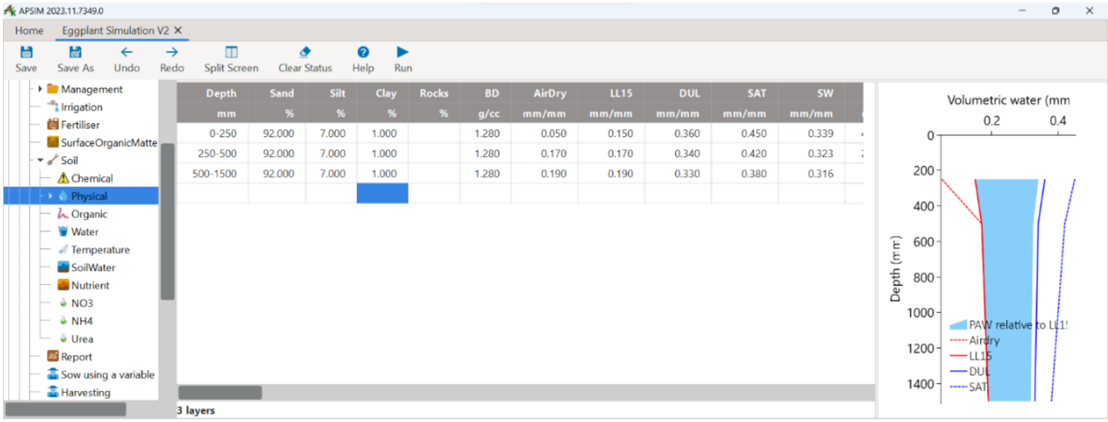
Table A1.13. Analysis results of soil samples for aubergine

Parameter	**Sample no.**				**Average**
	1	*2*	*3*	*4*	
Calcium carbonate ($CaCO_3$) (%)	28.42	30.62	25.48	25.97	27.62
pH	7.90	7.98	7.80	7.90	7.90
Electrical conductivity (EC) (dS/m)	7.35	4.46	7.72	4.29	5.96
Sodium adsorption ratio (SAR)	9.07	6.95	8.87	6.32	7.80
Calcium (Ca) (mg/L)	10.40	6.10	12.60	6.60	8.93
Magnesium (Mg) (mg/L)	30.10	17.00	33.40	17.30	24.45
Sodium (Na) (mg/L)	40.80	23.60	42.50	21.80	32.18
Potassium (K) (mg/L)	1.10	0.70	0.90	0.70	0.85
Chlorine (Cl) (mg/L)	50.60	0.00	1.90	1.60	13.53
Carbonate ion (CO_3) (mg/L)	1.00	1.00	1.00	1.00	1.00
Bicarbonate ion (CO_3) (mg/L)	3.20	3.50	3.50	3.20	3.35
Sulphate ion (SO_4) (mg/L)	20.20	11.60	23.00	12.00	16.70
Av. P (ppm)*****	3.20	3.60	8.90	6.00	5.43
Ex. K (ppm)*****	73.40	64.70	56.20	67.30	65.40
Iron (Fe) (ppm)	5.27	5.41	4.81	5.45	5.24
Copper (Cu) (ppm)	0.55	0.59	0.47	0.61	0.56
Manganese (Mn) (ppm)	3.59	3.47	3.70	4.55	3.83
Zinc (Zn) (ppm)	1.28	1.60	2.47	2.03	1.85
Boron (B) (ppm)	0.65	0.40	0.78	0.93	0.69

* Av. P = available phosphorus and Ex. K = exchangeable potassium.

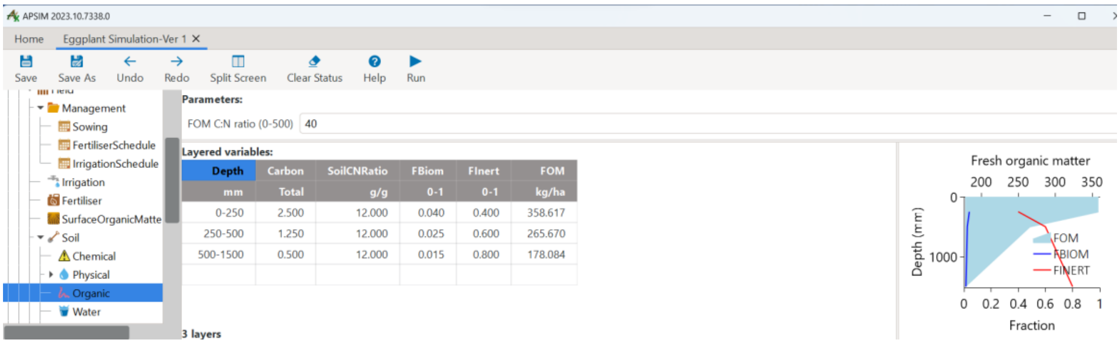
Source: ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Figure A1.3. The Agricultural Production Systems sIMulator (next generation) (APSIMx) format soil properties data for aubergine



Depth	Sand	Silt	Clay	Rocks	BD	AirDry	LL15	DUL	SAT	SW
mm	%	%	%	%	g/cc	mm/mm	mm/mm	mm/mm	mm/mm	mm/mm
0-250	92.000	7.000	1.000		1.280	0.050	0.150	0.360	0.450	0.339
250-500	92.000	7.000	1.000		1.280	0.170	0.170	0.340	0.420	0.323
500-1500	92.000	7.000	1.000		1.280	0.190	0.190	0.330	0.380	0.316

3 layers



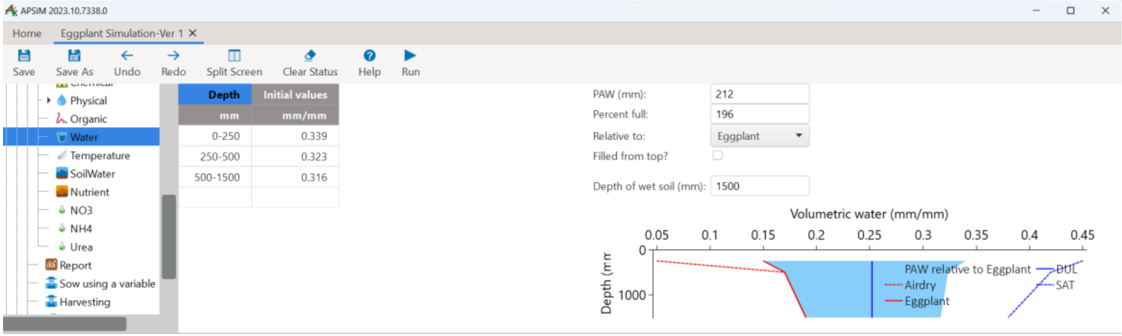
Parameters:

FOM C:N ratio (0-500): 40

Layered variables:

Depth	Carbon	SoilCNRatio	FBiom	FInert	FOM
mm	Total	g/g	0-1	0-1	kg/ha
0-250	2.500	12.000	0.040	0.400	358.617
250-500	1.250	12.000	0.025	0.600	265.670
500-1500	0.500	12.000	0.015	0.800	178.084

3 layers



Depth	Initial values
mm	mm/mm
0-250	0.339
250-500	0.323
500-1500	0.316

PAW (mm): 212

Percent full: 196

Relative to: Eggplant

Filled from top? ☐

Depth of wet soil (mm): 1500

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A1.3. Results and discussion

A1.3.1. Attainable and potential yield

First, APSIMx simulations were conducted using comprehensive input data, with the objective of replicating real-world management and environmental conditions to estimate the calibrated crop yield.

Second, by removing limitations related to management practices – such as suboptimal irrigation and nutrient levels – and simulating conditions with high water availability and nutrient sufficiency, the attainable yields were estimated (Figure A1.4). The APSIMx simulation results for aubergine indicated an attainable yield of approximately 58.2 t/ha. This compares to a reported actual yield of 64.2 t/ha, demonstrating a reasonable level of accuracy in the model's calibration. Similarly, for cabbage, the model estimated an attainable yield of approximately 61.5 t/ha, whereas the reported actual yield was 66 t/ha, reflecting a high level of agreement between the simulated and observed values (Table A1.14).

Finally, a potential yield estimation was conducted under optimal agronomic conditions and local climate specificity by removing key growth-limiting factors such as soil salinity, suboptimal pH and inadequate water or nutrient availability (Figure A1.5).

The irrigation was carefully managed using the APSIMx platform to ensure ideal moisture conditions. For aubergine, an average irrigation rate of 11.3 mm per plant per day was applied across the growing season, with water delivered to a soil depth of 100 mm, as supported by the findings in Müller, Ranquet Bouleau and Perona (2016) and Salim and Alalwany (2021) Similarly, Díaz-Pérez and Eaton (2015) reported an 8 mm irrigation threshold for optimal growth under comparable field conditions. For cabbage, an irrigation rate of 6 mm per plant was applied, with water reaching a depth of 250 mm, consistent with recommendations by Al-Rawahy, Rahman and Al-Kalbani (2004).

Soil pH was adjusted to optimal levels for each crop, with pH 6.2 for aubergine and pH 6.7 for cabbage, based on the ECOCROP database recommendations (FAO, 2022). Due to APSIMx's restrictions on fertilizer types, only essential nitrate-based and P-based fertilizers were used, despite broader guidance in the literature on optimal formulations for vegetable crops (Sharma and Brar, 2008; Tanko, 2015).

The optimum soil type for both crops was defined as medium organic, characterized by a texture of 40 percent sand, 40 percent silt and 20 percent clay. Soil physical parameters, such as wilting point, field capacity and saturation rate, were calculated using the Soil Hydraulic Properties Calculator (Saxton *et al*., 1986) and incorporated into the model.

Considering these optimized inputs, the potential yield for aubergine was simulated at 80.7 t/ha. This falls within the range of values reported for different regions, including 100 t/ha under lysimeter-monitored open-field conditions (Salim and Alalwany, 2021). The potential yield of cabbage was estimated to be 79 t/ha, which closely aligns with the reported maximum yield of 85 t/ha under OF systems (Table 26). These results provide strong evidence for the applicability of APSIMx in modelling potential crop performance under optimal agroenvironmental conditions.

Figure A1.4. Simulated attainable yield result by the Agricultural Production Systems sIMulator (APSIMx) for aubergine

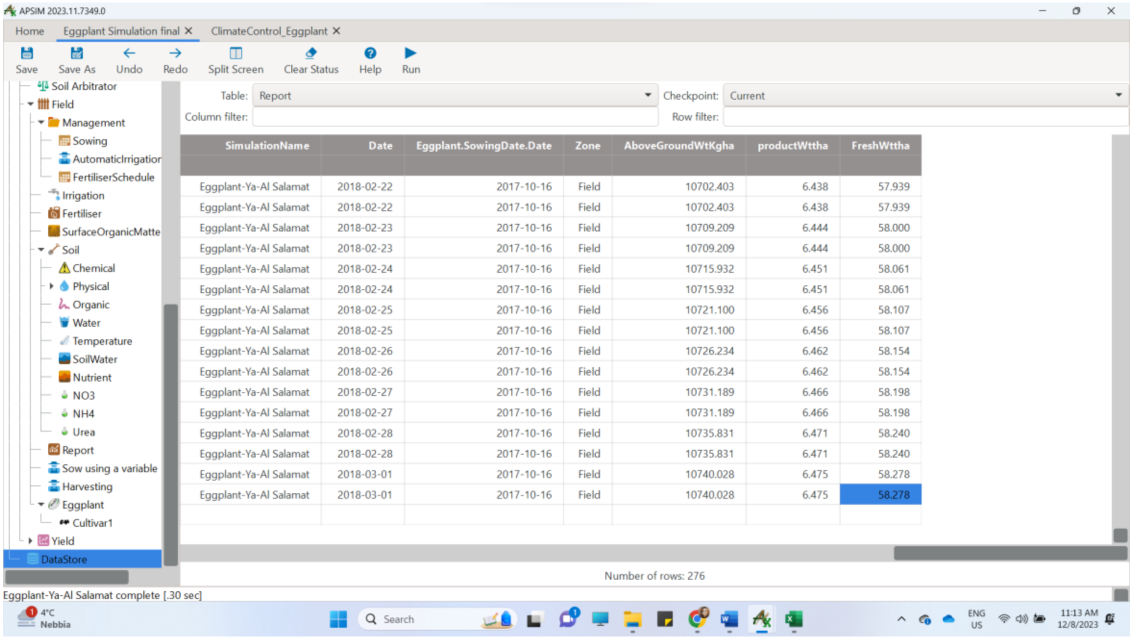


Table: Report
Checkpoint: Current
Column filter:
Row filter:

SimulationName	Date	Eggplant.SowingDate.Date	Zone	AboveGroundWtKgha	productWttha	FreshWttha
Eggplant-Ya-Al Salamat	2018-02-22	2017-10-16	Field	10702.403	6.438	57.939
Eggplant-Ya-Al Salamat	2018-02-22	2017-10-16	Field	10702.403	6.438	57.939
Eggplant-Ya-Al Salamat	2018-02-23	2017-10-16	Field	10709.209	6.444	58.000
Eggplant-Ya-Al Salamat	2018-02-23	2017-10-16	Field	10709.209	6.444	58.000
Eggplant-Ya-Al Salamat	2018-02-24	2017-10-16	Field	10715.932	6.451	58.061
Eggplant-Ya-Al Salamat	2018-02-24	2017-10-16	Field	10715.932	6.451	58.061
Eggplant-Ya-Al Salamat	2018-02-25	2017-10-16	Field	10721.100	6.456	58.107
Eggplant-Ya-Al Salamat	2018-02-25	2017-10-16	Field	10721.100	6.456	58.107
Eggplant-Ya-Al Salamat	2018-02-26	2017-10-16	Field	10726.234	6.462	58.154
Eggplant-Ya-Al Salamat	2018-02-26	2017-10-16	Field	10726.234	6.462	58.154
Eggplant-Ya-Al Salamat	2018-02-27	2017-10-16	Field	10731.189	6.466	58.198
Eggplant-Ya-Al Salamat	2018-02-27	2017-10-16	Field	10731.189	6.466	58.198
Eggplant-Ya-Al Salamat	2018-02-28	2017-10-16	Field	10735.831	6.471	58.240
Eggplant-Ya-Al Salamat	2018-02-28	2017-10-16	Field	10735.831	6.471	58.240
Eggplant-Ya-Al Salamat	2018-03-01	2017-10-16	Field	10740.028	6.475	58.278
Eggplant-Ya-Al Salamat	2018-03-01	2017-10-16	Field	10740.028	6.475	58.278

Number of rows: 276

Eggplant-Ya-Al Salamat complete [.30 sec]

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative.** (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Table A1.14. Aubergine and cabbage production analysis: comparative study of actual, calibrated, attainable, and potential yield on Al Salamat farm

Source	**Parameter**	**Aubergine**	**Cabbage**
(EAD, 2018)	Water consumption (L/plant)	162	185
	WUE (kg crop/m^3 water)	19.8	17.7
	Ya (t/ha)	64.2	66
Crop model results	Ycalib (t/ha)	58.2	61.5
	Yatt (t/ha)	73.4	70.4
	Yp (t/ha)	80.7	79
	RF	0.8	0.84
	Yg (t/ha)	9.2	4.4

Note: WUE: Water use efficiency, Ya = actual yield, Ycalib = calibrated yield, Yatt = attainable yield, Yp = potential yield, RF = reduction factor, and Yg = yield gap.

Source: **EAD (Environment Agency – Abu Dhabi).** 2018. *Crop calculator Year 1 field experiments*. Abu Dhabi.

Figure A1.5. Simulated potential yield result by the Agricultural Production Systems sIMulator (APSIMx) for cabbage

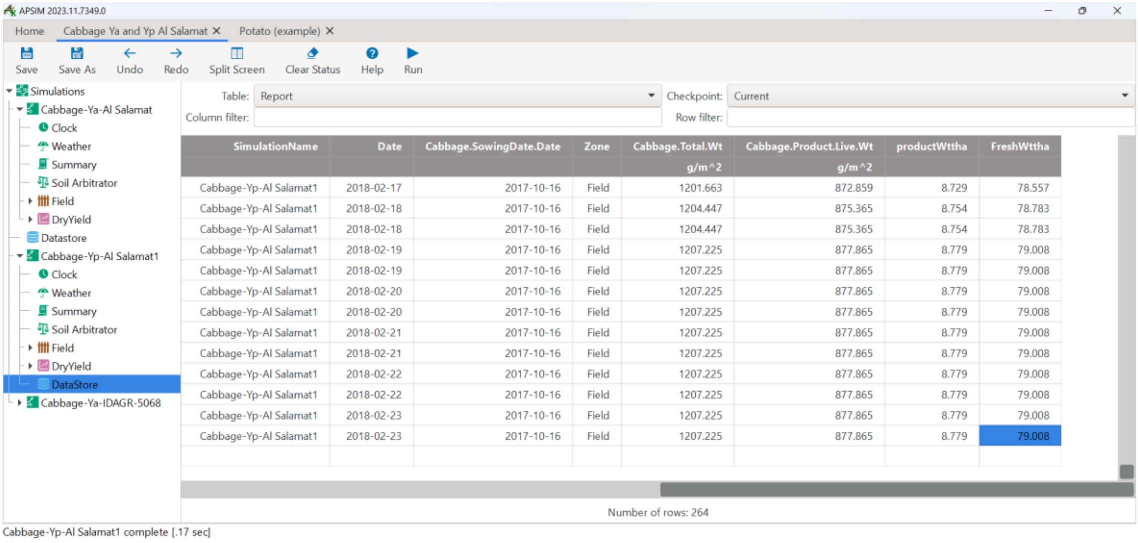


Table: Report

Checkpoint: Current

SimulationName	Date	Cabbage.SowingDate.Date	Zone	Cabbage.Total.Wt g/m^2	Cabbage.Product.Live.Wt g/m^2	productWttha	FreshWttha
Cabbage-Yp-Al Salamat1	2018-02-17	2017-10-16	Field	1201.663	872.859	8.729	78.557
Cabbage-Yp-Al Salamat1	2018-02-18	2017-10-16	Field	1204.447	875.365	8.754	78.783
Cabbage-Yp-Al Salamat1	2018-02-18	2017-10-16	Field	1204.447	875.365	8.754	78.783
Cabbage-Yp-Al Salamat1	2018-02-19	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-19	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-20	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-20	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-21	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-21	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-22	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-22	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-23	2017-10-16	Field	1207.225	877.865	8.779	79.008
Cabbage-Yp-Al Salamat1	2018-02-23	2017-10-16	Field	1207.225	877.865	8.779	79.008

Number of rows: 264

Cabbage-Yp-Al Salamat1 complete [.17 sec]

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative.** (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation.* [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A1.3.2. Sensitivity analysis

Air temperature sensitivity

The optimal air temperature ranges for aubergine and cabbage growth, as reported by ECOCROP (FAO, 2022), are 20 to 35 °C and 15 to 24 °C, with an absolute range extending from 9 to 40 °C and 7 to 32 °C, respectively. Studies on aubergine and cabbage yield sensitivity to air temperature were conducted using the APSIMx model, which includes a climate-control package (Figure A1.6). The model results were broadly consistent with the data provided by ECOCROP, indicating an optimal growth range of 15 to 35 °C and 20 to 32 °C for aubergine and cabbage, respectively (Figure A1.7).

Figure A1.6. Crop sensitivity to air temperature range for aubergine and cabbage

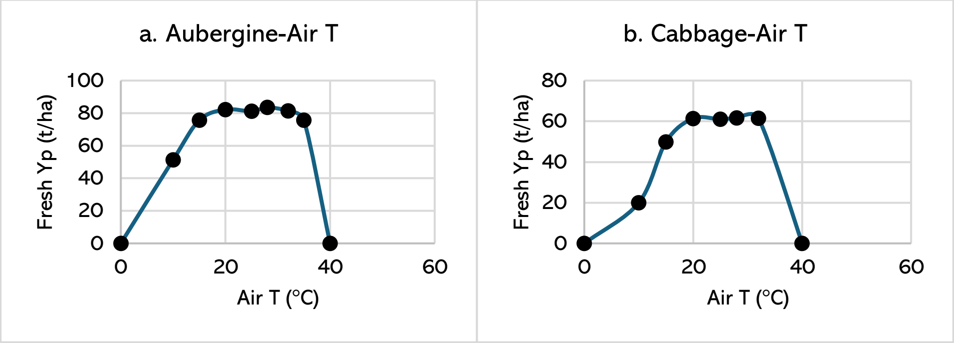
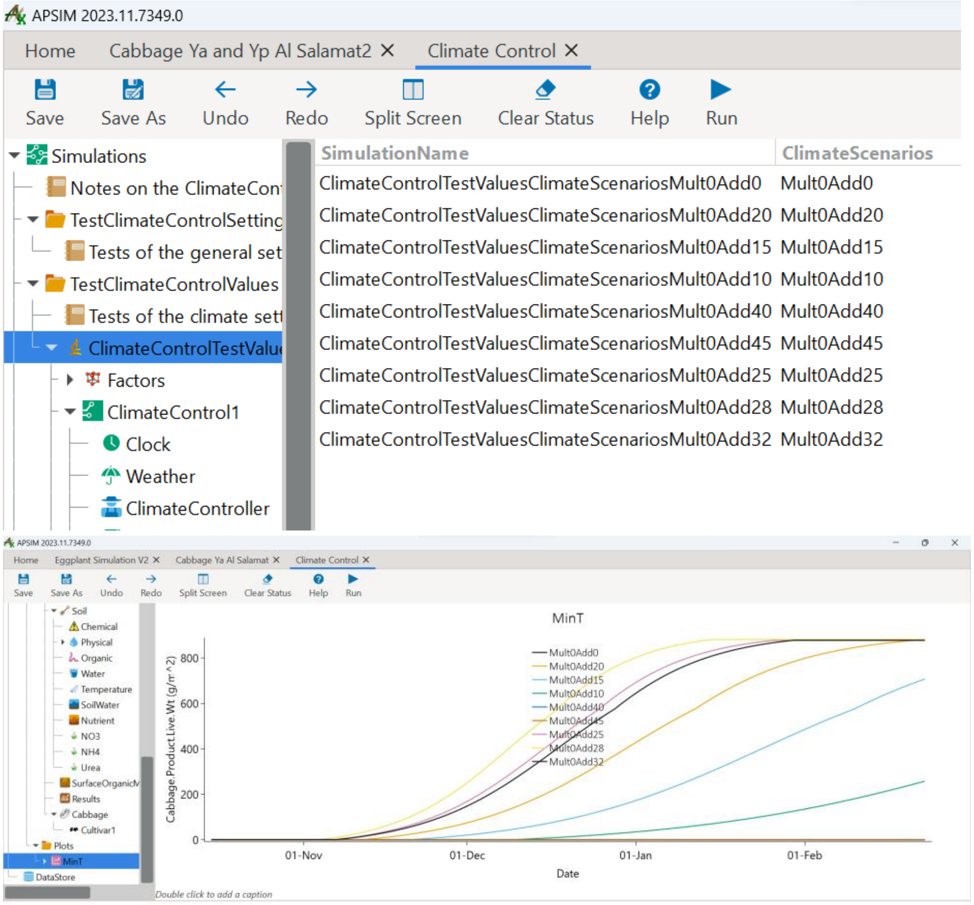


Figure A1.7. Agricultural Production Systems sIMulator (APSIMx) climate control package and yield sensitivity sample data under different minimum daily temperature conditions



SimulationName	ClimateScenarios
ClimateControlTestValuesClimateScenariosMult0Add0	Mult0Add0
ClimateControlTestValuesClimateScenariosMult0Add20	Mult0Add20
ClimateControlTestValuesClimateScenariosMult0Add15	Mult0Add15
ClimateControlTestValuesClimateScenariosMult0Add10	Mult0Add10
ClimateControlTestValuesClimateScenariosMult0Add40	Mult0Add40
ClimateControlTestValuesClimateScenariosMult0Add45	Mult0Add45
ClimateControlTestValuesClimateScenariosMult0Add25	Mult0Add25
ClimateControlTestValuesClimateScenariosMult0Add28	Mult0Add28
ClimateControlTestValuesClimateScenariosMult0Add32	Mult0Add32

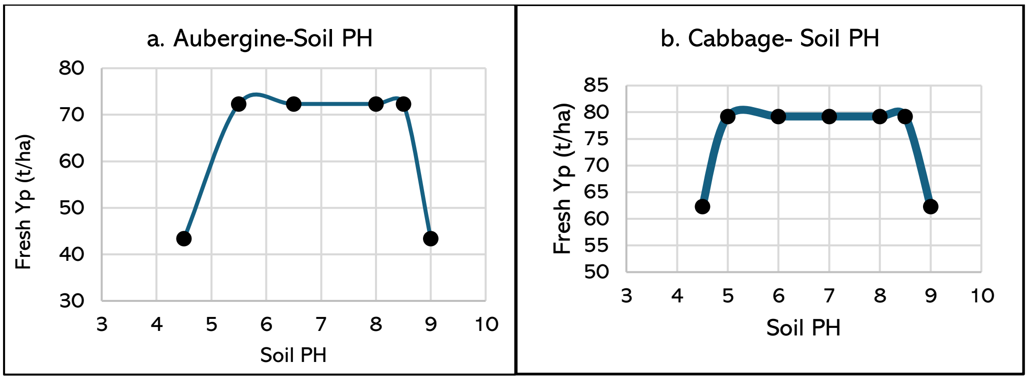
Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Soil pH sensitivity

The APSIMx model results and ECOCROP guidelines both suggest that aubergine and cabbage yields are highest in a soil pH range of 5.5 to 6.8 and 6 to 7.5, respectively, confirming that slightly acidic to neutral soil conditions are optimal for aubergine and cabbage growth. The APSIMx data showed a significant yield reduction when soil pH fell below ~5 or rose above ~8.5, which correlates with ECOCROP's defined absolute tolerance range for soil pH (Figure A1.8). Therefore, both sources agree on the optimal pH range for aubergine and cabbage cultivation and highlight the sensitivity of yield to soil pH levels outside this range.

Figure A1.8. Crop sensitivity to soil pH range for aubergine and cabbage

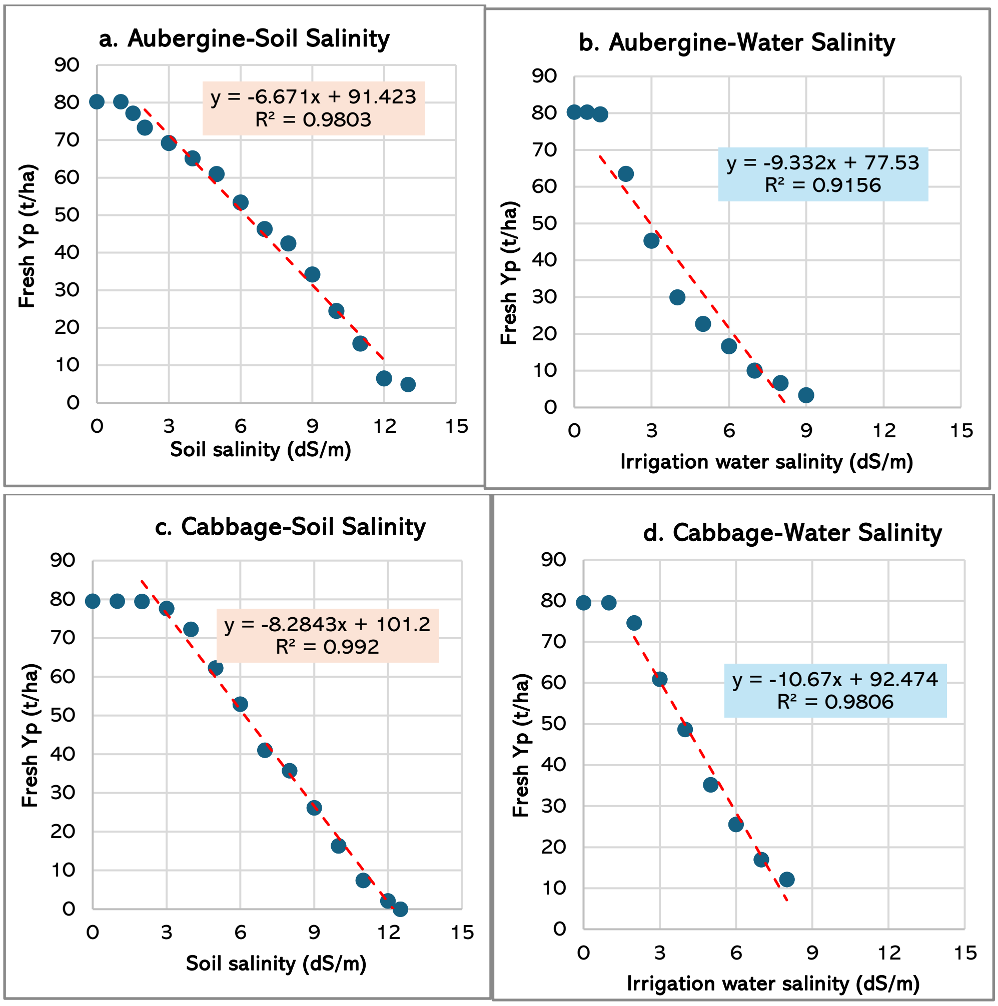


A1.3.3. Salinity sensitivity analysis

In studies of crop salinity sensitivity, various sources present differing thresholds for soil and water salinity that impact crop yields. ECOCROP (FAO, 2022), sets the soil salinity threshold for aubergine and cabbage to a less than 4 dS/m, which serves as a general benchmark for optimal crop growth. However, other studies report more conservative thresholds – indicating higher sensitivity – particularly for cabbage, where the soil salinity threshold is cited as less than 1.8 dS/m, and the water salinity threshold is less than 1.2 dS/m (Ayers and Westcot, 1985). These values suggest that crop performance may decline at salinity levels lower than those proposed by ECOCROP. It is important to note that extreme salinity levels can result in complete yield loss (for instance, soil salinity at 12 dS/m or water salinity at 8.1 dS/m has been reported to cause total yield failure for cabbage).

Further insights were derived from crop model simulations for aubergine and cabbage, using observed weather and soil data from the Al Salamat farm. These results suggest slightly revised salinity thresholds under local conditions. For aubergine, soil salinity should remain below 1.5 dS/m and water salinity below 1.0 dS/m, while for cabbage, the respective thresholds are 2.5 dS/m and 1.0 dS/m (Figure 18). These values provide a more location-specific indication of salinity sensitivity. It should be noted that salinity simulations were performed using the AquaCrop model, as APSIMx does not support a direct salinity sensitivity analysis. Using the same input parameters for potential yield, AquaCrop effectively modelled yield responses across varying soil and water salinity levels. The salinity response curves (Figure A1.9) were based on datasets filtered to exclude values below the crop-specific salinity thresholds, and the resulting slope indicated the rate of yield reduction beyond the tolerance limit.

Figure A1.9. Crop model results on aubergine and cabbage yields sensitivity to soil and water salinity



Appendix A2. Methodological approach for yield simulation using the Agricultural Production Systems sIMulator (next generation) (APSIMx) and AquaCrop models for date palm

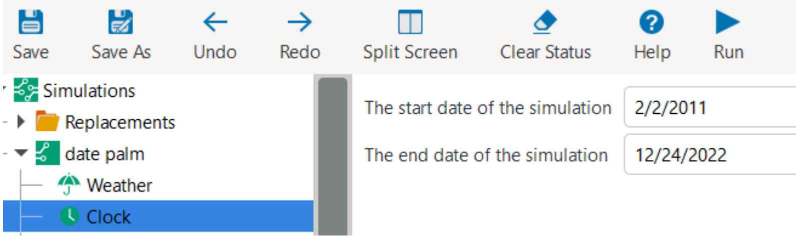
A2.1. Methodological approach

The APSIMx was applied specifically to the date palm simulations. The approach leveraged prior calibration and parameterization experiences obtained from the existing oil palm model (Alkhateeb *et al.*, 2015), as oil palm is a closely related perennial palm species. This provided a robust baseline for accurately simulating the specific biophysical, physiological and phenological processes relevant to date palm production systems, including the precise modelling of soil-water balance, nutrient cycling and responses to environmental and management practices.

A2.1.1. Simulation period

As date palms are perennial, a long-term simulation was used. Daily weather data for each target site from 2011 to 2022 were used to run the model (Figure A2.1).

Figure A2.1. Simulation period for date palm from 2011 to 2022



The start date of the simulation 2/2/2011

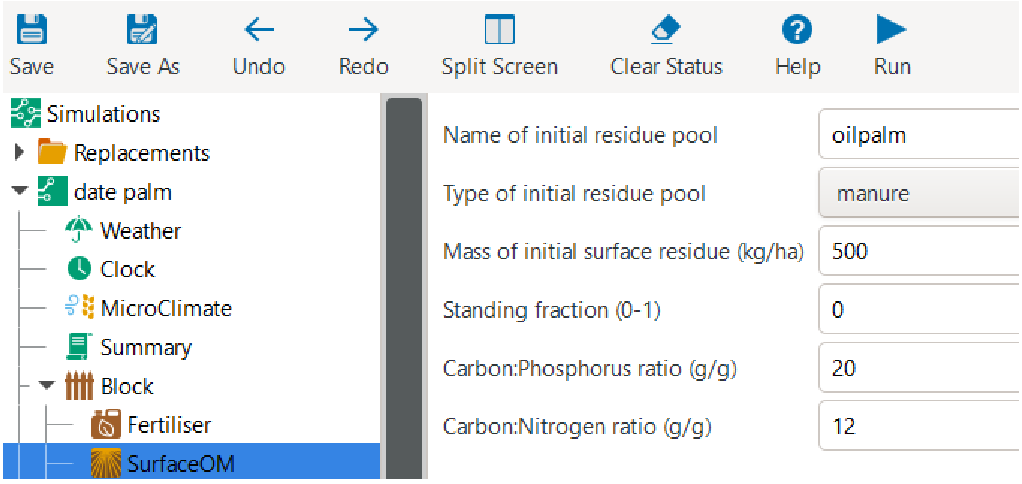
The end date of the simulation 12/24/2022

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

A2.1.2. Surface organic matter

The surface organic matter (SOM) component of APSIMx plays an important role in simulating nutrient cycling, soil health and carbon (C) sequestration. The module simulates the decay of organic matter depending on environmental conditions, such as temperature and moisture, as well as the quality of the residue, characterized by its C, N and P content. While developing the date palm model, the standard default values of the C:P ratio of 20 and C:N ratio of 12 were set (Probert *et al*, 1998; Thorburn *et al,* 2001) (Figure A2.2).

Figure A2.2. Initial soil organic matter setup for date palm



Name of initial residue pool	oilpalm
Type of initial residue pool	manure
Mass of initial surface residue (kg/ha)	500
Standing fraction (0-1)	0
Carbon:Phosphorus ratio (g/g)	20
Carbon:Nitrogen ratio (g/g)	12

Sources: **Al Muaini, A., Green, S., Abou Dahr, W.A., Kennedy, L., Kemp, P., Dawoud, M. & Clothier, B**. 2019. Water use and irrigation requirements for date palms on commercial farms in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 223: 105702. https://doi.org/10.1016/j.agwat.2019.105702
Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Irrigation management with saline groundwater of a date palm cultivar in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 211: 123–131. https://doi.org/10.1016/j.agwat.2018.09.042
Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Sallam, O., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Water requirements for irrigation with saline groundwater of three date palm cultivars with different salt tolerances in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 222: 213–220. https://doi.org/10.1016/j.agwat.2019.05.022
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A2.1.3. Calibration of crop parameters

The APSIMx date palm model was developed by customizing the existing oil palm module within the APSIMx framework. Approximately 19 crop-specific parameters were identified through an extensive review of the published literature, including studies conducted by ADAFSA and other relevant sources from regions with comparable agroenvironmental conditions. Of these, ten key parameters related to crop growth and development were calibrated based on the available experimental data and observations. The remaining nine parameters were adopted from the default settings of the oil palm model, for which no locally validated data were available (Figure A2.3). The calibrated parameters were as follows:

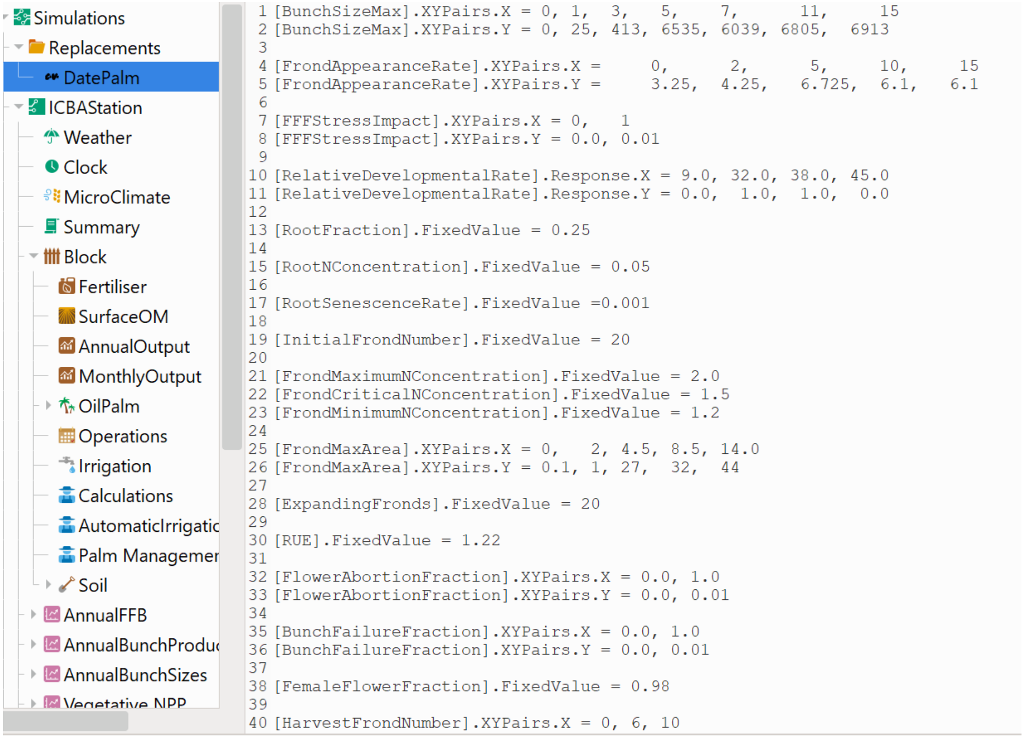
1. The bunch size was customized according to Al Muaini (2019), showing that tissue culture saplings start producing fruits from the fourth year, with a fruit weight from 20 to 25 kg from each tree.

2. The plant provides full potential yield from eight to ten years, with the majority from ten years, with production ranging from 70 to 250 kg/tree, depending on the variety. The frond

appearance rate was derived from Al-Yahyai and Manickavasagan (2012), confirming that one bunch of fruit requires eight to ten green leaves. The average annual production of leaves for adult date palm trees is 20, but varies between 10 and 28, with 50 to 90 leaves being the minimum number required for production.

3. Initially, it was decided to simulate date palm yield with minimal or no stress.
4. The relative growth rate or the effect of temperature on the appearance of fronds and bunches were taken from Abdul Aasit and Zaid (2002).
5. The root fraction was obtained from the method described by Mokany, Raison and Prokushkin (2006), showing that the date palm root fraction ranged between 20 and 30 percent.
6. The values of the N fraction in the roots, leaves and shoots were derived from Al-Ghamidi, Helal and Al-Whaibi (1999).
7. Leaf numbers at transplanting were collected from date palm experts (ICARDA, personal communication, 2024) and from Hodel and Pittenger (2003).
8. Radiation use efficiency was customized from Al Muaini *et al*. (2019).
9. The rate of flower abortion was derived from Al-Dulaimy *et al*. (2023).
10. The remaining coefficients were derived from (Al Muaini, *et al*., 2019a, 2019b, 2019c, 2022), default values of the model, and from an extensive review of published work in the United Arab Emirates and neighbouring countries or countries with similar climatic conditions (including Zaid and Arias Jiménez, 2002; Al Hajjaj and Ayad, 2018; AGMRC, 2011; Ashraf and Hamidi-Esfahani, 2011; Rachid *et al*., 2021; Mohammed *et al*, 2021; Kruse *et al*., 2019).

Figure A2.3. Crop growth parameters for date palm model



```
[BunchSizeMax].XYPairs.X = 0, 1,  3,   5,    7,      11,     15
[BunchSizeMax].XYPairs.Y = 0, 25, 413, 6535, 6039, 6805,  6913

[FrondAppearanceRate].XYPairs.X =     0,      2,      5,     10,     15
[FrondAppearanceRate].XYPairs.Y =     3.25,  4.25,   6.725,  6.1,   6.1

[FFFStressImpact].XYPairs.X = 0,   1
[FFFStressImpact].XYPairs.Y = 0.0, 0.01

[RelativeDevelopmentalRate].Response.X = 9.0, 32.0, 38.0, 45.0
[RelativeDevelopmentalRate].Response.Y = 0.0,  1.0,  1.0,  0.0

[RootFraction].FixedValue = 0.25

[RootNConcentration].FixedValue = 0.05

[RootSenescenceRate].FixedValue =0.001

[InitialFrondNumber].FixedValue = 20

[FrondMaximumNConcentration].FixedValue = 2.0
[FrondCriticalNConcentration].FixedValue = 1.5
[FrondMinimumNConcentration].FixedValue = 1.2

[FrondMaxArea].XYPairs.X = 0,   2, 4.5, 8.5, 14.0
[FrondMaxArea].XYPairs.Y = 0.1, 1, 27,  32,  44

[ExpandingFronds].FixedValue = 20

[RUE].FixedValue = 1.22

[FlowerAbortionFraction].XYPairs.X = 0.0, 1.0
[FlowerAbortionFraction].XYPairs.Y = 0.0, 0.01

[BunchFailureFraction].XYPairs.X = 0.0, 1.0
[BunchFailureFraction].XYPairs.Y = 0.0, 0.01

[FemaleFlowerFraction].FixedValue = 0.98

[HarvestFrondNumber].XYPairs.X = 0, 6, 10
```

Sources: **Al Muaini, A., Green, S., Abou Dahr, W.A., Kennedy, L., Kemp, P., Dawoud, M. & Clothier, B**. 2019. Water use and irrigation requirements for date palms on commercial farms in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 223: 105702. https://doi.org/10.1016/j.agwat.2019.105702

Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Irrigation management with saline groundwater of a date palm cultivar in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 211: 123–131. https://doi.org/10.1016/j.agwat.2018.09.042

Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Sallam, O., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Water requirements for irrigation with saline groundwater of three date palm cultivars with different salt tolerances in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 222: 213–220. https://doi.org/10.1016/j.agwat.2019.05.022

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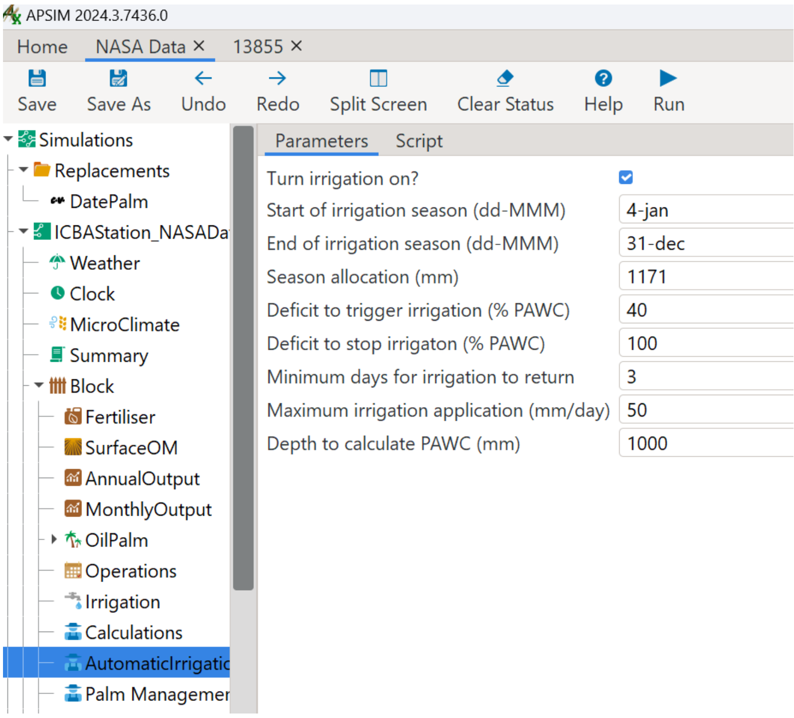
A2.1.3. Irrigation

To simulate potential and attainable yields across target farms, an irrigation level of 2 000 mm per season was applied based on expert feedback from date palm specialists in the United Arab Emirates (ICARDA, personal communication, 2024). For attainable yield simulations, the same high irrigation levels were maintained to reflect the optimal water availability under the best management practices.

According to Al Muaini (2019), the crop evapotranspiration (ETc) for the Khalas variety of date palm was 781 mm under high water availability and low salinity conditions (5 dS/m) and 444 mm under water-limited and high-salinity conditions (15 dS/m). In the simulations conducted for the ICBA research site, an additional 25 percent was added to the ETc values to account for irrigation inefficiencies and natural variations in tree size. An additional 25 percent was also added to support salt-leaching requirements. Consequently, 1 171 mm and 666 mm of irrigation were used to represent the high- and low-water scenarios, respectively. For the broader simulation across 181 farms, 1 171 mm was used for the Khalas variety and 1 200 mm for the Lulu variety to simulate the attainable yields.

Irrigation in the APSIMx model was implemented using the default oil-palm irrigation module. Water was applied when soil moisture dropped to 40 percent of plant-available water content (PAWC) and replenished up to 100 percent of the PAWC. A fixed application depth of 50 mm was used per irrigation event to reflect practical field conditions and efficient water-use strategies (Figure A2.4).

Figure A2.4. Irrigation scheduling used in date palm simulation



Turn irrigation on?	☑
Start of irrigation season (dd-MMM)	4-jan
End of irrigation season (dd-MMM)	31-dec
Season allocation (mm)	1171
Deficit to trigger irrigation (% PAWC)	40
Deficit to stop irrigaton (% PAWC)	100
Minimum days for irrigation to return	3
Maximum irrigation application (mm/day)	50
Depth to calculate PAWC (mm)	1000

Sources: **Al Muaini, A., Green, S., Abou Dahr, W.A., Kennedy, L., Kemp, P., Dawoud, M. & Clothier, B**. 2019. Water use and irrigation requirements for date palms on commercial farms in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 223: 105702. https://doi.org/10.1016/j.agwat.2019.105702

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Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Sallam, O., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Water requirements for irrigation with saline groundwater of three date palm cultivars with different salt tolerances in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 222: 213–220. https://doi.org/10.1016/j.agwat.2019.05.022

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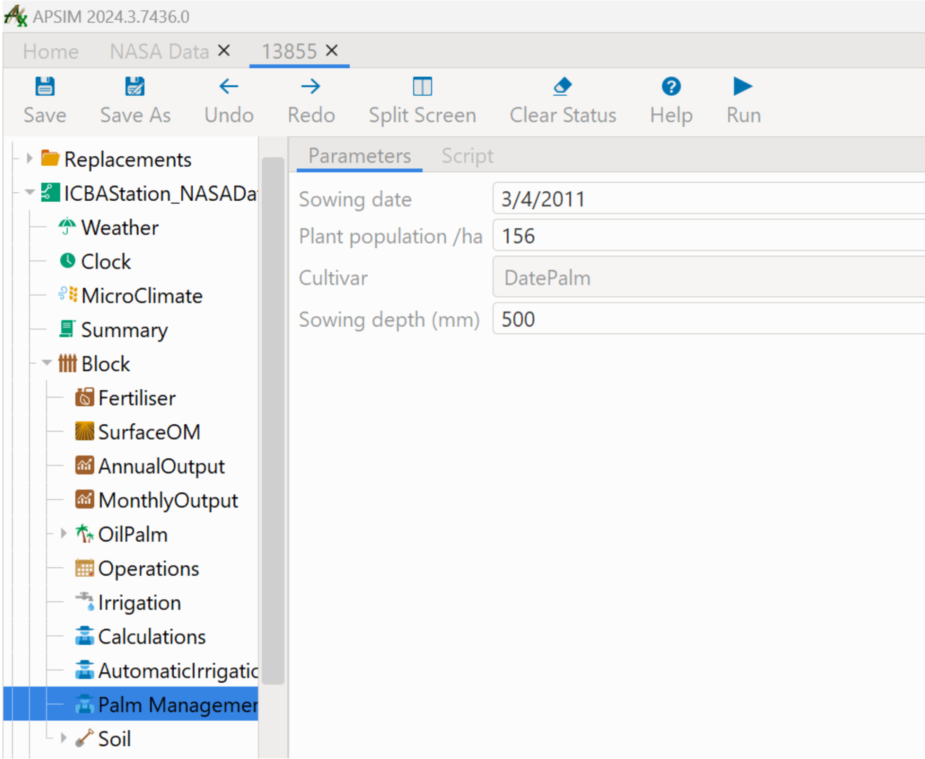
A2.1.4. Palm management practices

Date palms with 20 leaves (initial) were planted at a spacing of 8 × 8 m (156 stem/ha) (Figure A2.5). The sowing depth used for the oil palm simulation was assumed to be 50 cm (Alkhateeb *et al*., 2015), with root length at planting generally being reported to be 30 to 60 cm long, so a 50 cm depth was used for better representation.

Figure A2.5. Date palm planting density and sowing depth



Sowing date: 3/4/2011
Plant population /ha: 156
Cultivar: DatePalm
Sowing depth (mm): 500

Sources: **Al Muaini, A., Green, S., Abou Dahr, W.A., Kennedy, L., Kemp, P., Dawoud, M. & Clothier, B**. 2019. Water use and irrigation requirements for date palms on commercial farms in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 223: 105702. https://doi.org/10.1016/j.agwat.2019.105702

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Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Sallam, O., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Water requirements for irrigation with saline groundwater of three date palm cultivars with different salt tolerances in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 222: 213–220. https://doi.org/10.1016/j.agwat.2019.05.022

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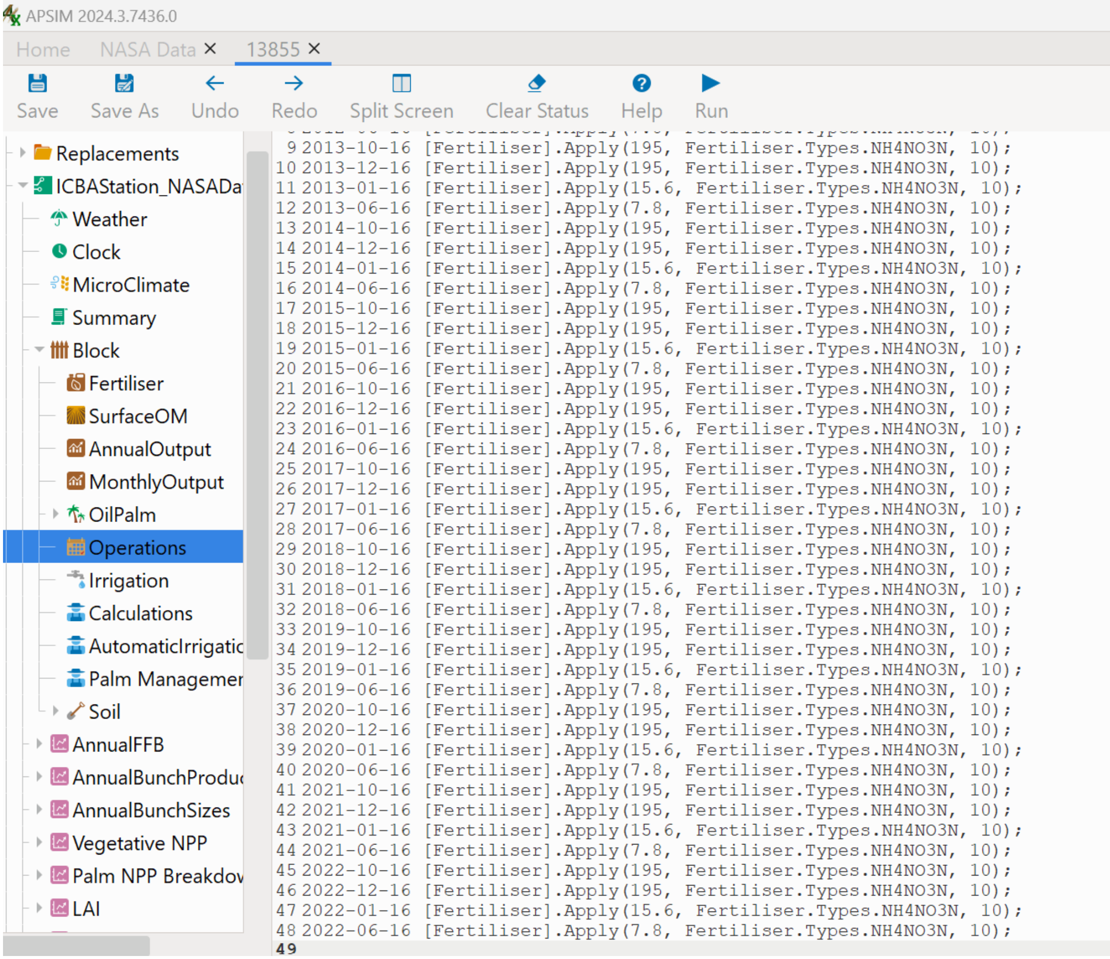
A2.1.5. Fertilizer

Fertilizer was applied four times at 1.25 kg N/tree during mid-October and mid-December, equivalent to 195 kg N/ha respectively and 0.1 to 0.05 kg N/tree in January and June, a total of 2.65 kg N/tree or 413.5 kg N/ha was applied for the Khalas variety (Al Muaini *et al*., 2019a, 2019b, 2019c) (Figure A2.6).

For the Lulu variety (for the potential yield), as there was no N stress observed even with 400 kg N, 200 kg N/ha was applied for the attainable yield.

Figure A2.6. fertilizer input data to simulate attainable yield for date palm



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2013-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2013-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2013-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2013-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
2014-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
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2014-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2014-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
2015-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2015-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2015-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2015-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
2016-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2016-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2016-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2016-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
2017-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2017-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2017-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2017-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
2018-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2018-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2018-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2018-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
2019-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2019-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2019-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2019-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
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2020-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2020-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2020-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
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2021-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
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2022-10-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2022-12-16 [Fertiliser].Apply(195, Fertiliser.Types.NH4NO3N, 10);
2022-01-16 [Fertiliser].Apply(15.6, Fertiliser.Types.NH4NO3N, 10);
2022-06-16 [Fertiliser].Apply(7.8, Fertiliser.Types.NH4NO3N, 10);
```

Sources: **Al Muaini, A., Green, S., Abou Dahr, W.A., Kennedy, L., Kemp, P., Dawoud, M. & Clothier, B**. 2019. Water use and irrigation requirements for date palms on commercial farms in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 223: 105702. https://doi.org/10.1016/j.agwat.2019.105702

Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Irrigation management with saline groundwater of a date palm cultivar in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 211: 123–131. https://doi.org/10.1016/j.agwat.2018.09.042

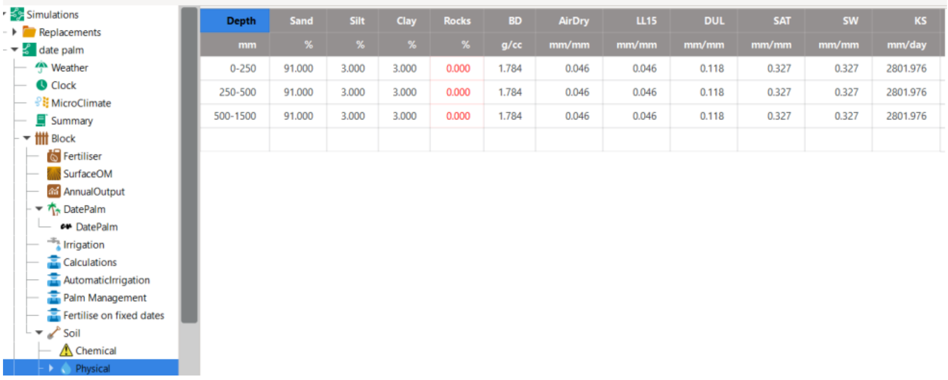
Al Muaini, A., Green, S., Dakheel, A., Abdullah, A.H., Sallam, O., Abou Dahr, W.A., Dixon, S., Kemp, P. & Clothier, B. 2019. Water requirements for irrigation with saline groundwater of three date palm cultivars with different salt tolerances in the hyper-arid United Arab Emirates. *Agricultural Water Management*, 222: 213–220. https://doi.org/10.1016/j.agwat.2019.05.022

APSIM (Agricultural Production Systems sIMulator) Initiative. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

A2.1.6. Preparation of soil file

For all target farms, the soil profile was calibrated using measured data provided by ADAFSA (ADAFSA, personal communication, 2024), based on 310 soil survey databases. The wilting point (critical lower limit [CLL]) (mm/mm), field capacity (drainage upper limit [DUL]) (mm/mm), bulk density (BD) (g/cm^3), saturated upper limit (SAT) (mm/mm), and hydraulic conductivity (KS) (mm/day) were derived using the sand, silt and clay proportions in the soil hydraulic properties tool (Saxton *et al*. 1986) (Figure A2.7 and Figure A2.8).

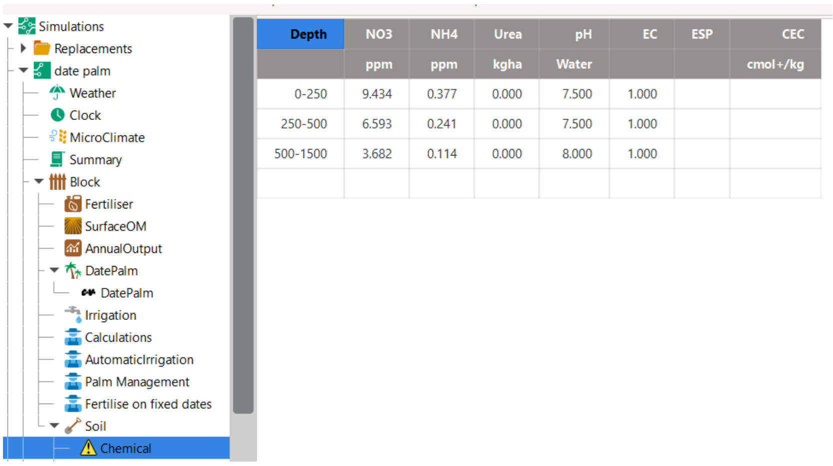
Figure A2.7. Example of soil physical parameters input data (farm ID_AGR 15137)



Depth	Sand	Silt	Clay	Rocks	BD	AirDry	LL15	DUL	SAT	SW	KS
mm	%	%	%	%	g/cc	mm/mm	mm/mm	mm/mm	mm/mm	mm/mm	mm/day
0-250	91.000	3.000	3.000	0.000	1.784	0.046	0.046	0.118	0.327	0.327	2801.976
250-500	91.000	3.000	3.000	0.000	1.784	0.046	0.046	0.118	0.327	0.327	2801.976
500-1500	91.000	3.000	3.000	0.000	1.784	0.046	0.046	0.118	0.327	0.327	2801.976

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Figure A2.8. Example of soil initial nitrate (NO_3), ammonium (NH_4) content and pH (farm ID_AGR 15137)



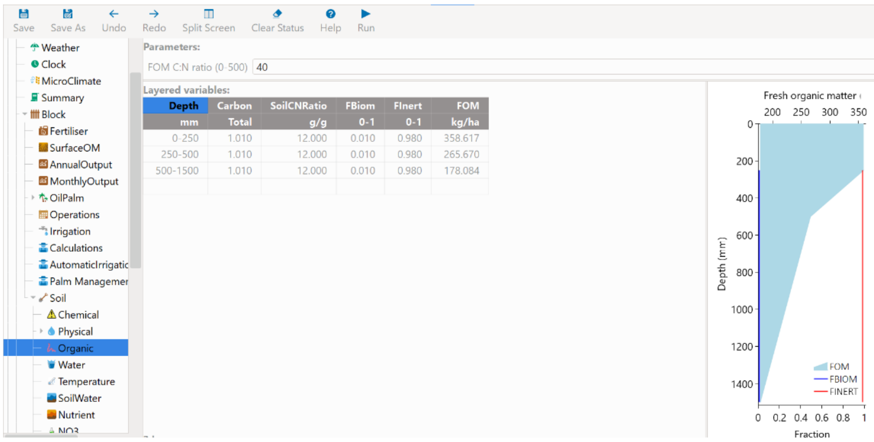
Depth	NO3	NH4	Urea	pH	EC	ESP	CEC
	ppm	ppm	kgha	Water			cmol+/kg
0-250	9.434	0.377	0.000	7.500	1.000		
250-500	6.593	0.241	0.000	7.500	1.000		
500-1500	3.682	0.114	0.000	8.000	1.000		

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A2.1.7. Soil organic carbon (SOC)

All target farms had their own measured soil organic carbon (SOC) contents, and the respective measured values were used to simulate each farm (Figure A2.9).

Figure A2.9. Initial soil organic carbon (SOC) content (farm ID_AGR 15137)



Parameters:

FOM C:N ratio (0-500) 40

Layered variables:

Depth mm	Carbon Total	SoilCNRatio g/g	FBiom 0-1	FInert 0-1	FOM kg/ha
0-250	1.010	12.000	0.010	0.980	358.617
250-500	1.010	12.000	0.010	0.980	265.670
500-1500	1.010	12.000	0.010	0.980	178.084

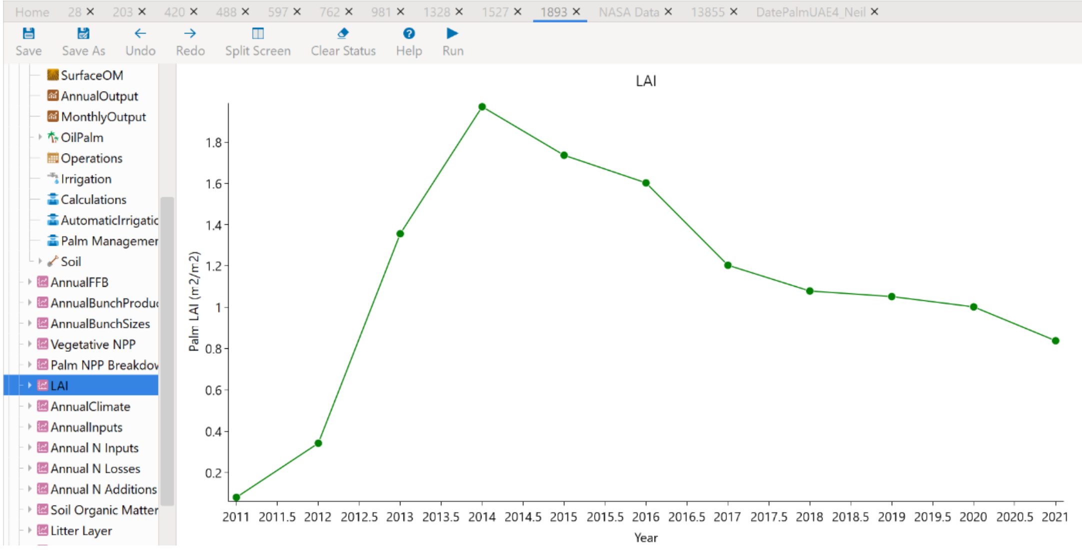
Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A2.2. Results and discussion

A2.2.1. Leaf area index

The leaf area index (LAI) of the date palm gradually increased, reaching its peak around the sixth to seventh year of growth. Beyond this stage, the LAI either stabilized or exhibited slight fluctuations, depending on the management practices applied (Figure A2.10). However, modelled LAI values appear to be slightly overestimated compared with field measurements, as the LAI values were measured at 1.25 in Al Muaini *et al*. (2019). This indicates the need for long-term measured data to further calibrate and refine the LAI estimates in the model.

Figure A2.10. Leaf area development under attainable yield condition (farm ID_AGR. 1893, variety Lulu)

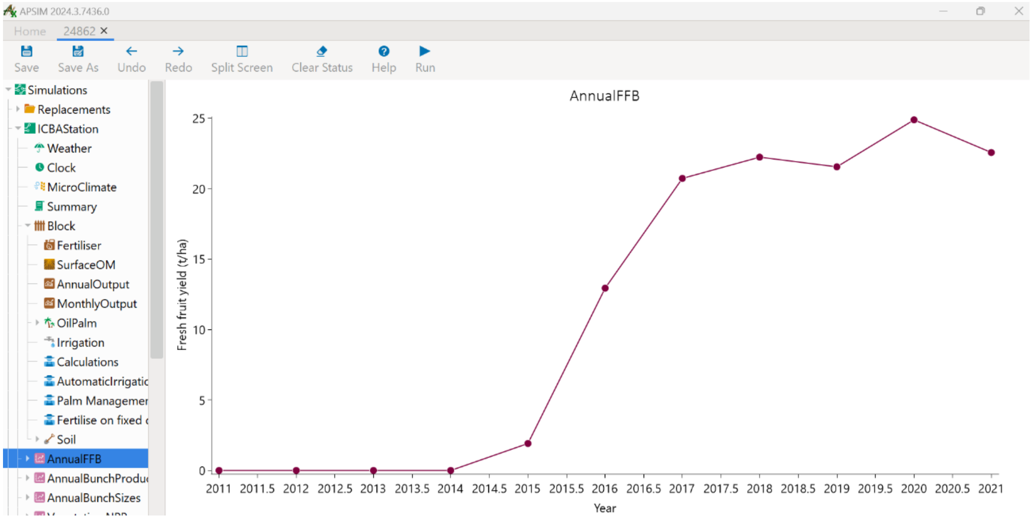


Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A2.2.2. Simulated potential and attainable yield

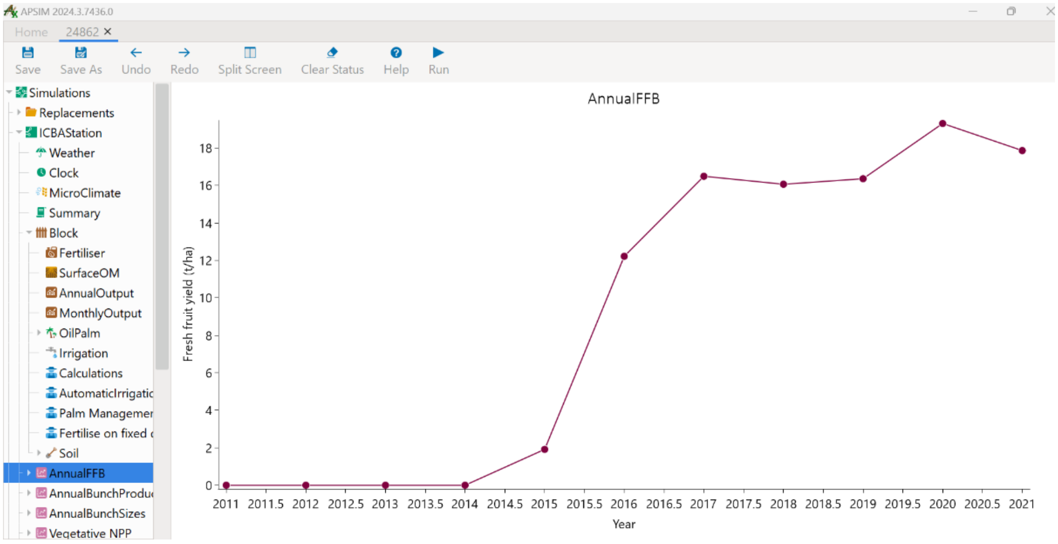
Date palm transplants began fruiting in the fifth year. Fruit yield increased gradually, peaking production at around nine to ten years (Figure A2.11 and Figure A2.12).

Figure A2.11. Annual fruit potential yield (farm ID No. 24862, variety Lulu)



Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Figure A2.12. Annual fruit attainable yield (farm ID No. 24862, variety Lulu)



Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A2.2.3. Yield comparison with the International Center for Biosaline Agriculture (ICBA) research site

To compare the simulated and measured yields, the model was compared with the measured data from Al-Muaini *et al*. (2019). Date palms were planted with the same spacing of 8 m × 8 m (156 stem/ha) and the same amount of water and fertilizers were applied. The results were very similar (with a yield difference of only −30 kg/ha under 1 171 mm water application and +670 kg/ha under low water application (666 mm) for the Khalas variety (Table A2.1). Mohamed, Ali and El-Ghany (2018) reported that using deep drip irrigation at 1 700 mm/season for eight-year-old Siwy variety date palms spaced at 49 m² per tree resulted in a maximum yield of 100 kg per date palm. This was equivalent to 20.4 t/ha.

To validate the model, simulated yields were compared with measured data from a study that used the same planting density of 8 × 8 m spacing (156 stems/ha) and identical amounts of water and fertilizers were applied (Al Muaini *et al*., 2019a, 2019b, 2019c). For instance, the simulated results were in close agreement with the measured values, with a yield difference of only −30 kg/ha under 1 171 mm of water application and +670 kg/ha under low water application (666 mm) for the Khalas variety (Al-Muaini *et al*., 2019a, 2019b, 2019c) (Table A2.1). In a related study, deep drip irrigation using 1 700 mm/season for eight-year-old Siwy date palms planted at a spacing of 49 m² per tree resulted in a maximum yield of 100 kg per palm, equivalent to 20.4 t/ha (Mohamed, Ali and El-Ghany, 2018).

Table A2.1. Measured and simulated yield, amount of water application and water use efficiency (WUE) for date palm at the International Center for Biosaline Agriculture (ICBA) Research Station

No	**Variety**	**Irrigation (L)**	**Simulated irrigation (mm)**	**WUE**	***Ya***	***Ycalib***	***Yatt***	***Yp***	***RF***	***Yg***
1	Khalas (high water)	50 080	1 171	0.78	6.13	6.10	11.4	21	0.29	5.3
2	Khalas (low water)	28 445	666	0.92	4.10	4.77	11.4	21	0.20	7.3
3	Lulu (high water)	50 080	1 171	1.94	15.2	14.24	18.7	25.2	0.60	3.5
4	Lulu (low water)	28 445	666	2.27	10.1	9.38	18.7	25.2	0.40	8.6

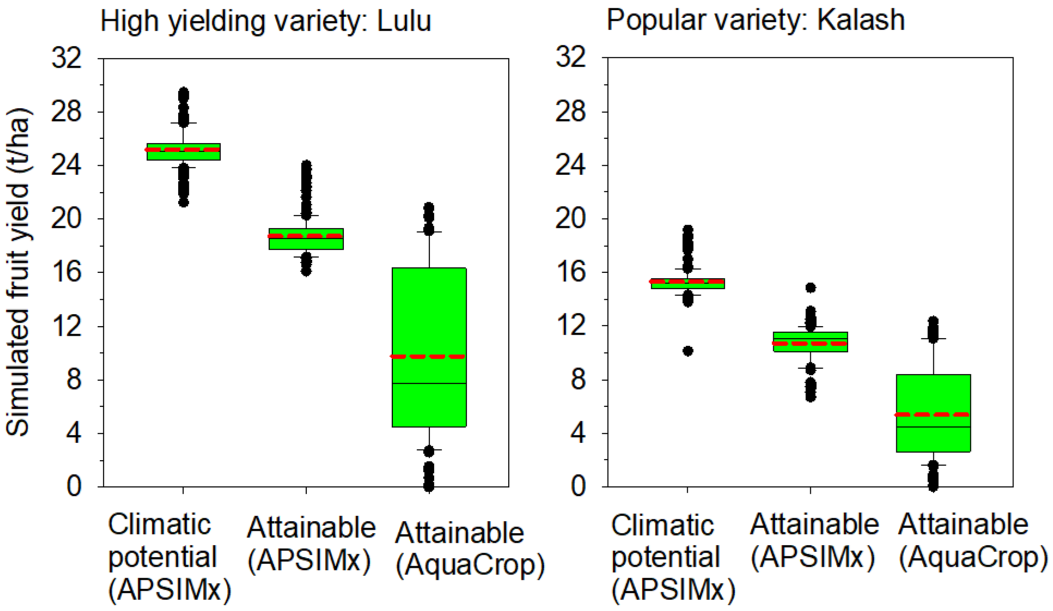
Note: WUE = water use efficiency (kg crop/m³ water), Ya = reported actual yield, Ycalib = calibrated yield (considering real-world conditions), Yatt = attainable yield (under best management practices), Yp = potential yield (climate-specific without any water, soil, or nutrient stress), Yg = yield gap between attainable and actual yields and RF = reduction factor (calculated based on the division of actual yield by potential yield). All yields are fresh yields (t/ha).

A2.2.4. Simulated attainable yield in target farms

In this assessment, both potential and attainable yield estimations were based on best management practices, including the application of optimal irrigation and fertilizer rates, as well as the appropriate date palm management strategies described previously. Across the target farms, the simulation results indicated an average climatic potential yield of 25.2 t/ha for the Lulu variety, ranging from 21 to 29 t/ha, and 15.3 t/ha for the Khalas variety, ranging from 6 to 19 t/ha (Figure A2.13). The average attainable yield, simulated under good management practices, was 18.7 t/ha for the Lulu variety (ranging from 16 to 24 t/ha), and 10.7 t/ha for the Khalas variety (ranging from 7 to 15 t/ha) at the Tamar stage (fully ripped), with a moisture content of <25 percent (Navarro, 2006).

To simulate the climatic potential yield, 2 000 mm of annual irrigation and 400 kg/ha of N (elemental) were applied to represent ideal conditions with no water or nutrient stress and excluded pest and disease impacts. For attainable yield simulations, 1 200 mm of irrigation and 200 kg/ha of N were applied for the Lulu variety, whereas 1 171 mm of irrigation and 413 kg/ha of N were used for the Khalas variety, as reported by Al-Muaini *et al*. (2019). The APSIMx model does not account for salinity levels in soil and water; therefore, the attainable yields were simulated using only soil pH, soil type and site-specific climate data. To address the effect of salinity, a separate analysis was conducted using the AquaCrop model. In both scenarios, a date palm planting density of 8 × 8 m (156 stems/ha) was adopted following the configuration used by Al-Muaini (2019c), which is slightly higher than the 105 plants/ha recommended for cultivation in the Abu Dhabi Emirate (Zaid and Arias-Jiménez, 2002).

Figure A2.13. Simulated climatic potential and attainable fruit yield of date palm in target farms



Note: The red dotted lines and thin black lines inside the boxes show the mean and median, respectively.

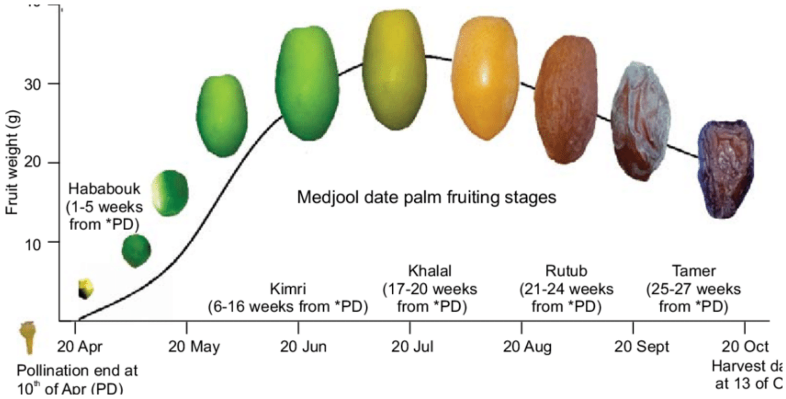
A2.2.5. Maturity stage and moisture content of date palm fruits

The development of date fruit progresses through five maturity stages over a period of approximately six to eight months (Al-Hajjaj and Ayad, 2018; AGMRC, 2011; Ashraf and Hamidi-Esfahani, 2011) (Figure A2.14):

1. rapid fruit growth;
2. colour development;
3. moisture loss;
4. sugar accumulation; and
5. full ripening.

For both Khalas and Lulu varieties, APSIMx simulation results were reported at the Tamer stage, which corresponds to a moisture content of approximately 20 percent, consistent with the range of 18 to 24 percent (Al-Muaini *et al.,* 2019).

Figure A2.14. Different date palm fruiting stages from pollination date to harvest



Source: **Al-Hajjaj, H.S. & Ayad, J.Y**. 2018. Effect of foliar boron applications on yield and quality of Medjool date palm. *Journal of Applied Horticulture*, 20(3): 182–189. https://horticultureresearch.net/jah/2018_20_3_182_189.PDF

A2.2.6. Lifespan yield dynamics of date palms

Date palm is among the most important agricultural crop tree in arid and semi-arid regions of the world, particularly in the Near East and North Africa, and is known for its longevity and resilience. It can typically produce fruit for 40 to 60 years but can often exceed 100 years under optimal conditions (Rachid *et al*., 2021). The peak production phase of date palms usually begins when the trees are approximately 10 to 15 years old. During this stage, the palms are fully mature and produce the highest yield. This peak period can last approximately 20 to 30 years (Zaid and Arias-Jiménez, 2002). Management practices such as revitalization pruning (removing old and less productive fronds), soil rejuvenation (by adding organic amendments) and irrigation adjustments (modifying irrigation techniques to suit the reduced water application) can extend productive life and maintain fruit quality.

A2.2.7. Sensitivity analysis

This assessment presents the results of the sensitivity analysis of key limiting factors affecting date palms and date production, carried out using the APSIMx and AquaCrop crop simulation models. An overview of the sensitivity outputs along with detailed information on each variable and its corresponding threshold is presented in Table A2.2.

Table A2.2. Overview of sensitivity analysis results for date palm regarding different limiting factors using the Agricultural Production Systems sIMulator (next generation) (APSIMx) and AquaCrop models

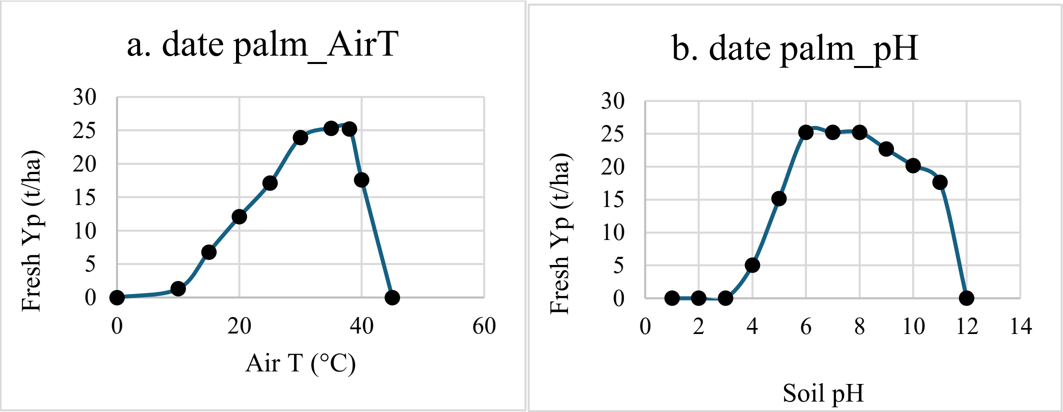
No	Variable	Code	Threshold	Model
1	Optimum soil salinity (dS/m)	ECe-opt	<4	AquaCrop
2	Absolute soil salinity (dS/m)	ECe-abs	32	AquaCrop
3	Optimum water salinity (dS/m)	ECw-opt	<2.7	AquaCrop
4	Absolute water salinity (dS/m)	ECw-abs	21	AquaCrop
5	Optimum minimum seasonal air T (°C)	T-min-opt	30	APSIMx
6	Optimum maximum seasonal air T (°C)	T-max-opt	38	APSIMx
7	Absolute minimum seasonal air T (°C)	T-min-abs	9	APSIMx
8	Absolute maximum seasonal air T (°C)	T-max-abs	45	APSIMx
9	Optimum minimum soil pH	pH-min-opt	6	APSIMx
10	Optimum maximum soil pH	pH-max-opt	8	APSIMx
11	Absolute minimum soil pH	pH-min-abs	3	APSIMx
12	Absolute maximum soil pH	pH-max-abs	12	APSIMx
13	Optimum vapour pressure deficit (kPa)	VPD-opt	>0.9	APSIMx
14	Optimum plant available water content (%)	PAWC-opt	30	APSIMx
15	Optimum nitrogen (N) input (kg/ha/growing season)	N-opt	150	APSIMx
16	Optimum hardpan depth (m)	HP-opt	2	AquaCrop
17	Optimum ground water table depth(m)	GW-opt	2	AquaCrop
18	Optimum ground water salinity (dS/m)	ECgw-opt	<5	AquaCrop
19	Absolute ground water salinity (dS/m)	ECgw-abs	30	AquaCrop

Temperature and soil pH

Based on the APSIMx model outputs, the optimal seasonal average temperature for date palm growth ranged from 32 to 38 °C. Seasonal average temperatures exceeding 45 °C or falling below 9 °C significantly reduced the growth and yield (Figure A2.15a). It is important to note that these values refer to seasonal averages rather than daily extreme values. In the Abu Dhabi Emirate, maximum daytime temperatures often exceed 50 °C during summer, although only a sustained seasonal average above 45 °C negatively impacts productivity. The optimal temperature range for date palm development is 32 to 38 °C. Growth ceases below 7 °C, and prolonged exposure to subzero temperatures can result in metabolic dysfunction and leaf damage (Zaid and Arias-Jiménez,, 2002).

Regarding soil pH, APSIMx simulations indicated that pH values below 3 or above 12 severely impaired date palm development, while the optimal pH range was between 6 and 8 (Figure A2.15b). Arid and semi-arid regions – the primary zones for global date palm cultivation – typically exhibit alkaline soils because of the presence of base cations such as Ca^{2+}, Mg^{2+}, K^+, and Na^+ (Alotaibi *et al.*, 2023). These soils are generally calcareous and contain various forms of calcium carbonate ($CaCO_3$). Although date palms can tolerate alkaline and calcareous soils, their development may be affected by reduced nutrient availability (especially P) and decreased fertilizer-use efficiency.

Figure A2.15. Date palm sensitivity to a) air temperature and b) soil pH using the Agricultural Production Systems sIMulator (next generation) (APSIMx) model



Source: APSIM (Agricultural Production Systems sIMulator) Initiative. (n.d.). APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.

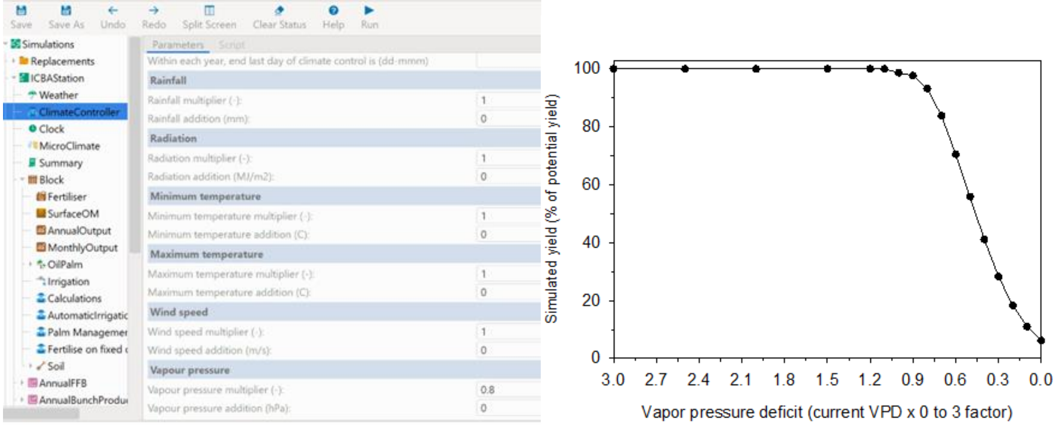
Vapour pressure deficit (VPD)

As the climate controller module of APSIMx does not have the ability to directly analyse the effect of relative humidity, it was indirectly analysed using the VPD, which is available in the APSIMx module, and uses a current average annual VPD ranging from 0.7 to 2 kPa. The simulation results showed that the optimal VPD was the average current VPD × 0.9 and above for date palm (when multiplying the current VPD by a 0 to 3 scale) (Figure A2.16), indicating that drier air was favoured by date palm and that decreasing VPD by increasing relative humidity was not beneficial.

Kruse *et al*. 2019) reported that the VPD varied across seasons (Kruse *et al*., 2019). Vapour pressure deficit provides a balance that promotes adequate transpiration necessary for nutrient uptake and cooling, photosynthesis, growth, and stress avoidance of the plant without causing excessive water loss. It is worth mentioning the studies by Mohammed *et al*. (2021) and Elhadi Matallah *et al*. (2022) on the optimal temperature (T) and relative humidity (RH) for the ripening phase and for maintaining fruit quality. For example, the artificial ripening of unripe Biser date palm fruits can be achieved using a combination of 50 °C temperature and 50 percent RH (Mohammed *et al*, 2021). The study by Elhadi

Matallah *et al*. (2022) identified 37 percent as the optimum average RH under open field conditions throughout the phenological cycle of the date palm. However, using APSIMx and based on VPD sensitivity analysis, an optimum threshold above 0.9 kPa was reported (Figure A2.16).

Figure A2.16. (left) Climate controller module of the Agricultural Production Systems sIMulator (next generation) (APSIMx) for running vapour pressure deficit (VPD) sensitivity analysis, and (right) date palm response to different VPDs (current VPD × 0 to 3 factor)



Within each year, end last day of climate control is (dd-mmm):

Rainfall

Rainfall multiplier (-): 1
Rainfall addition (mm): 0

Radiation

Radiation multiplier (-): 1
Radiation addition (MJ/m2): 0

Minimum temperature

Minimum temperature multiplier (-): 1
Minimum temperature addition (C): 0

Maximum temperature

Maximum temperature multiplier (-): 1
Maximum temperature addition (C): 0

Wind speed

Wind speed multiplier (-): 1
Wind speed addition (m/s): 0

Vapour pressure

Vapour pressure multiplier (-): 0.8
Vapour pressure addition (hPa): 0

Sources: **APSIM (Agricultural Production Systems sIMulator) Initiative**. (n.d.). *APSIM: The Leading Software Framework for Agricultural Systems Modelling and Simulation*. [Accessed on 15 November 2023]. https://www.apsim.info. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Soil and irrigation water salinity

Regarding the sensitivity analysis of soil and water salinity, there was no direct effect of salinity on growth and yield in APSIMx. However, the literature review shows that date palms are quite tolerant to soil and irrigation water salinity. The best soil and irrigation water for palm trees has less than 4 dS/m soil and less than 2.7 dS/m irrigation water salinity (Ayers and Westcot, 1985) (Table A2.3).

Regarding the sensitivity of different date palm varieties to soil salinity – specifically Lulu, Khalas and Shahlah cultivated under 5 dS/m and 15 dS/m soil salinity at the ICBA research station – it has been demonstrated that the Lulu variety exhibits a greater tolerance to salinity than Khalas (Al Muaini *et al*., 2019). Therefore, it would not be accurate to conclude that soil salinity has no impact on date palm yield at the varietal level. However, conducting separate sensitivity analyses for each variety individually was not feasible within the scope of this study.

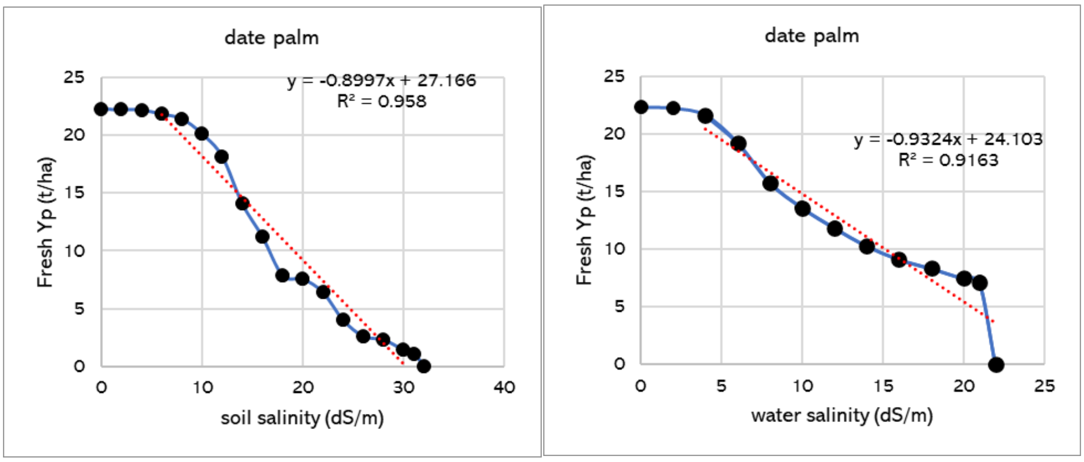
Similar to other crops, the AquaCrop model was used for the soil and water salinity sensitivity analysis of date palm (Figure A2.17).

Table A2.3. Date palm yield sensitivity to soil and irrigation water salinity

Salinity	No yield loss (100% yield)	90% yield (10% yield loss)	25% yield loss	50% yield loss	100% yield loss
Soil (dS/m)	4	6.8	11	18	32
Water (dS/m)	2.7	4.5	7.3	12	21

Source: **Ayers, R.S. & Westcot, D.W**. 1985. *Water quality for agriculture*. FAO Irrigation and Drainage Paper No. 29. Rome, FAO. https://www.fao.org/4/t0234e/t0234e00.htm

Figure A2.17. Date palm sensitivity to soil (ECe) and water (ECw) salinity



Leaching fraction

The leaching fraction (LF) is essential for managing soil salinity in agriculture and is achieved by flushing excess salt from the root zone with irrigation water. The effectiveness of LF largely depends on the amount of irrigation water, soil hydraulic properties, and environmental factors such as ET rates. These variables collectively determine the water volume required for adequate leaching. Precise management of LF requires an understanding of the soil texture, structure, hydraulic conductivity, crop water usage, and local climate conditions (Mace and Amrhein, 2001). Conducting an LF sensitivity analysis necessitates the development of distinct algorithms for each crop. These algorithms must consider the key parameters that influence the yield response to varying LF levels. This approach enables the simulation of each plant's yield under different LF conditions, helping to identify the optimal LF for each localized scenario. Owing to this complexity, a sensitivity analysis to evaluate the yield response to varying leaching factors cannot be directly conducted using APSIMx or AquaCrop as these models do not support the dynamic adjustment of LF. AquaCrop uses a static value of 1.5 in AquaCrop and APSIMx does not have a module to simulate the LF. Therefore, this type of analysis is beyond the scope of this project given the constraints of past deadlines.

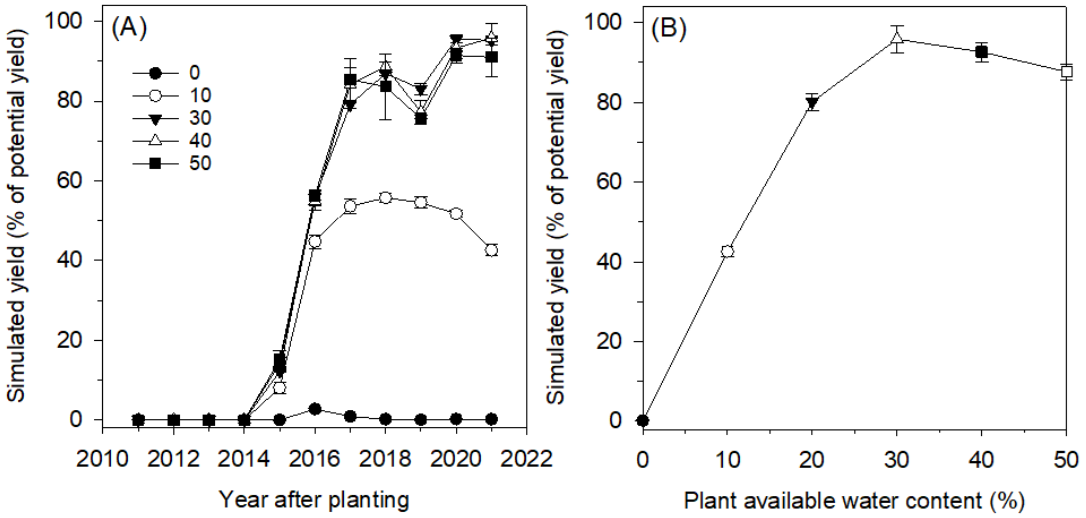
Plant-available water content

Sandy soil textures predominate in arid and semi-arid regions where most global date palm cultivation occurs (Alotaibi *et al*., 2023). Although date palms can grow across a range of soil textures, deep sandy to sandy loam soils are generally preferred for optimal root development and effective drainage. However, conducting soil texture sensitivity analyses using crop models is challenging because of the complex interactions between soil type, water availability, and nutrient dynamics. These interrelated factors make it difficult to isolate the individual effects of soil texture on yield.

Under optimal water and nutrient supply conditions, soil texture has a limited influence on yield. However, reductions in water availability and soil C and N content reveal a stronger role of soil texture in yield outcomes. Thus, it is important to evaluate the effect of soil water-holding capacity, and PAWC specifically, as it provides valuable insight into the relationship between soil properties and yield performance.

The APSIMx date palm model allows for the simulation of crop sensitivity to PAWC. The results indicated that irrigation was not required when soil moisture exceeded 30 percent of PAWC. However, when the PAWC fell below this threshold, significant yield reductions began to emerge (Figure A2.18).

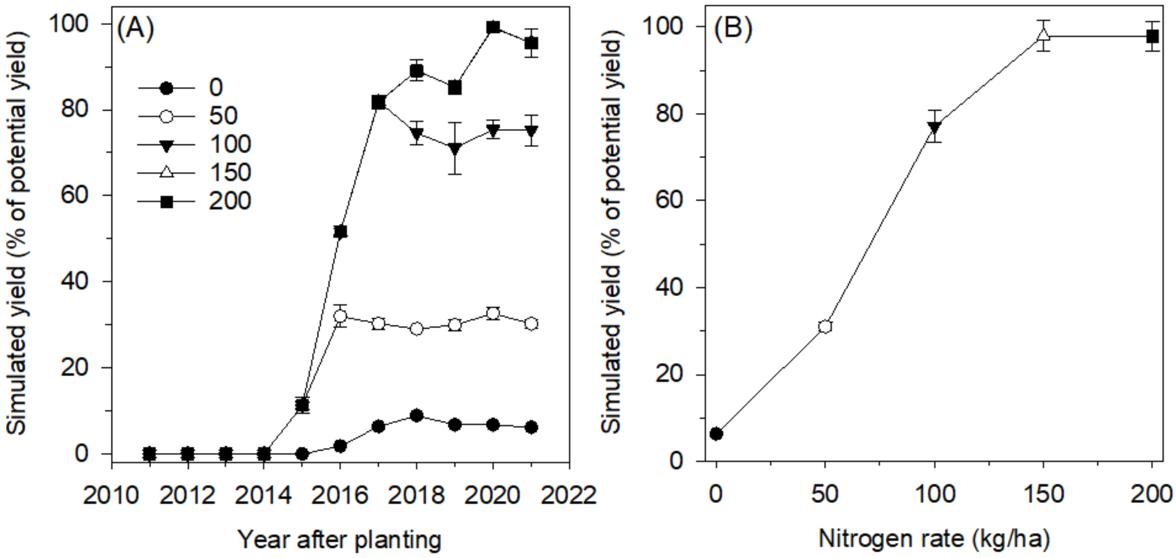
Figure A2.18. A). Simulated yield response of date palm against different plant available water content (PAWC) ranging from 0 to 50 percent and B) simulated yield (percentage of potential yield) under different plant-available water



Nitrogen (N) fertilizer rates

The optimal N application rate for date palms varies depending on factors such as soil type, climate, palm age, and specific cultivar characteristics. Younger palms (less than three years old) typically require lower fertilizer inputs, whereas mature palms may demand more than 1 kg of N annually. Sensitivity analysis using the APSIMx model was conducted from 2011 to 2022, testing five N application rates (0 kg N/ha, 50 kg N/ha, 100 kg N/ha, 150 kg N/ha, and 200 kg N/ha). The simulation results demonstrated a positive yield response of up to 150 kg N/ha (Figure A2.19). While the annual yield increased significantly with N application rates up to 150 kg/ha, there was no substantial yield improvement between 150 and 200 kg/ha. This suggests that the application of more than 150 kg N/ha may not be efficient. Excessive N use, particularly under suboptimal irrigation or soil conditions, may lead to nutrient leaching, economic inefficiencies and negative environmental impacts. Therefore, a balanced and site-specific approach to N fertilization is recommended.

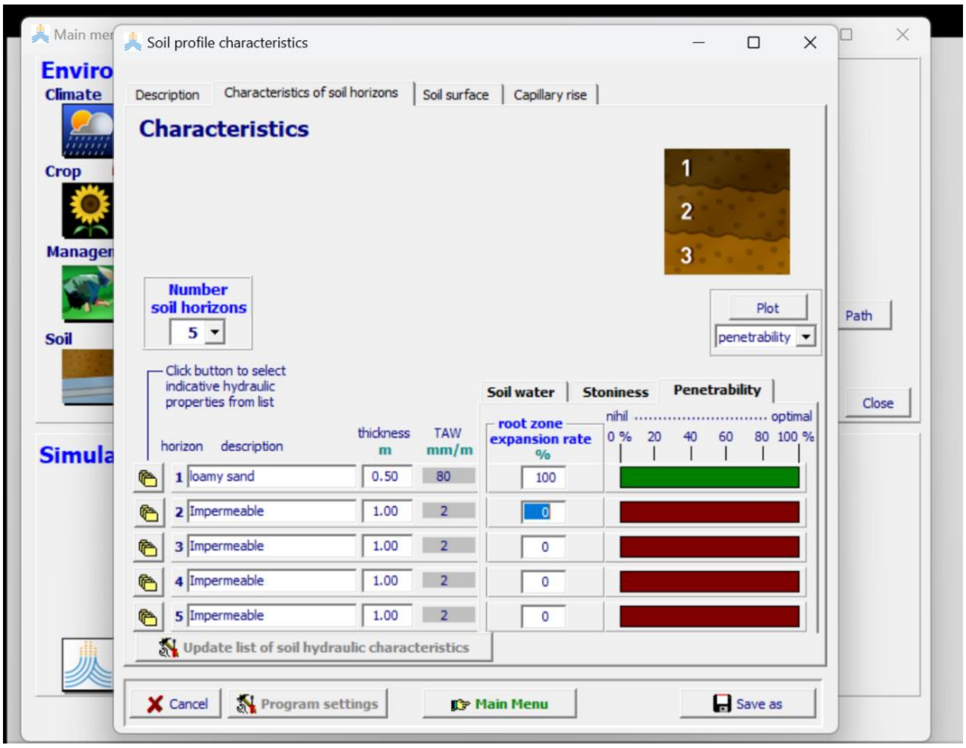
Figure A2.19. A: Simulated yield response (as percentage of potential yield) of date palm to different nitrogen (N) fertilizer application rates (time-series response across years after planting) and B: simulated yield response (as percentage of potential yield) of date palm at varying N application rates



Soil hardpan

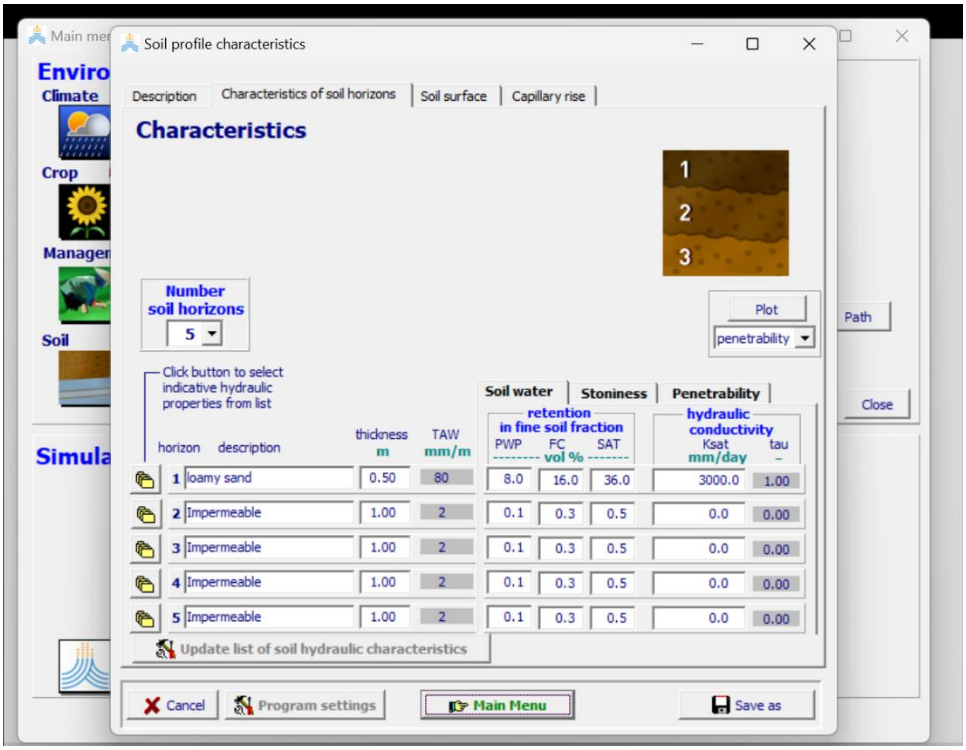
A sensitivity analysis was conducted using the AquaCrop model to assess the impact of the soil hardpan on date palm yield. The model was simulated under five different conditions, varying the soil permeability and depth of the hardpan, which influenced both root zone expansion and soil water availability (Figure A2.20). The results indicated that the presence of a hardpan at a depth of 2 m or deeper did not significantly affect yield. However, when the hardpan was shallow – particularly less than 0.5 m – it severely restricted fruit production and resulted in near-total yield loss. Notably, substantial yield variability was observed when the hardpan lay between 2 and 0.5 m (Figure A2.21). The rooting depth of date palms is influenced by both the cultivar and soil conditions. Typically, in six- to seven-year-old palms, the roots can reach depths of up to 2 m (Zaid *et al.*, 2002).

Figure A2.20. Configuration of AquaCrop model for simulating soil hardpan considering soil water and permeability (root zone expansion)



Number soil horizons: 5

horizon	description	thickness m	TAW mm/m	root zone expansion rate %
1	loamy sand	0.50	80	100
2	Impermeable	1.00	2	0
3	Impermeable	1.00	2	0
4	Impermeable	1.00	2	0
5	Impermeable	1.00	2	0

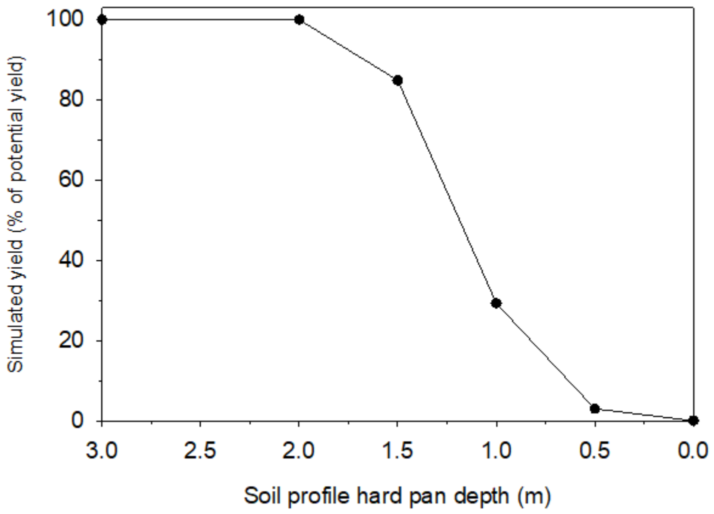


Number soil horizons: 5

horizon	description	thickness m	TAW mm/m	retention in fine soil fraction PWP vol %	FC vol %	SAT vol %	hydraulic conductivity Ksat mm/day	tau –
1	loamy sand	0.50	80	8.0	16.0	36.0	3000.0	1.00
2	Impermeable	1.00	2	0.1	0.3	0.5	0.0	0.00
3	Impermeable	1.00	2	0.1	0.3	0.5	0.0	0.00
4	Impermeable	1.00	2	0.1	0.3	0.5	0.0	0.00
5	Impermeable	1.00	2	0.1	0.3	0.5	0.0	0.00

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

Figure A2.21. Effect of soil hardpan on yield of date palm

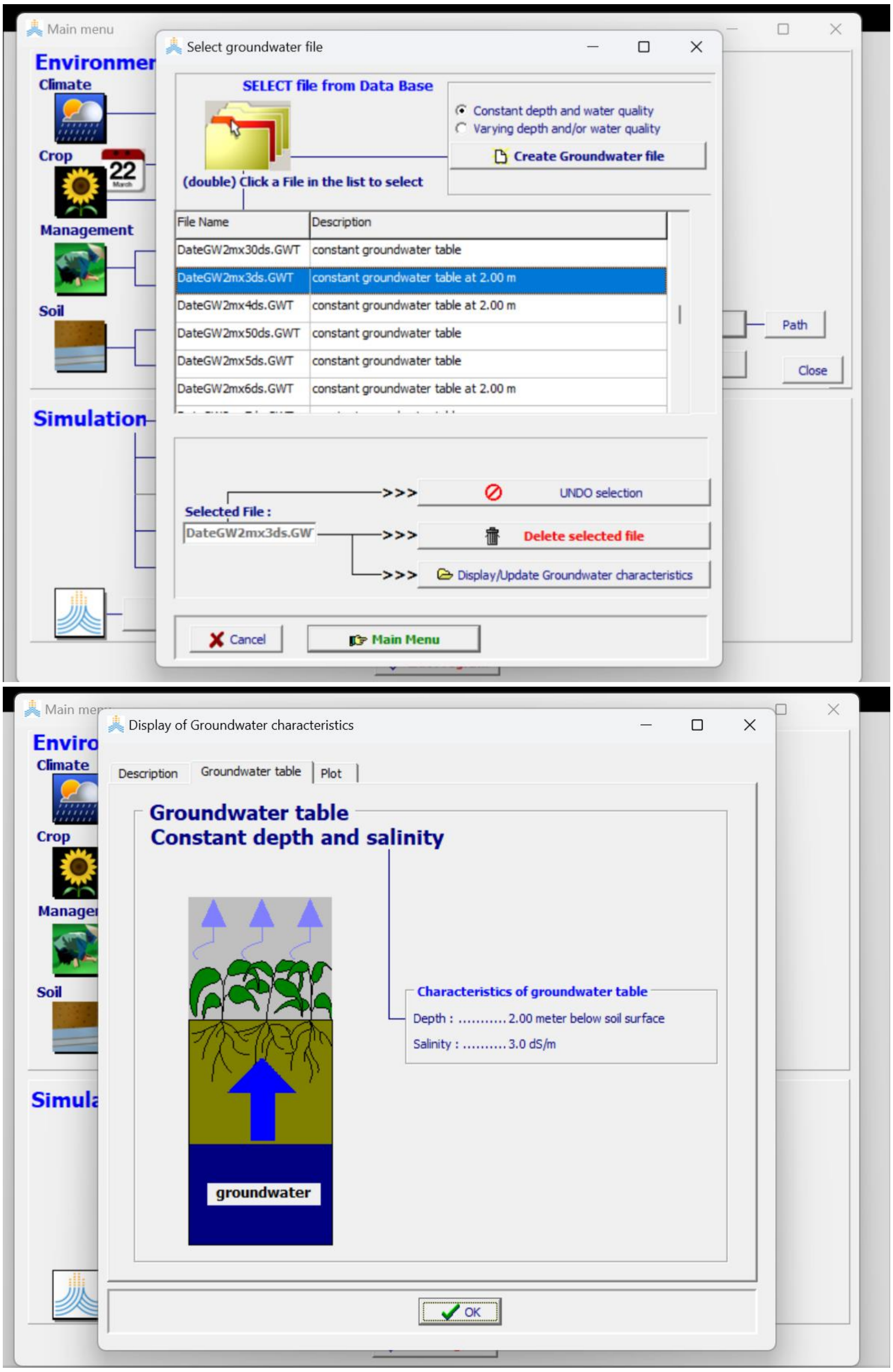


Groundwater table depth and salinity

A sensitivity analysis of date palms was performed at four different groundwater table depths (ranging from 2 to 4 m), with groundwater salinity ranging from 2 to 30 dS/m using the AquaCrop model (Figure A2.22). Because the measured dataset was lacking, a constant depth and salinity method was used. Date palms are deep-rooted plants that typically perform well under a shallow groundwater table (<3 m depth), and the yield was not significantly different between the 3 to 5 m groundwater depths (Figure A2.23a). In a Tunisian study by Askri *et al*. (2014) which compared the effects of the shallow water table, salinity and irrigation frequency on date palm water use, it was found that a 1.4 m shallow groundwater table depth did not decrease date palm yield. For the summer season, high irrigation frequency and shallow groundwater were needed to maintain high water content and low salinity in the root zone, thereby increasing date palm transpiration rates. Conversely, in winter, these factors had no significant effects. This study suggests that with appropriate water management, even a water table depth as shallow as 1.4 m did not necessarily lead to yield reduction if other conditions, such as salinity and irrigation practices, were adequately managed. The optimal groundwater depth for date palm cultivation could range from 0.5 to 2.8 m (Xihua *et al*., 2014). In the Weigan River irrigation district of China, Wenjia *et al*. (2023) found that the suitable groundwater table range for date palm cultivation was between 3 and 5 m to support optimal vegetation growth and maintain sustainable water resource use and ecological stability.

Similarly, the sensitivity analysis for groundwater salinity showed that more than 80 percent of the potential yield was possible with groundwater salinity of up to 6 dS/m and freshwater irrigation (Figure A2.23b). The results are very consistent with those reported by Ayres *et al*. (1994), showing a 100 percent yield under irrigation water salinity of 2.7 dS/m and soil salinity of 4.0 dS/m. However, excessive groundwater salinity can adversely impact growth by affecting the water uptake and nutrient availability.

Figure A2.22. Snapshots of the AquaCrop model used for date palm sensitivity to groundwater table depth and salinity



● Constant depth and water quality
○ Varying depth and/or water quality

File Name	Description
DateGW2mx30ds.GWT	constant groundwater table
DateGW2mx3ds.GWT	constant groundwater table at 2.00 m
DateGW2mx4ds.GWT	constant groundwater table at 2.00 m
DateGW2mx50ds.GWT	constant groundwater table
DateGW2mx5ds.GWT	constant groundwater table
DateGW2mx6ds.GWT	constant groundwater table at 2.00 m

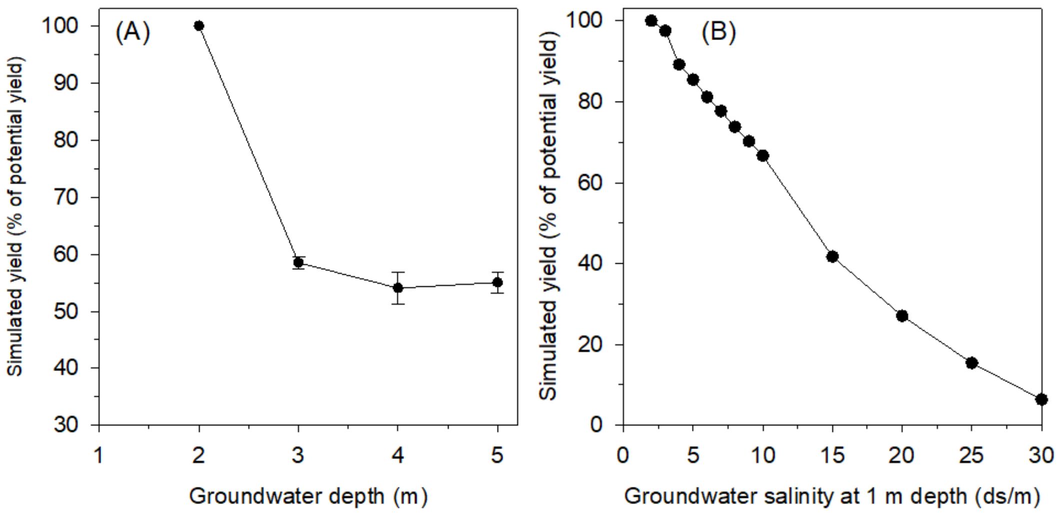
Selected File : DateGW2mx3ds.GW

Groundwater table
Constant depth and salinity

Characteristics of groundwater table
Depth : ....2.00 meter below soil surface
Salinity : ....3.0 dS/m

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

Figure A2.23. Date palm sensitivity to A) groundwater table depth and B) groundwater salinity



Appendix A3. Methodological approach for yield simulation using AquaCrop models for cherry tomato, alfalfa and maize

A3.1. Methodological approach

A3.1.1. AquaCrop model overview

AquaCrop is a crop growth model developed by the Land and Water Division of FAO to address food security and assess environmental and management effects on crop production (Salman *et al*., 2021). It simulates the yield responses of annual and perennial herbaceous and woody crops to water. It is particularly well-suited to conditions in which water is a crucial limiting factor in crop production (Vanuytrecht *et al*., 2014). Compared with other models, AquaCrop has a significantly smaller number of parameters and attempts to strike a balance between simplicity, accuracy and robustness (Steduto *et al*., 2009). The key features of AquaCrop include simulating the root zone water content, canopy ground cover, canopy expansion, stomatal conductance, canopy senescence, and harvest index (HI) in response to water stress (Steduto *et al*., 2009). AquaCrop can be used as a planning tool to assist in management decisions considering crop management practices, soil, irrigation, groundwater salinity, and soil properties in irrigated and rainfed agriculture (Quantitative Plant, n.d.). It is aimed at users of extension services, consulting firms, governmental agencies, non-governmental organizations (NGOs), farmer associations, irrigation districts, economists, and policy analysts needing crop models for planning and assessing water needs for projects and regions (Steduto *et al*., 2009). AquaCrop is a standard crop water productivity software model with a graphical user interface (GUI), database and stand-alone program for iterative or multiple parallel runs.

Key aspects of AquaCrop's approach to modelling crop growth include:

- **Root zone water content**: This monitors soil moisture dynamics and influences plant transpiration rates.
- **Canopy expansion**: This determines leaf area development and photosynthetic capacity.
- **Stomatal conductance**: This regulates gas exchange between plants and the atmosphere.
- **Biomass accumulation**: This tracks plant dry matter accumulation over time.
- **Harvest index**: This is the proportion of aboveground biomass allocated to grain or other edible parts.
- **Water use efficiency**: This quantifies the biomass produced per unit of water consumed.

These factors interact dynamically throughout the growing period to produce realistic crop yield estimates under various environmental conditions and management regimes. AquaCrop has been successfully applied across multiple species and environments, providing valuable insights into crop performance and informing agricultural decision-making.

A3.1.2. AquaCrop data requirement

The AquaCrop model requires various inputs to simulate the crop yield response to water. These inputs include weather data, crop and soil characteristics, and management practices (Vanuytrecht *et al*., 2014). Specifically, the inputs consisted of weather data, crop characteristics, soil characteristics, and management practices. The model uses this information to simulate factors such as root zone water content, canopy development, stomatal conductance, and HI in response to water stress. AquaCrop is designed as a relatively simple model focusing on water, making it suitable for a wide range of practitioners involved in irrigated and rainfed agriculture (Raes *et al*., 2023).

A3.1.3. Data compilation and AquaCrop parameterization

The exercise started with data compilation, followed by model parameterization and then guided by the results template, model simulations for the sensitivity analysis and the optimum and attainable yields of target farms. Given the data limitations of the 43 crops (and thus the choice of AquaCrop), the calibration process relied heavily on the limited data provided, literature and estimation based on the authors' experience with AquaCrop (FAO Irrigation and drainage paper No. 56 [Allen *et al*., 1998]) and AquaCrop's default values as per the reference manual (Raes *et al*., 2023).).

A3.1.4. Climate data

Daily weather data for the target sites – covering the period from 1 January 2011 to 1 January 2023 – were provided in .txt format. The dataset included the maximum and minimum temperatures (°C), relative humidity (percentage), wind speed (m/s), rainfall (mm) and solar radiation (MJ/m^2). Climate data files were generated for each farm using the AquaCrop model.

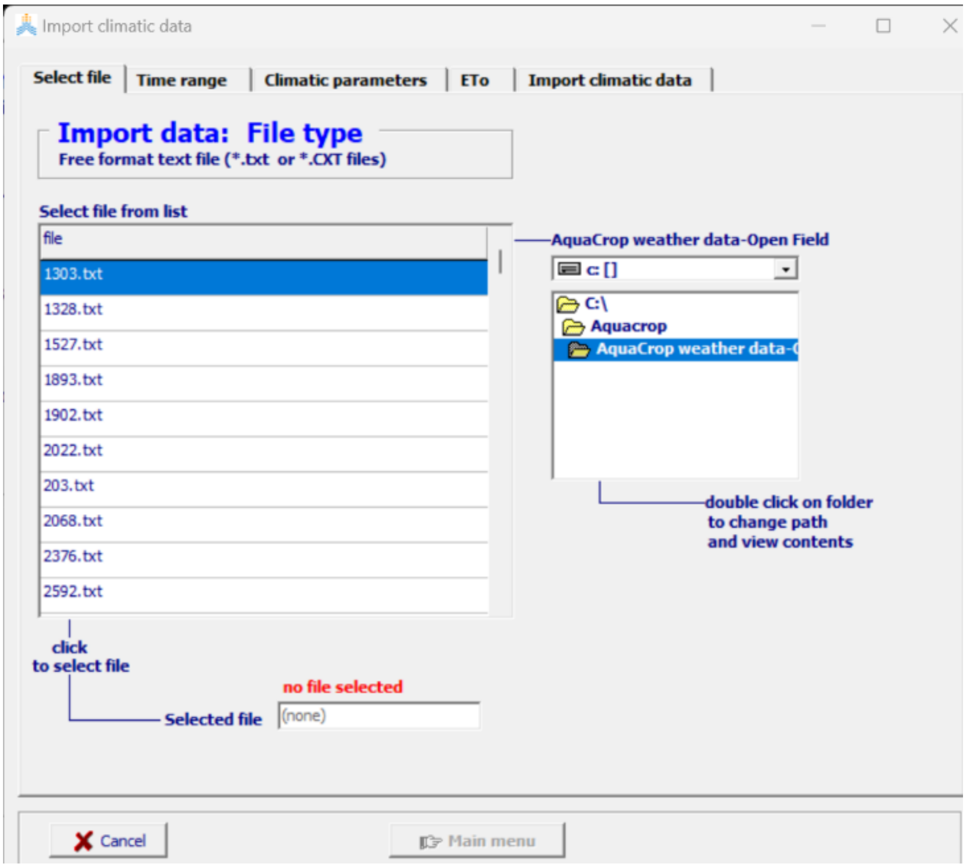
The process for creating climate files in AquaCrop followed the following steps:

- AquaCrop > Start > Climate > Select/Create Climate File > Import/Create (the user then navigates to the folder containing the raw climate data, selects the desired file, sets the time range and relevant climate parameters, inputs reference evapotranspiration (Eto) data, and imports the temperature, ETo and rainfall values).

The file was then saved using the respective farm ID (AGR_ID) to maintain consistency (Figure A3.1). This process resulted in the creation of four files for each farm:

1. a temperature file (. Tnx);
2. precipitation files (. PLU);
3. a reference ET file (. ETo); and
4. a main climate file (. CLI).

Figure A3.1. Climate file creation in the AquaCrop model



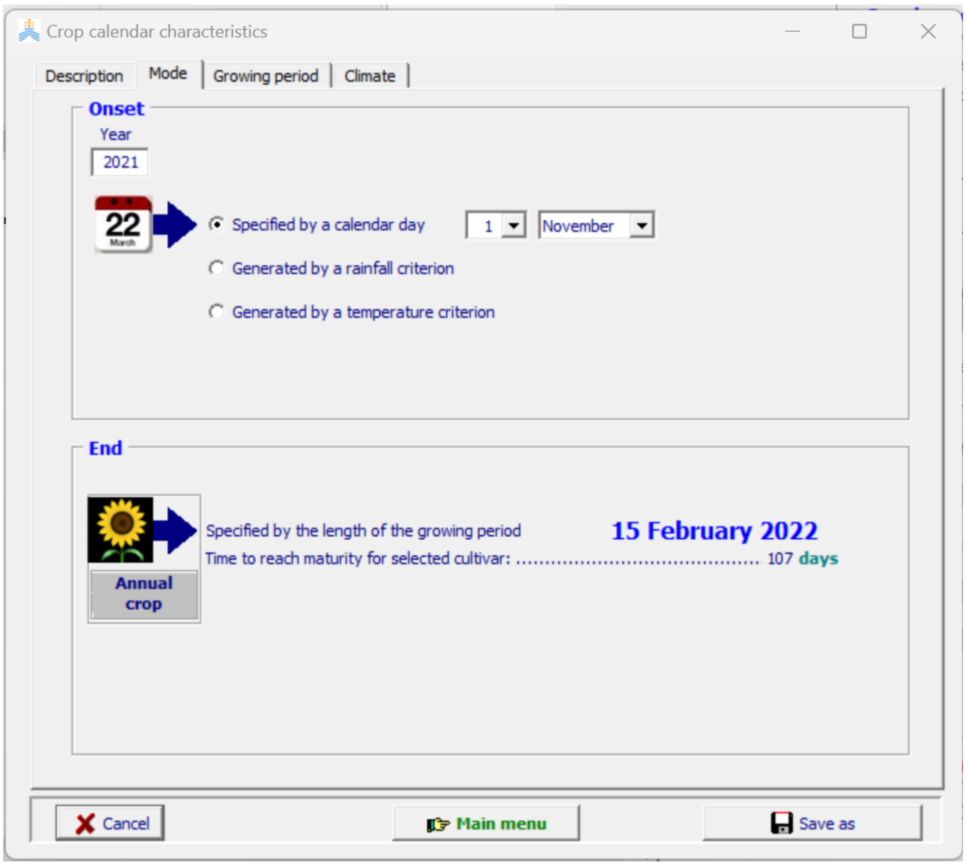
Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

A3.1.5. Crop calendar

A crop calendar file was generated for each crop to guide the simulation process (a sample crop calendar file is shown in Figure A3.2). To ensure consistency across simulations, the onset of the growing period was fixed at a specific date based on the data provided. For most annual crops, the simulation period was set from late 2020 to late 2021 (covering one full year), whereas for perennials and fruit trees, simulations began in late 2021 and extended according to the crop cycle duration. This reference season was uniformly applied to all crops and farms for comparative purposes. Although the full weather dataset covers 2011 to 2022, the corresponding input database files will be made available to enable future simulations for any season within this range.

Given that the growing conditions being studied were solely irrigation-dependent, the following were not applicable: the day number (between 1 and 366) at the start of the time window for the onset criterion, the length (days) of the time window for the onset criterion, the preset value for the generation of the onset criterion, the number of successive days, and the number of occurrences. The day number (between 1 and 366) for the onset of the growing period was set at the specific sowing date (e.g. 305 for 1 November). The detailed sowing, planting and transplanting dates used in the simulations are provided in Table A3.1.

Figure A3.2. The AquaCrop crop calendar module



Onset

Year: 2021

● Specified by a calendar day: 1 November

○ Generated by a rainfall criterion

○ Generated by a temperature criterion

End

Specified by the length of the growing period: **15 February 2022**

Time to reach maturity for selected cultivar: .... 107 days

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

Table A3.1. Planting or sowing and transplanting dates used for the 43 crops during the AquaCrop simulation

No	Crop	Date
1	Cherry tomato	01/11/2021
2	Alfalfa	01/11/2021
3	Maize	01/11/2021
5	Cauliflower	01/10/2021
6	Onion	01/11/2021
7	Broccoli	01/10/2021
7	Potato	10/11/2021
8	Sweet melon	01/10/2021
9	Watermelon	01/10/2021
10	Quinoa	22/10/2021
11	Common bean	20/10/2021

No	Crop	Date
12	Beetroot	20/10/2021
13	Carrot	15/10/2021
14	Pumpkin	20/10/2021
15	Sweet potato	15/10/2021
16	Jute mallow	22/10/2021
17	Okra	10/10/2021
18	Strawberry	10/10/2021
19	Turnip	28/10/2021
20	Parsley	01/11/2021
21	Grape	01/10/2020
22	Leucaena	04/10/2020
23	Napier grass	10/10/2020
24	Panicum	15/10/2020
25	Raspberry	16/10/2020
26	Buffel grass	16/10/2020
27	Butternut squash	01/10/2020
28	Cassava	24/10/2020
29	Radish	03/10/2020
30	Rhodes grass	05/10/2020
31	Blueberry	07/10/2020
32	Local almond	02/10/2020
33	Papaya	04/10/2020
34	Sesbania	09/10/2020
35	Banana	01/10/2020
36	Guava	04/10/2020
37	Lime/lemon	04/10/2020
38	Mango	01/10/2020
39	Orange	05/10/2020
40	Pomegranate	10/10/2020
41	Fig	01/10/2020

No	Crop	Date
42	Moringa	05/10/2020
43	Ziziphus (sidr)	10/10/2020

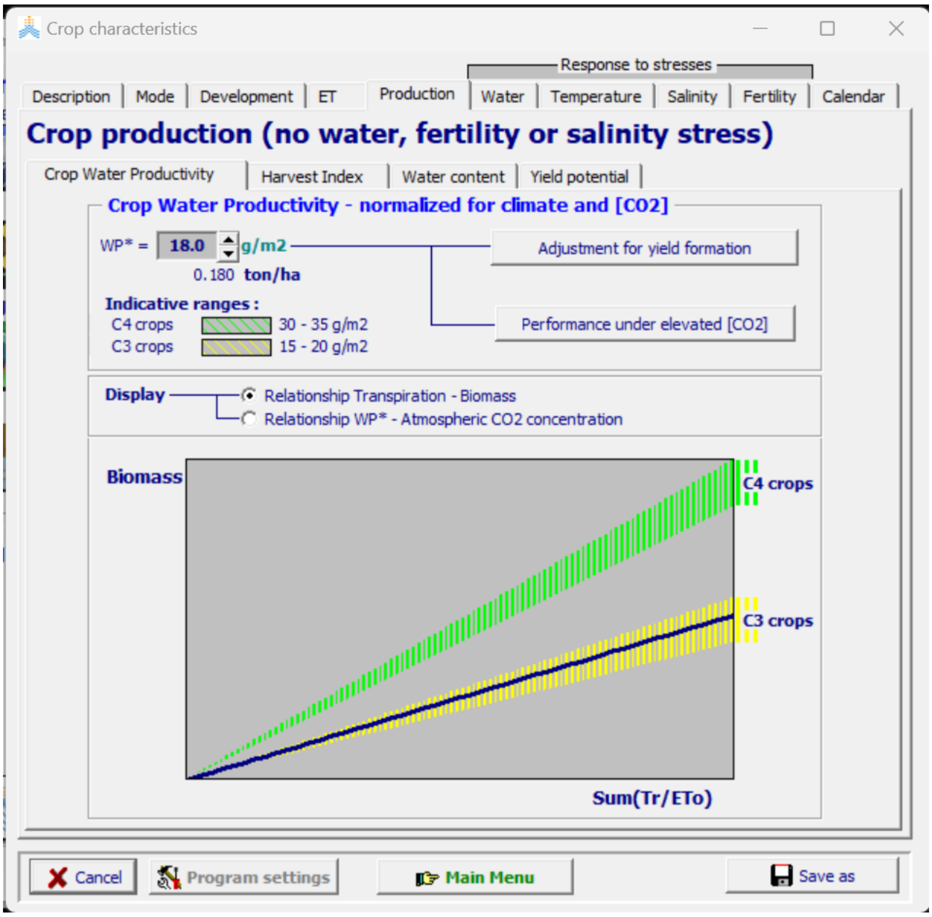
Source: ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A3.1.6. Crop

For crop-specific data entry and calibration, individual crop files were developed to facilitate clarity and traceability (Figure A3.3). Most of the raw input data were provided by ADAFSA (ADAFSA, personal communication, 2024). Where data were incomplete, secondary sources, including literature and databases, were consulted to fill the gaps. Utilizing climate and soil data from one farm or location, initial individual AquaCrop parameterization and calibration were performed and a calibrated crop file was provided for each simulated crop.

As a first step, each crop was defined as either fruit- or grain-producing, while noting whether it was sown or transplanted. Most of the crop parameters listed in Table A3.2 were used for calibration when data was available, with default model values being applied if the data was lacking. Minimum effective rooting depth (m) was calibrated for transplanted crops and when simulating regrowth conditions. The response of canopy expansion was not treated as a calibration parameter and the transfer of assimilates from above-ground parts to the root system was also not considered. For determining the crop cycle, it was decided to use calendar days rather than growing degree days.

Figure A3.3. Crop file parameterization from transplantation to recovered transplantation, from transplantation to maximum rooting depth, senescence, maturity, and flowering



Crop production (no water, fertility or salinity stress)

Crop Water Productivity - normalized for climate and [CO2]

WP* = 18.0 g/m2

0.180 ton/ha

Indicative ranges :

C4 crops	🟩	30 - 35 g/m2
C3 crops	🟨	15 - 20 g/m2

Display
● Relationship Transpiration - Biomass
○ Relationship WP* - Atmospheric CO2 concentration

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

Table A3.2. Selected crop-related input variables

Parameter	Units
Soil water depletion factors (p) are adjusted by reference evapotranspiration (Eto)	mm
Base and upper temperature below which crop development does not progress	°C
Total length of crop cycle	Growing degree-days (GDD)
Soil water depletion factor for canopy expansion (p-exp) (upper and lower thresholds)	n/a
Shape factor for water stress coefficient for canopy expansion (shape factor = **0 = straight line (linear correlation)),** shape factor **>0 S-shaped (sigmoidal relationship)**	n/a

Parameter	**Units**
Soil water depletion fraction for stomatal control (p - sto) (upper and lower thresholds)	n/a
Shape factor for water stress coefficient for stomatal control	0.0 = straight line
Soil water depletion factor for canopy senescence (p - sen) (upper threshold)	n/a
Shape factor for water stress coefficient for canopy senescence	0.0 = straight line
Amount (ETo) during dormant period to be exceeded before crop is permanently wilted	mm
Soil water depletion factor for pollination (p - pol) (upper threshold)	n/a
Soil moisture for anaerobiotic point at which deficient aeration occurs	%
Considered soil fertility stress for calibration of stress response	%
Minimum air temperature below which pollination starts to fail (cold stress)	°C
Maximum air temperature above which pollination starts to fail (heat stress)	°C
Minimum growing degrees required for full crop transpiration	°C
Electrical conductivity of soil saturation extract at which crop can no longer grow	dS/m
Electrical conductivity of soil saturation extract at which crop starts to be affected by soil salinity	dS/m
Calibrated distortion of canopy cover (CC) due to salinity stress (range)	% (0 [none] to +100 [very strong])
Calibrated response of stomata stress to electrical conductivity of soil water (ECsw) (range)	% (0 [none] to +200 [extreme])
Crop coefficient when canopy is complete but prior to senescence	n/a
Decline of crop coefficient as a result of ageing, nitrogen (N) deficiency, etc.	%/day
Minimum and maximum effective rooting depth	m
Maximum root water extraction in top quarter of root zone	m^3 of water/m^3 soil daily
Maximum root water extraction in bottom quarter of root zone	m^3 of water/m^3 soil daily
Soil surface covered by an individual seedling at 90 emergences	%/cm^2
Canopy size of individual plant (regrowth) on first day	cm^2
Number of plants per hectare	plant/ha

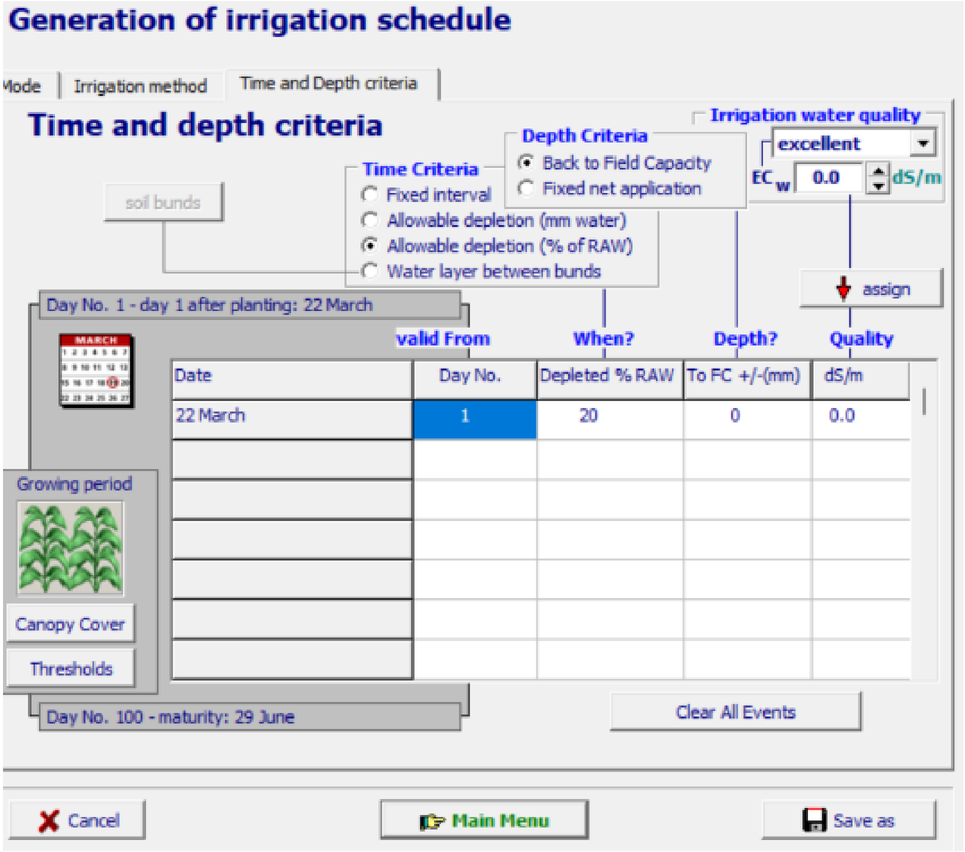
Parameter	Units
Canopy growth coefficient (CGC)	Increase in CC (fraction soil cover per day)
Number of years at which maximum canopy cover (CCx) declines to 90 percent of its value due to self-thinning	%
Maximum canopy cover in fraction of soil cover	%
Canopy decline coefficient (CDC)	Decrease in CC (in fraction per day)
Time from sowing to emergence	Calendar days
Time from sowing to maximum rooting depth	Calendar days
Time from sowing to start senescence	Calendar days
Time from sowing to maturity (length of crop cycle)	Calendar days
Time from sowing to flowering	Calendar days
Length of the flowering stage	days
Excess of potential fruits	%
Building up of harvest Index starting at flowering	days
Water productivity normalized for ETo and CO_2 (WP*)	g/m^2
Percentage of normalized water productivity (WP*) during the yield formation	% WP*
Sink strength quantifying biomass response to elevated atmospheric CO_2 concentration	%
Reference harvest index (HIo)	%
Possible increase of harvest index (HI) due to water stress before flowering	%
Allowable maximum increase of specified HI	%
Dry matter content of fresh yield	%
Minimum effective rooting depth in first year (required only in case of regrowth)	m

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

A3.1.7. Irrigation

As the growing mode is irrigation, an irrigation file (.IRR) was created (Figure A3.4). The simulation was performed under optimal water availability. The irrigation schedule generation was automated, with the time criterion based on an allowable fraction of RAW and the depth criterion based on back-to-field capacity (FC). This file was utilized for the water salinity sensitivity analysis by varying the irrigation water EC at given intervals.

Figure A3.4. Screenshot of the irrigation file



Time Criteria
○ Fixed interval
○ Allowable depletion (mm water)
● Allowable depletion (% of RAW)
○ Water layer between bunds

Depth Criteria
● Back to Field Capacity
○ Fixed net application

Irrigation water quality
excellent
EC_w 0.0 dS/m

Day No. 1 - day 1 after planting: 22 March

Date	Day No.	Depleted % RAW	To FC +/-(mm)	dS/m
22 March	1	20	0	0.0

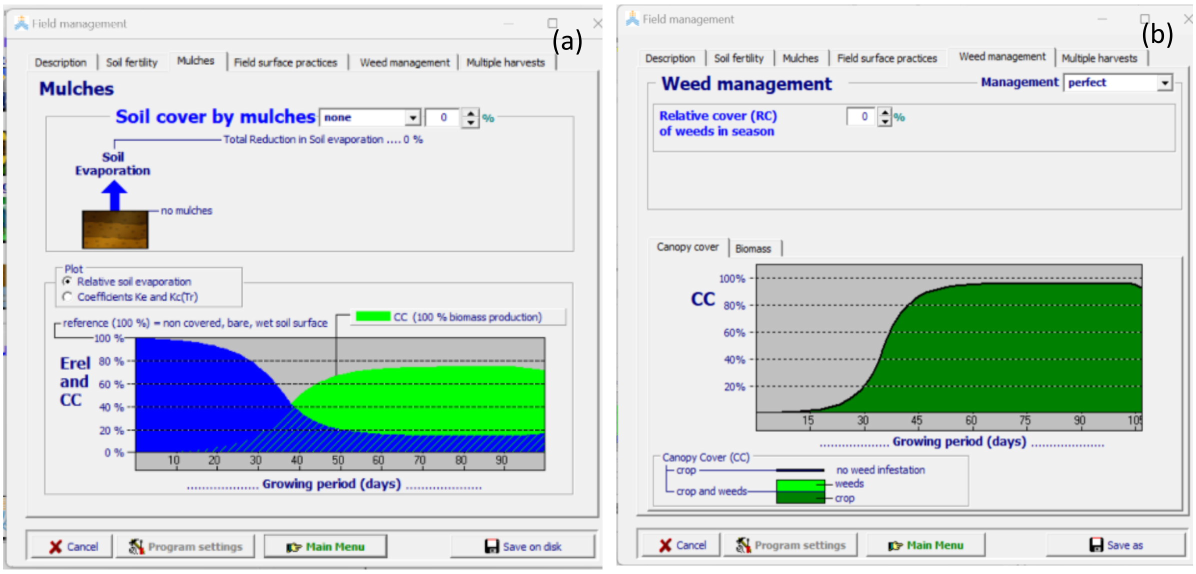
Day No. 100 - maturity: 29 June

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

A3.1.8. Field management

For conventional cropping systems, it was assumed that 0 percent of the ground surface was covered by mulch during the growing period. Soil fertility was set to non-limiting conditions to isolate the effects of other variables on crop performance. Soil bunds were not included in the simulation and surface runoff was considered negligible and not influenced by field surface practices. Weed management was assumed to be optimal with no impact on crop growth. Where applicable, multiple harvests were considered on a crop-by-crop basis. A separate field management file was created for each crop to capture these assumptions, and these files were appended to the report (Figure A3.5a and Figure A3.5b).

Figure A3.5. Field management file with assumed (a) no mulching and (b) perfect weed management



(a) Soil cover by mulches: none 0 %

Total Reduction in Soil evaporation .... 0 %

● Relative soil evaporation

○ Coefficients Ke and Kc(Tr)

(b) Management: perfect

Relative cover (RC) of weeds in season: 0 %

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

A3.1.9. Soil profile

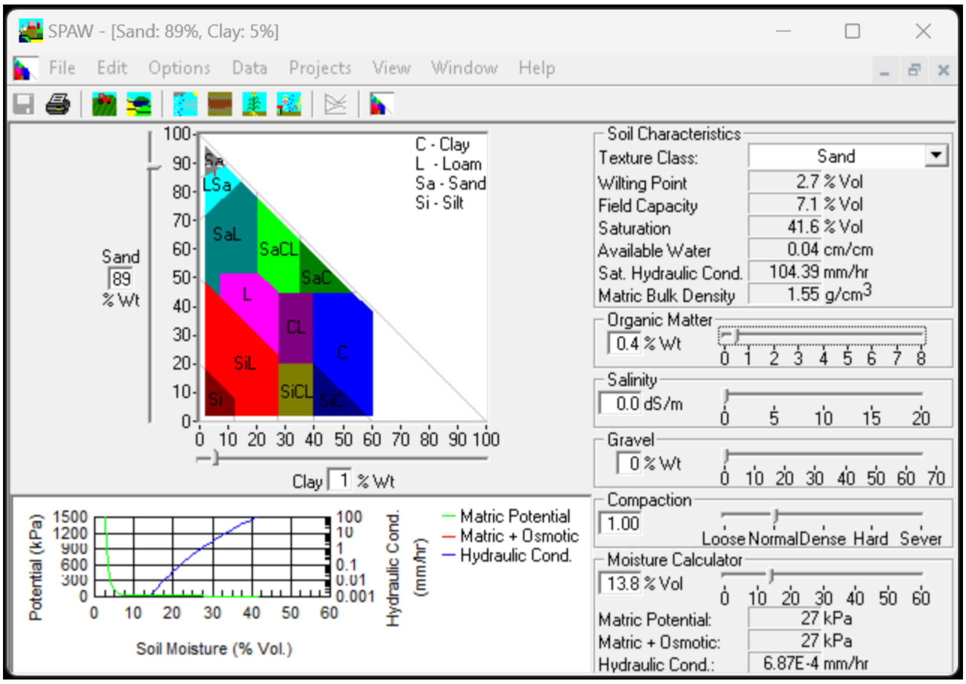
The primary farm-specific soil and related database included various soil characteristics, encompassing both physical properties (sand, silt and clay content) and chemical attributes (soil and water electrical conductivity and percentage of TOC). However, it lacked the essential soil hydraulic parameters required for AquaCrop modelling, such as textural class, wilting point, saturation, and hydraulic conductivity (Figure A3.6).

Hence, the data were further processed using the Soil-Plant-Air-Water (SPAW) model (Saxton, 2017). The available values for TOC, sand, silt, and clay content were used to derive the necessary soil hydraulic properties. Key parameters were obtained from this process, including the soil textural class, wilting point (%Vol), field capacity (%Vol), saturation (%Vol), and daily saturated hydraulic conductivity (mm/day). All the soil data from the 170 target farms underwent this processing step.

Once the hydraulic characteristics were determined, AquaCrop soil profile files were developed for each of the 170 farms. The process began by identifying the soil textural class, which guided the creation of the skeleton soil file. This classification was particularly important, as it informed the selection of the appropriate curve number for each profile. Among the 170 farms, the dominant soil texture was sandy (135 farms), followed by loamy sand (29 farms) and sandy loam (6 farms).

After generating and naming all skeleton files using the standard ID_AGR format, the SPAW-derived hydraulic parameters were entered into AquaCrop using the soil horizon input interface. This step was essential, as these parameters influence the calculation of total available water (TAW) and soil water retention threshold (τ) (Figure A3.7).

Figure A3.6. A graphical user interface (GUI) of the Soil-Plant-Air-Water (SPAW) model used in soil hydraulic properties derivation for the AquaCrop soil profile file



SPAW - [Sand: 89%, Clay: 5%]

Sand 89 % Wt

Clay 1 % Wt

Soil Characteristics

Texture Class:	Sand
Wilting Point	2.7 % Vol
Field Capacity	7.1 % Vol
Saturation	41.6 % Vol
Available Water	0.04 cm/cm
Sat. Hydraulic Cond.	104.39 mm/hr
Matric Bulk Density	1.55 g/cm^3

Organic Matter 0.4 % Wt

Salinity 0.0 dS/m

Gravel 0 % Wt

Compaction 1.00

Moisture Calculator 13.8 % Vol

Matric Potential:	27 kPa
Matric + Osmotic:	27 kPa
Hydraulic Cond.:	6.87E-4 mm/hr

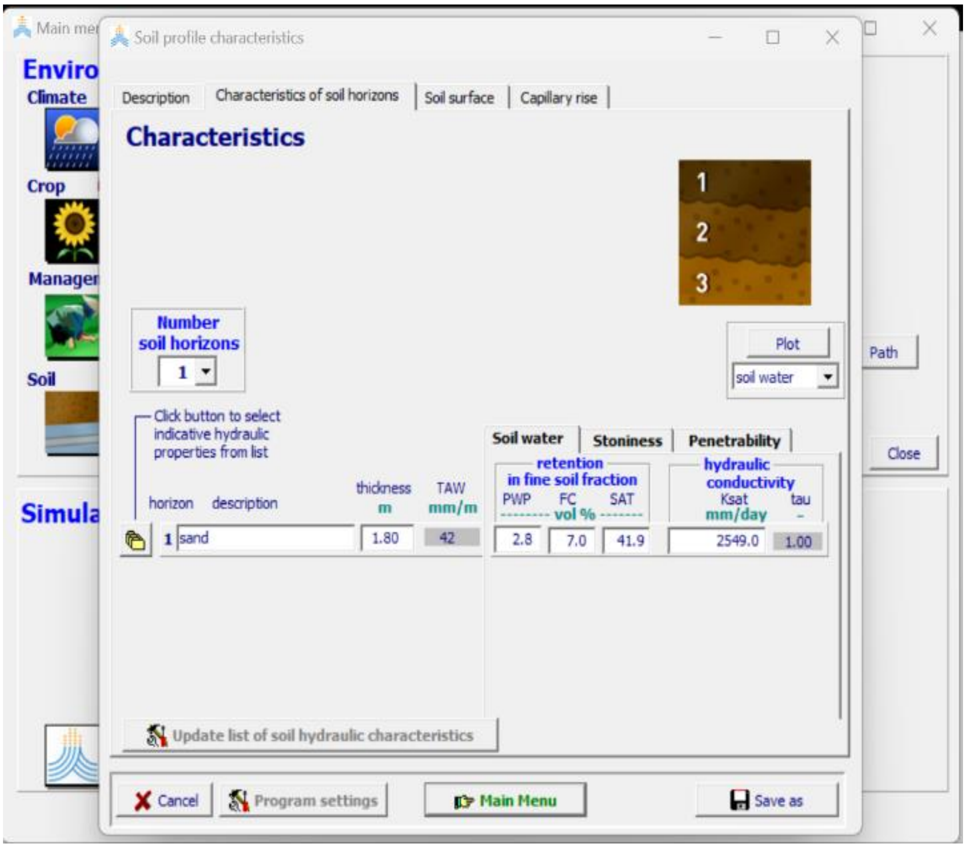
Note: The sample screenshot is based on site with farm ID_AGR 10176 properties (i.e. 89 percent sand, 1 percent clay and 0.4 percent total organic carbon).

Sources: **Saxton, K.E., Rawls, W.J., Romberger, J.S. & Papendick, R.I.** 1986. Estimating generalized soil-water characteristics from texture. *Soil Science Society of America Journal*, 50(4):1031–1036. https://doi.org/10.2136/sssaj1986.03615995005000040039x

Saxton, K.E. **&** Rawls, W.J. 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil Science Society of America Journal*, 70: 1569–1578. https://doi.org/10.2136/sssaj2005.0117

Saxton, K. 2017. *Soil - Plant - Atmosphere - Water Field and Pond Hydrology*. Washington, DC, United States Department of Agriculture (USDA). https://doi.org/10.15482/USDA.ADC/1529226

Figure A3.7. A sample file of a soil profile characteristics file



Number soil horizons: 1

Plot: soil water

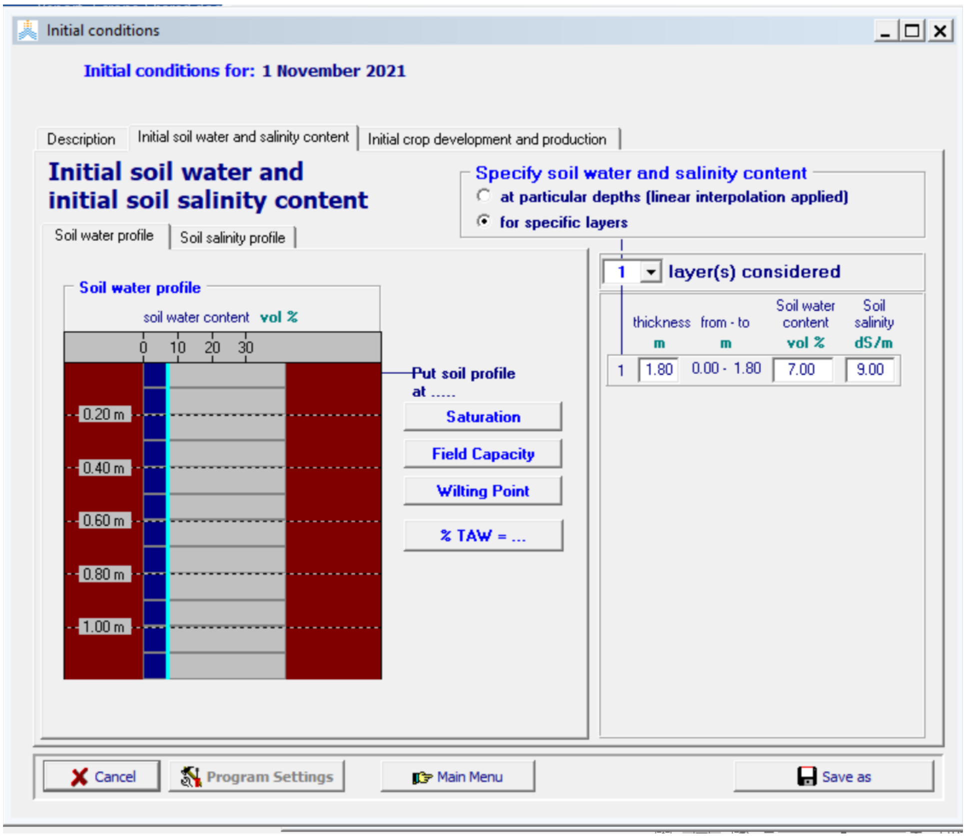
horizon	description	thickness m	TAW mm/m	retention in fine soil fraction PWP vol %	FC vol %	SAT vol %	hydraulic conductivity Ksat mm/day	tau -
1	sand	1.80	42	2.8	7.0	41.9	2549.0	1.00

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

A3.1.10. Initial conditions

A file for the initial conditions for each simulation was created (Figure A3.8). The initial canopy cover (CC) that could be reached without water stress was used as the default. Depending on the crop type, the amount of biomass (t/ha) produced before the simulation period and the initial effective rooting depth capable of being reached without water stress were set. This is particularly critical for perennial and fruit trees. Using this file, a sensitivity analysis of the soil salinity was performed.

Figure A3.8. Sample of initial soil conditions file parameterization



Initial conditions for: 1 November 2021

Initial soil water and initial soil salinity content

Specify soil water and salinity content

○ at particular depths (linear interpolation applied)

● for specific layers

1 layer(s) considered

	thickness m	from - to m	Soil water content vol %	Soil salinity dS/m
1	1.80	0.00 - 1.80	7.00	9.00

Source: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.

A3.1.11. Annuals, perennials and fruit trees simulations

AquaCrop is a comprehensive model that can be used for a wide range of crops including fodder, vegetables, grains, fruits, oils, and tubers. The model can be widely applicable to most major crop and plant products worldwide grown under different climate and soil conditions, without local calibration, once it has been adequately parameterized for a particular crop species. Nevertheless, some model parameters are dependent on location, crop cultivar and management practices and must be fitted by the user. Climate and soil are location-specific, and crop cultivars, timing of the crop cycle, water management, and agronomic practices are user-specific.

To simulate the yield response of crops to water using AquaCrop, the crops were categorized into three broad categories: annual, perennial, and fruit trees. While AquaCrop has been widely applied in annuals and perennials, significant applications have also been made on fruit trees. Examples include table grapes parameterization and simulation (Er-Raki *et al.*, 2021), addressing water stress in banana-based cropping systems (Stevens, 2021), a simulation of pomegranate growth and yield under different climatic conditions, water, and soils in Egypt (Arafat, Abo Taleb and Ahmed, 2019) and an exploration of optimal fertigation strategies for orange production using AquaCrop (Qin *et al.*, 2016). In the following subsections, the simulations for annuals, perennials and fruit trees are briefly described.

Annual crops

AquaCrop version 7.1 (Raes *et al*., 2023) was used in yield modelling under this project. The model was run on calendar days for all the annual crops considered. The calibration step of the models is a basic requirement to increase the accuracy and validity of the simulations. The AquaCrop model was calibrated for a specified annual crop during a selected cropping season using a secondary dataset of harvestable yield, biomass yield and CC. Simulations were run with the AquaCrop model for specific annual crops, starting with estimated or estimated parameter values for default annual crops, and then comparing the output with the measured data and secondary data sourced from relevant literature. The parameters were then adjusted, and the simulation was run and compared again. This was repeated until the simulated results agreed closely with the expected yield data, ensuring that an iterative process was at the heart of the calibration process.

Perennial pasture and forage crops

AquaCrop version 7.1 (Raes *et al*., 2023) was used in this project to simulate the yield response of all perennial pasture and forage crops to water. The model was run in calendar days mode, and the perennial herbaceous forage crop file of alfalfa was taken as a reference for pasture and forage crops. The standard Windows version 7.1 user interface includes a database of perennial herbaceous forage crops with multiple harvests, the amount of biomass and the crop yield harvested at each cut during the growing cycle in the case of multiple cuttings or harvests. In this study, calibration guidelines were followed from Hsiao *et al*. (2022). The calibration process was performed by running the model with specific input information on weather conditions, soil characteristics, field management practices, and crop parameters. For the perennials, the calibration involved adjusting the non-conservative parameters, including initial canopy cover (CCo) (percentage), maximum canopy cover (CCx) (percentage), time from sowing to start of senescence (days), and maximum effective rooting depth (m) until a close match was observed between the selected literature and simulated biomass. For the first stage – from sowing to first harvest – the soil surface cover of an individual seed at 90 percent emergence, as observed in the field (from relevant literature), and the final yield at the time of cutting were considered. For harvests after the first cut, the canopy cover after harvesting (CCini) was specified at a value of 40 percent for perennial herbaceous forage crops.

Fruit trees

AquaCrop version 7.1 (Raes *et al*., 2023) was used in this project to simulate the yield response of all fruit trees to water. The model was run in calendar days mode, and the crop file of the default fruit was used as a reference for fruit crops. The standard Windows version 7.1 user interface included a database of fruit crops with multiple harvests, the amount of biomass and crop yield harvested at each fruit harvest during the growing cycle in the case of multiple fruit pickings. The calibration process was performed by running the model with specific input information on weather conditions, soil characteristics, field management practices, and crop parameters. Throughout the fruit crop cycle, the amount of water stored in the root zone was simulated by calculating the incoming (rainfall and irrigation, if any) and outgoing (runoff, ETo and deep percolation) water fluxes at its boundaries. Root zone depletion determines the magnitude of the water stress coefficients (Ks) affecting:

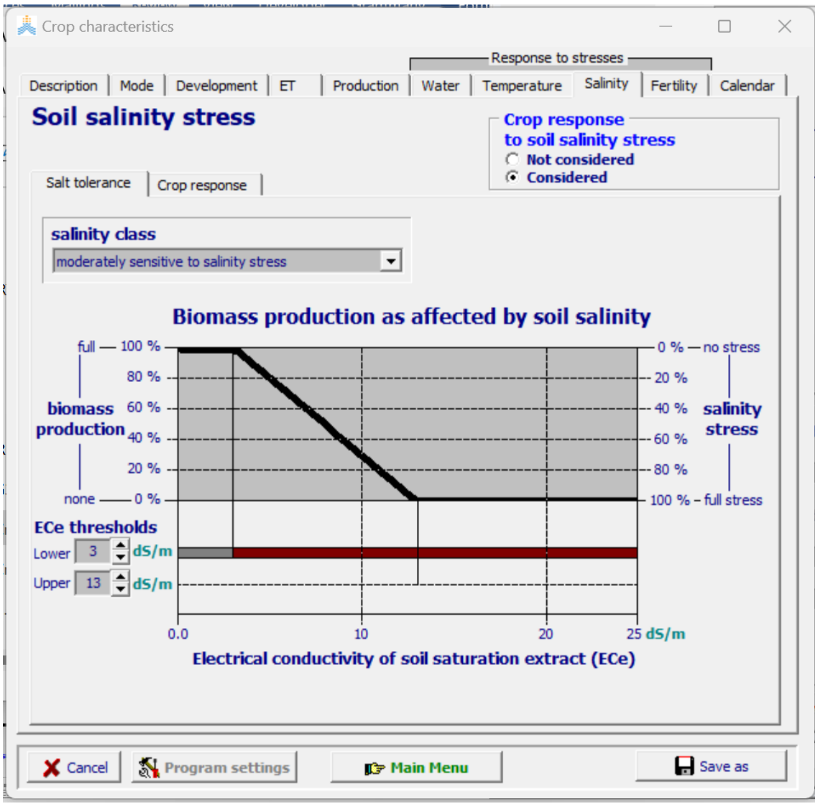
- Canopy cover (CC) expansion;
- stomatal conductance and transpiration per unit CC;
- canopy senescence and decline; and
- harvest index.

Each of these effects has its own threshold depletion and response curve. Additionally, the root system deepening rate is a function of Ks for stomatal conductance. If water stress occurs, the simulated CC will be lower than the potential canopy cover (CCpot) under no-stress conditions. The coefficient for transpiration (KcTr) is proportional to CC, and hence, is continuously adjusted throughout the simulation. Aboveground biomass was derived from transpiration using normalized water productivity (WP*), a conservative parameter. At the end of the crop cycle, the yield was calculated as the product of simulated B and the adjusted HI. In this study, non-limiting water conditions were applied.

A3.1.12. Crop sensitivity

The crops were subjected to sensitivity analyses for soil salinity (ECe) and water salinity (ECw). The crop module was used in response to the stress tab of the model. Salinity thresholds were custom-adjusted for each crop based on individual soil and water salinities. The thresholds were based on the FAO Irrigation and Drainage Paper No. 29 (Ayers and Westcot, 1985) (Figure A3.9).

Figure A3.9. A sample crop file, soil salinity parameterization (3 to 13 dS/m)



Crop characteristics

Soil salinity stress

Crop response to soil salinity stress
○ Not considered
● Considered

salinity class: moderately sensitive to salinity stress

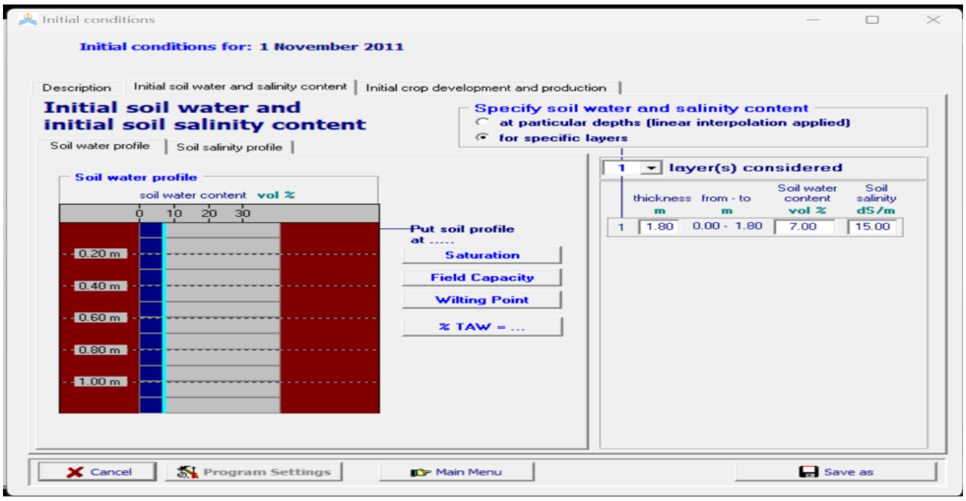
ECe thresholds
Lower 3 dS/m
Upper 13 dS/m

Sources: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Soil salinity

For the different electrical conductivity levels, irrigation water quality (ECw) values were adjusted in the “Specify Water and Salinity Content” subtab under the “Initial Soil Water and Salinity Content” tab of the irrigation management module in accordance with crop-specific salinity tolerance thresholds (Ayers and Westcot, 1985) (Figure A3.10).

Figure A3.10. Initial conditions file parameterization



Initial conditions for: 1 November 2011

Initial soil water and initial soil salinity content

Specify soil water and salinity content
○ at particular depths (linear interpolation applied)
● for specific layers

1 layer(s) considered

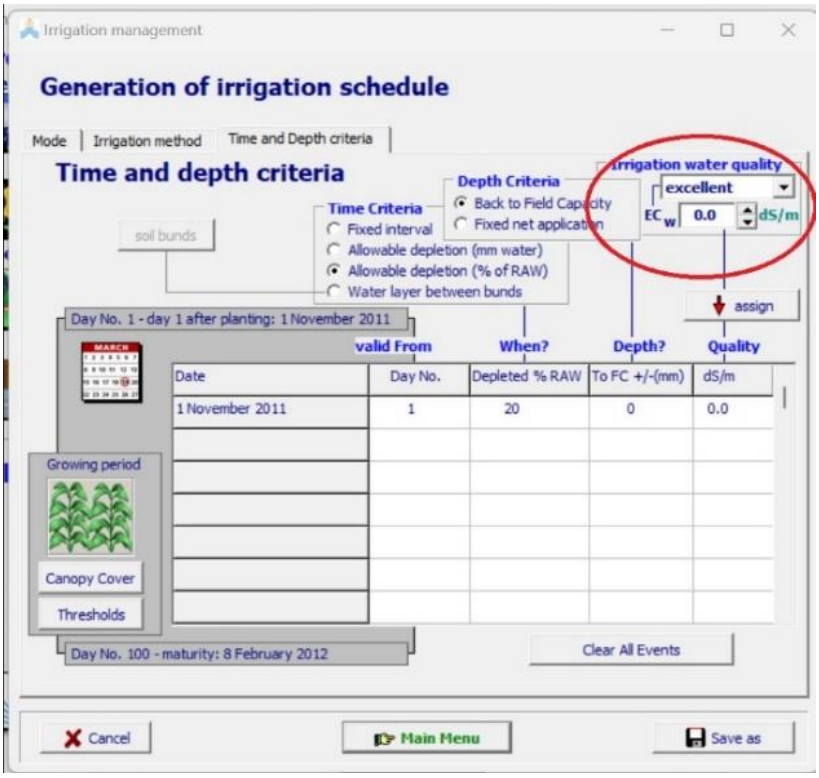
	thickness m	from - to m	Soil water content vol %	Soil salinity dS/m
1	1.80	0.00 - 1.80	7.00	15.00

Sources: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO’s crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

Water salinity

Water salinity sensitivity analysis was conducted using an irrigation management file (. MAN). Within the “Time and Depth Criteria” tabs of the irrigation management module, irrigation water quality (ECw) values were systematically varied from zero to crop-specific salinity tolerance thresholds based on established guidelines (Ayers and Westcot, 1985) (Figure A3.11).

Figure A3.11. Irrigation water quality adjustment (ECw)



Irrigation management

Generation of irrigation schedule

Time and depth criteria

Time Criteria
○ Fixed interval
○ Allowable depletion (mm water)
● Allowable depletion (% of RAW)
○ Water layer between bunds

Depth Criteria
● Back to Field Capacity
○ Fixed net application

Irrigation water quality: excellent
EC_w 0.0 dS/m

Day No. 1 - day 1 after planting: 1 November 2011

	valid From	When?	Depth?	Quality
Date	Day No.	Depleted % RAW	To FC +/-(mm)	dS/m
1 November 2011	1	20	0	0.0

Day No. 100 - maturity: 8 February 2012

Sources: **FAO (Food and Agriculture Organization of the United Nations).** (n.d.). *AquaCrop: FAO's crop water productivity model*. [Accessed on 10 January 2024]. https://www.fao.org/aquacrop. Licence: CC-BY-4.0.
ADAFSA (Abu Dhabi Agriculture and Food Safety Authority), personal communication, 2024.

A3.2. Results and discussion

A3.2.1. AquaCrop model set-up

The AquaCrop model was designed to simulate crop yield under conditions of salinity stress and has been shown to provide accurate yield estimations when crops are irrigated with saline water (Mondal *et al*., 2015; Zhai *et al*., 2020). The model incorporates a soil salinity stress coefficient to represent the effect of salinity on crop growth. The relationship between biomass production and soil salinity stress in AquaCrop was modelled using a convex curve, with a lower threshold of approximately 2 dS/m, an upper threshold of approximately 10 dS/m and a shape factor of approximately 2.4 (Mondal *et al*., 2015).

A3.2.2. Potential yield and fresh yield conversions

The potential yields of the 43 crops were compiled based on an extensive literature review and data provided by ADAFSA (2019, 2020), serving as the initial benchmark for yield simulations (Table A3.3). The corresponding conversion factors (CF) were derived to align the simulated yield outputs with the reported potential yields (Table A3.3).

Table A3.3. Potential yield (t/ha) and conversion factors (CF) used to align the simulated results alongside the potential yield of the 43 crops

No	**Crop**	**Potential yield (Yp) (t/ha)**	**Conversion factors (CF)**	**Reference for Yp**
1	Cherry tomato	24	2.93	Al Tamimi *et al.* (2022) Hirich and Choukr-Allah (2017) and Katerji *et al*. (2013)
2	Alfalfa	20	2.71	Ahn *et al*. (2009) and Raes *et al*. (2023)
3	Maize	17	1.46	Katerji *et al*. (2013) and Soltani and Alimardani (2016)
4	Cauliflower	20	2.00	Mujeeb-ur-Rahman *et al.* (2007)
5	Onion	40	5.99	Gebretsadik and Dechassa (2018) and Gedam *et al*. (2021)
6	Broccoli	22	2.19	De Pascale *et al*. (2005) and Kumar *et al.* (2018)
7	Potato	80	6.15	Journal *et al.* (2022)
8	Sweet melon	35	4.25	Ibrahim (2012) and Seymen *et al.* (2025)
9	Watermelon	30	4.31	Morgounov *et al*. (2022), Nantoumé *et al.* (2012) and Wang *et al*. (2023)
10	Quinoa	3.5	1.28	Cárdenas-Castillo *et al*. (2021) and Kulaz *et al*. (2025)
11	Common bean	9	0.97	Magalhães *et al*. (2019)
12	Beetroot	17.5	2.07	Sinta and Garo (2021)
13	Carrot	33	3.35	Ciza *et al*. (2022)
14	Pumpkin	28	5.25	ADAFSA (2019) and Morgounov *et al.* (2022)
15	Sweet potato	20	1.65	Gobena *et al.* (2022)
16	Jute mallow	8	2.21	Mgolozeli *et al*. (2022) and Rao *et al.* (2014)
17	Okra	10.5	2.39	Sheferie *et al*. (2023)
18	Strawberry	14.5	1.62	Bosch *et al*. (2022) and Sønsteby *et al.* (2022)
19	Turnip	17.5	1.08	Nawaz *et al*. (2020) and Tuulos *et al.* (2015)

No	**Crop**	**Potential yield (Yp) (t/ha)**	**Conversion factors (CF)**	**Reference for Yp**
20	Parsley	12.5	1.30	Jadczak *et al*. (2019)
21	Grape	37	1.10	Medrano *et al*. (2015) and Raffa *et al*. (2022)
22	Leucaena	25	1.05	Rengsirikul *et al*. (2011)
23	Napier grass	45	1.09	Haryani *et al*. (2018)
24	Panicum	50	1.08	Jank *et al.* (2013) and Nakamanee *et al*. (2008)
25	Raspberry	24	1.16	Sawicka *et al*. (2023)
26	Buffel grass	46	1.11	Alhammad *et al*. (2023) and Osman *et al*. (2008)
27	Butternut squash	30	5.64	Wetzel and Stone (2019)
28	Cassava	28	1.22	Fermont *et al*. (2009), Ngongo *et al.* (2022) and Onyenali *et al*. (2025)
29	Radish	40	11.24	Brintha and Seran (2010)
30	Rhodes grass	43	1.07	Arshad *et al*. (2016) and Osman *et al*. (2008)
31	Blueberry	15	1.03	Salvo *et al*. (2012)
32	Local almond	20	1.23	Gutiérrez-Gordillo *et al*. (2020)
33	Papaya	30	2.34	Raja (2010) and Salinas *et al.* (2023)
34	Sesbania	20	1.10	Azeem *et al*. (2025) and Chanda *et al*. (2018)
35	Banana	20	1.46	Jayasinghe *et al*. (2022) and Shahraki *et al*. (2023)
36	Guava	15	1.04	Heuzé *et al*. (2012)
37	Lime/lemon	12	1.17	Mira-García *et al*. (2023) and Pérez-Pérez *et al*. (2016)
38	Mango	15	1.07	Shahraki *et al.* (2023)
39	Orange	50	4.21	El Mokh *et al*. (2021), Saitta *et al*. (2021) and Sanders (2005)
40	Pomegranate	15	1.25	Beelagi *et al* (2023), Meena *et al.* (2023) and Tarantino *et al.* (2021)

No	Crop	Potential yield (Yp) (t/ha)	Conversion factors (CF)	Reference for Yp
41	Fig	15	1.17	Eslami *et al*. (2025) and Moura *et al.* (2023)
42	Moringa	25	1.18	Zheng *et al*. (2016)
43	Ziziphus (sidr)	25	1.20	Wolle *et al*. (2019)

Sources: See References.

A3.2.3. Attainable and potential yields

Among the 43 crops assessed, cherry tomato, alfalfa and maize were selected as methodological reference crops to demonstrate the step-by-step simulation process and sensitivity analysis. These crops represent a range of growth habits and management requirements across different production systems. Under OF conditions, cherry tomato showed a high average climatic potential yield of 19.9 t/ha, while the mean attainable yield dropped to 7.3 t/ha, reflecting the effects of environmental and biophysical constraints. Alfalfa also exhibited a similar pattern, with an average potential yield of 19.9 t/ha, but a much lower mean attainable yield of only 0.5 t/ha, indicating strong limitations likely due to water or salinity stress. For maize, the model simulated mean potential yield of 15.3 t/ha and an average attainable yield of 4.3 t/ha, again showing significant yield gaps.

Beyond these samples, the analysis revealed notable variability in the simulated potential and attainable yields across all crops and production systems. Some crops consistently exhibited high potential yields, whereas others showed relatively low attainable yields, reflecting the impact of diverse crop characteristics, environmental conditions and biophysical parameters. These findings underscore the importance of crop- and site-specific strategies to optimize production and minimize yield gaps under the conditions of the Abu Dhabi Emirate (Table A3.4, Table A3.5 and Table A3.6).

A statistical summary of all the simulated potential and attainable yields was generated using the AquaCrop model under the three production systems across the 170 farms, considering their respective climate, soil, and irrigation conditions (Table A3.4, Table A3.5 and Table A3.6).

Table A3.4. Summary statistics of the simulated climatic potential and attainable yield under open field (OF) conditions

Crop	Attainable yields (t/ha)				Crop	Potential yields (t/ha)			
	Mean	STDev	Max	Min		Mean	STDev	Max	Min
Alfalfa	0.5	2.3	19.3	0.0	**Alfalfa**	19.9	0.8	20	9.7
Common bean	0.5	1.2	5.1	0.0	**Common bean**	4.8	1.7	9	2.6
Banana	5.9	6.7	20.0	0.0	**Banana**	19.7	0.2	20	19.1

Crop	**Attainable yields (t/ha)**				**Crop**	**Potential yields (t/ha)**			
	Mean	STDev	Max	Min		Mean	STDev	Max	Min
Broccoli	6.7	7.9	22.8	0.0	**Broccoli**	21.4	0.4	22	18.3
Beetroot	4.5	6.0	18.4	0.0	**Beetroot**	16.9	0.3	17.5	15.3
Butternut squash	7.2	9.8	29.8	0.0	**Butternut squash**	28.7	0.7	30	25.0
Buffel grass	12.6	15.0	45.8	0.0	**Buffel grass**	44.7	0.7	46.1	41.9
Carrot	5.1	9.6	32.4	0.0	**Carrot**	31.4	2.5	33	0.0
Cherry tomato	7.3	7.0	23.2	0.0	**Cherry tomato**	19.9	2.9	24	0.0
Cauliflower	5.3	6.8	20.0	0.0	**Cauliflower**	19.2	0.5	20	16.5
Fig	5.8	1.7	14.5	0.0	**Fig**	14.3	1.1	15	0.0
Grape	10.5	14.7	43.1	0.0	**Grape**	42.4	0.4	43.5	40.1
Guava	2.4	4.3	14.9	0.0	**Guava**	14.8	0.1	15	14.6
Cassava	4.2	8.3	27.9	0.0	**Cassava**	27.1	2.8	28	0.0
Local almond	7.0	2.5	19.4	0.0	**Local almond**	19.3	0.3	20	18.3
Leucaena	7.1	6.2	24.8	0.0	**Leucaena**	24.4	0.2	24.9	23.6
Lemon	0.8	2.1	11.8	0.0	**Lemon**	11.7	0.9	12	0.0
Mango	4.0	5.2	16.5	0.0	**Mango**	16.3	0.1	16.6	15.8
Jute mallow	1.8	2.5	7.9	0.0	**Jute mallow**	7.6	0.2	8	6.3
Moringa	6.6	8.2	24.9	0.0	**Moringa**	24.2	1.9	25.1	0.0
Napier	11.2	14.3	44.6	0.0	**Napier grass**	43.5	0.6	44.8	40.8
Okra	3.1	3.5	10.5	0.0	**Okra**	10.4	0.1	10.5	9.4
Onion	5.8	11.5	39.3	0.0	**Onion**	36.4	1.6	40	30.9
Orange	12.7	15.9	49.8	0.0	**Orange**	49.2	0.4	50	47.7
Pomegranate	7.4	1.5	14.9	0.0	**Pomegranate**	14.7	1.1	15.1	0.0
Pumpkin	7.0	9.9	28.0	0.0	**Pumpkin**	25.3	2.9	28	0.0
Panicum	13.0	15.4	49.7	0.0	**Panicum**	48.7	0.6	50	46.1
Potato	9.6	21.0	79.0	0.0	**Potato**	73.6	3.0	80	64.5
Papaya	9.4	10.2	29.9	0.0	**Papaya**	29.6	0.3	30.1	28.1
Parsley	2.3	3.5	11.8	0.0	**Parsley**	10.9	0.5	12	8.4
Quinoa	2.0	1.0	3.5	0.0	**Quinoa**	3.2	0.3	3.5	0.0
Radish	13.6	13.2	36.5	0.0	**Radish**	35.3	2.9	39.9	0.0
Rhodes grass	14.8	14.3	42.8	0.0	**Rhodes grass**	41.5	3.3	43.1	0.0

Crop	**Attainable yields (t/ha)**				**Crop**	**Potential yields (t/ha)**			
	Mean	STDev	Max	Min		Mean	STDev	Max	Min
Ziziphus (sidr)	6.3	8.0	24.8	0.0	**Ziziphus (sidr)**	24.4	1.9	25	0.0
Sesbania	6.0	6.9	19.9	0.0	**Sesbania**	19.3	1.5	20.1	0.0
Maize	4.3	5.5	16.1	0.0	**Maize**	15.3	0.5	17.1	13.7
Sweet melon	6.0	10.6	34.6	0.0	**Sweet melon**	33.5	0.7	35.5	29.6
Sweet potato	3.6	6.3	19.8	0.0	**Sweet potato**	19.3	0.3	19.9	18.3
Turnip	3.2	5.0	17.1	0.0	**Turnip**	16.0	1.3	17.5	0.0
Watermelon	5.9	9.7	29.8	0.0	**Watermelon**	28.5	2.7	30	0.0

Table A3.5. Summary statistics of the simulated climatic potential and attainable yield under shade house (SH) conditions

Crop	**Attainable yields (t/ha)**				**Crop**	**Potential yields (t/ha)**			
	Mean	**STDev**	**Max**	**Min**		**Mean**	**STDev**	**Max**	**Min**
Common bean	0.4	1.0	4.3	0.0	**Common bean**	4.0	0.3	4.4	2.9
Blueberry	3.4	4.8	14.9	0.0	**Blueberry**	14.6	0.2	15.0	13.9
Banana	3.7	5.6	20.0	0.0	**Banana**	19.8	0.1	20.1	19.5
Butternut squash	5.5	9.8	29.6	0.0	**Butternut squash**	28.5	0.7	29.7	24.8
Cherry tomato	1.6	4.0	15.9	0.0	**Cherry tomato**	16.0	0.2	16.5	15.4
Fig	1.0	2.6	14.6	0.0	**Fig**	14.5	0.1	14.7	14.3
Grapes	7.9	11.8	36.6	0.0	**Grape**	36.2	0.3	37.1	35.8
Guava	2.2	3.8	14.9	0.0	**Guava**	14.8	0.1	15.0	14.6
Lemon	0.2	1.2	11.9	0.0	**Lemon**	11.8	0.1	12.0	11.2
Okra	2.0	3.4	10.5	0.0	**Okra**	10.4	0.1	10.5	9.9
Orange	9.0	15.6	49.9	0.0	**Orange**	49.5	0.3	50.1	48.8
Pomegranate	2.4	4.2	15.0	0.0	**Pomegranate**	14.9	0.1	15.1	14.7
Pumpkin	2.7	6.9	27.4	0.0	**Pumpkin**	26.4	0.8	28.1	24.6
Papaya	5.3	8.2	30.0	0.0	**Papaya**	29.8	0.2	30.1	29.4
Parsley	1.7	3.3	11.8	0.0	**Parsley**	11.2	0.4	12.0	10.1
Raspberry	4.9	7.3	23.9	0.0	**Raspberry**	23.5	0.3	24.0	23.0

Crop	Attainable yields (t/ha)				Crop	Potential yields (t/ha)			
	Mean	STDev	Max	Min		Mean	STDev	Max	Min
Strawberry	2.4	4.4	14.2	0.0	**Strawberry**	13.9	0.4	14.5	9.4
Sweet melon	7.0	11.7	34.2	0.0	**Sweet melon**	33.4	1.2	34.3	26.5
Sweet potato	2.6	5.6	19.9	0.0	**Sweet potato**	19.5	0.3	19.9	16.3
Watermelon	5.8	9.8	28.4	0.0	**Watermelon**	27.7	0.5	28.5	26.2

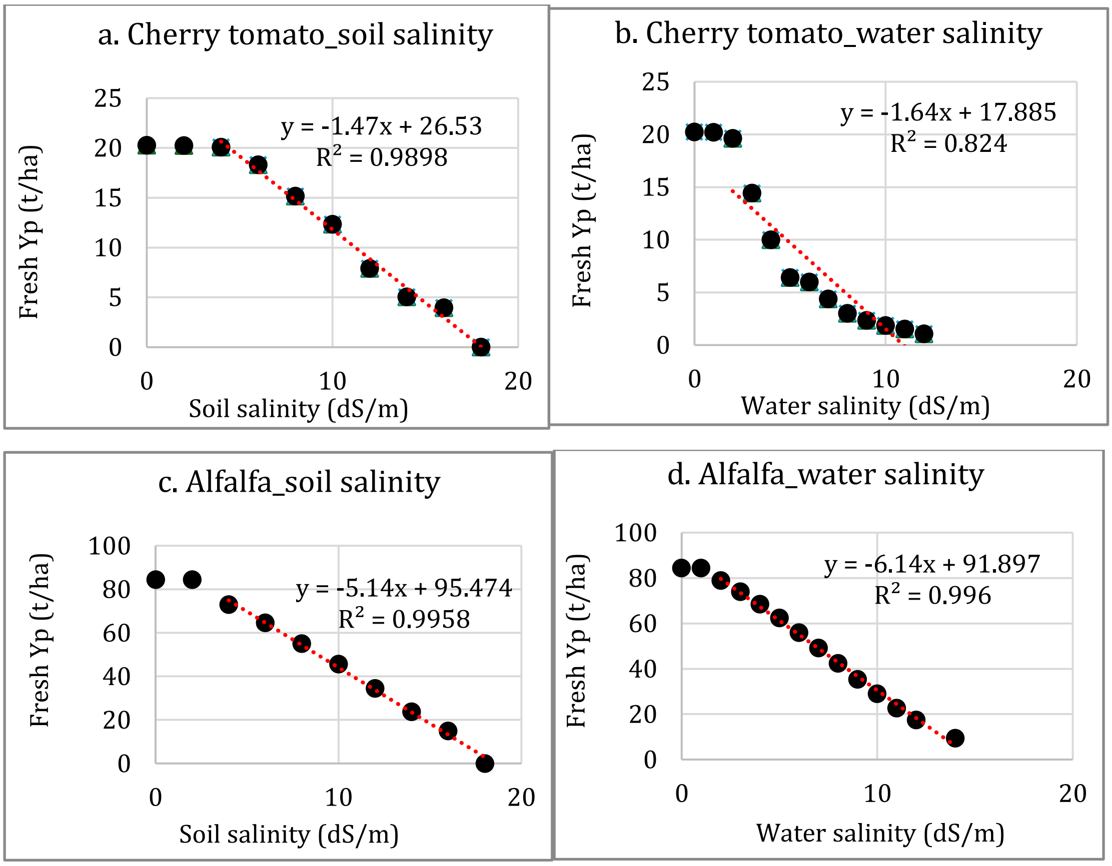
Table A3.6. Summary statistics of the simulated climatic potential and attainable yield under greenhouse (GH) conditions

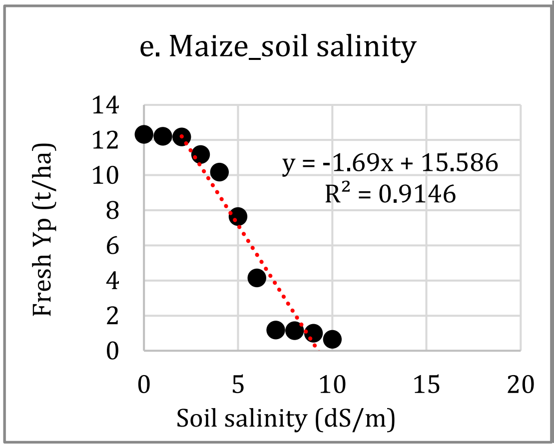
Crop	Attainable yields (t/ha)				Crop	Potential yields (t/ha)			
	Mean	STDev	Max	Min		Mean	STDev	Max	Min
Common bean	0.3	0.9	4.0	0.0	**Common bean**	3.0	0.5	4.7	2.3
Blueberry	2.7	4.2	14.8	0.0	**Blueberry**	14.0	1.1	14.9	2.8
Banana	3.6	5.7	19.8	0.0	**Banana**	19.3	0.3	19.9	18.8
Butternut squash	6.1	4.6	27.6	0.0	**Butternut squash**	26.6	1.2	29.7	24.2
Cherry tomato	1.3	3.6	15.7	0.0	**Cherry tomato**	15.3	0.5	17.0	14.6
Fig	1.9	3.4	14.5	0.0	**Fig**	14.1	0.2	14.6	13.7
Grape	22.8	8.8	35.5	0.0	**Grape**	35.1	0.6	36.9	33.3
Guava	2.9	4.0	14.8	0.0	**Guava**	14.4	0.2	14.9	14.1
Lemon	0.4	1.2	10.1	0.0	**Lemon**	11.3	1.3	11.9	2.8
Okra	1.8	3.0	10.3	0.0	**Okra**	9.9	0.2	10.4	9.2
Orange	9.4	14.5	49.6	0.0	**Orange**	48.2	0.7	49.8	47.1
Pomegranate	2.6	4.1	14.9	0.0	**Pomegranate**	14.5	0.5	15.0	10.3
Pumpkin	3.1	7.2	26.5	0.0	**Pumpkin**	23.4	1.6	29.2	20.5
Papaya	5.1	8.3	29.7	0.0	**Papaya**	29.0	0.4	29.9	28.4
Parsley	1.4	2.6	11.2	0.0	**Parsley**	9.3	0.9	12.0	7.7
Raspberry	4.3	6.4	23.6	0.0	**Raspberry**	22.5	0.5	23.8	21.6
Strawberry	2.1	4.0	14.0	0.0	**Strawberry**	12.9	0.6	14.4	11.6
Sweet melon	5.7	10.2	34.2	0.0	**Sweet melon**	31.0	1.8	35.0	26.6
Sweet potato	2.1	4.7	19.9	0.0	**Sweet potato**	19.4	0.2	19.9	18.8
Watermelon	4.8	8.9	29.0	0.0	**Watermelon**	26.6	1.2	29.7	24.1

A3.2.4. Sensitivity analysis

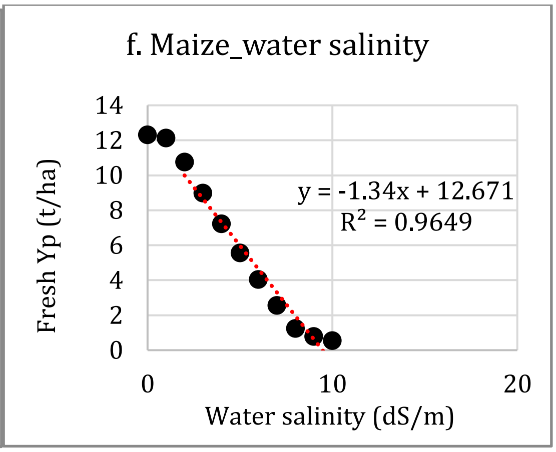
The yield sensitivity analysis for cherry tomato, alfalfa and maize under increasing soil and water salinity levels revealed distinct crop-specific responses (Figure A3.12). For cherry tomato, the slope of the regression line indicated a slightly higher sensitivity to water salinity (−1.64) than to soil salinity (−1.47), suggesting that the yield decreased more rapidly with increasing water salinity. In contrast, alfalfa showed a pronounced decline in yield with salinity, particularly in response to water salinity (−6.14) compared to soil salinity (−5.14), confirming that water quality plays a more limiting role for this crop. On the other hand, maize exhibited greater sensitivity to soil salinity, with a steeper yield reduction slope (−1.69) than for water salinity (−1.34), indicating that soil conditions are more critical for maintaining yield potential in this crop. These slope values provide a clear indication of the relative importance of managing soil versus water salinity in different crops. The optimal and absolute sensitivity thresholds for all 43 crops are summarized in Table 10 (Section 3.2) and detailed results for the three representative crops are presented in Figure A3.12.

Figure A3.12. Sensitivity of fresh potential yield of cherry tomato, alfalfa and maize to soil salinity (ECe) and water salinity (ECw)





e. Maize_soil salinity



f. Maize_water salinity

Appendix A4. Recommendations for high-value crop species of potentially high suitability currently not cultivated in the Abu Dhabi Emirate

A4.1. Methodological approach

The research was conducted through a combination of literature review, library studies and expert interviews to gather and analyse relevant information.

A4.1.1. Criteria for crop selection

The selection of underutilized crops was guided by a set of specific criteria designed to assess their adaptability to unique climatic and soil conditions of the Abu Dhabi Emirate, as well as their economic potential and agricultural value (Table A4.1). The following criteria were used to evaluate each crop.

- Temperature tolerance: Given the extreme temperatures in the emirate, it was essential to select crops that can withstand high daily maximum temperatures and relatively low minimum temperatures. The selected crops needed to demonstrate resilience to temperature variations, with a particular focus on those that could thrive at temperatures ranging from 8.2 °C to 49.4 °C.
- Rainfall requirements: The Abu Dhabi Emirate experiences minimal rainfall, with an average long-term yearly rainfall of 31.35 mm and an average annual rainfall of 37.5 mm. Therefore, crops that required minimal water and were able to survive in low-rainfall environments were prioritized.
- Soil salinity tolerance: Soil salinity is a significant challenge in the Abu Dhabi Emirate, with ECw levels reaching 47.8 dS/m and soil salinity ECe) levels exceeding 40 dS/m at various soil depths. Crops able to tolerate high salinity levels were considered more suitable for the emirate.
- pH range adaptability: The soil pH in the Abu Dhabi Emirate varies from less than 6.5 to more than 9. Crops with a wide pH tolerance range were selected to ensure that they could adapt to the varying soil pH levels found in the different regions of the emirate.
- Soil texture preferences: The soil in the Abu Dhabi Emirate predominantly consists of sand (average of 91.7 percent), with low percentages of clay (average of 1.5 percent) and silt (average of 3 percent). Crops able to grow well in sandy soils were preferred.
- Chilling hour requirements: The Abu Dhabi Emirate has fewer than 200 chilling hours, which is essential for certain crops to break dormancy and promote growth. Crops with low chilling hours were selected to align with the climatic conditions.

- Economic value: The economic potential of each crop was evaluated based on its market demand, potential uses and profitability. Crops with high economic value and marketability were prioritized.

Table A4.1. Criteria designed to assess uncultivated crops adaptability to the climatic and soil conditions of the Abu Dhabi Emirate

Parameters	**Min**	**Max**	**Average**	**Unit**
Latitude	22.64	26.07	24.355	°N
Longitude	51.49	56.38	53.935	°E
Altitude	0	1 910	149	m
Altitude range for agricultural areas	0	455	138.6	m
Slope	<0.5	45	2.2	%
Minium daily air temperature	8.2	34.5	21.35	°C
Maximum daily air temperature	21.5	49.4	35.45	°C
Long term yearly rainfall	–	–	31.35	mm
Average rainfall	21.7	56.1	37.5	mm
Water salinity	0	47.8	10.3	dS/m
Soil salinity (25–50 cm)	0	>40	13.2	dS/m
Soil salinity (0–25 cm)	0	>40	9.4	dS/m
Soil salinity (50–150 cm)	0	>40	8.5	dS/m
Soil pH	<6.5	>9	8.1	–
Soil parameter (sand)	55	100	91.7	%
Soil parameter (clay)	0	9	1.5	%
Soil parameter-(silt)	0	28	3	%
Soil parameter (coarse sand)	0	29	2	%
Soil parameter (coarse silt)	0	15	1.85	%
Soil parameter (bulk density)	0	1.95	0.72	g/cm^3
Groundwater depth	<10	230	58	m
Chilling hours	–	<200	–	hours

A4.1.2. Sources of data

The data used in this appendix were gathered from multiple sources to ensure a comprehensive and accurate evaluation of the underutilized crops. The primary sources included a thorough literature review of academic journals, research papers, books, and reports from agricultural research institutions that discuss the characteristics and adaptability of underutilized crops in arid and semiarid environments. Additionally, expert interviews were conducted with agronomists, horticulturists, soil scientists, and representatives of agricultural research organizations and universities. These interviews provided valuable insights and practical knowledge regarding the cultivation and potential of underutilized crops in the context of the Abu Dhabi Emirate.

A4.2. Results and discussion

A4.2.1. Review of selected crops

This study identified 11 crops – jatropha (*Jatropha curcas*), castor bean (*Ricinus communis*), camelina (*Camelina sativa*), teff (*Eragrostis tef*), purslane (*Portulaca oleracea*), safflower (*Carthamus tinctorius*), jojoba (*Simmondsia chinensis*), guayule (*Parthenium argentatum*), sweet sorghum (*Sorghum bicolor*), prickly pear (*Opuntia ficus-indica*), and coconut (*Cocos nucifera*) – as suitable candidates for cultivation in the Abu Dhabi Emirate). These selections were based on their adaptability to the country's arid climate, which is characterized by extreme heat, limited water availability and high soil salinity. Crops span different photosynthetic pathways (C3, C4, and crassulacean acid metabolism [CAM]), providing insights into their physiological efficiency and suitability under varying environmental conditions. For example, C4 crops such as teff and sweet sorghum are particularly efficient in high-temperature environments, whereas CAM plants such as prickly pear exhibit high water-use efficiency by fixing C at night. Table A4.2 presents the classifications of the selected crops, providing a foundation for understanding their potential performance in the Abu Dhabi Emirate farming systems. The following sections provide crop-specific assessments of their agronomic strengths and constraints under local environmental parameters.

Table A4.2. Selected crops along with their scientific names and plant classifications

Crop	Scientific name	Plant class	Class specification
Jatropha	*Jatropha curcas*	C3	Some C3 plants have developed specific adaptations to cope with drought conditions, such as deep root systems, reduced leaf area, and leaf modifications to reduce water loss.
Castor bean	*Ricinus communis*	C3	
Camelina	*Camelina sativa*	C3	
Safflower	*Carthamus tinctorius*	C3	
Jojoba	*Simmondsia chinensis*	C3	
Guayule	*Parthenium argentatum*	C3	

Crop	Scientific name	Plant class	Class specification
Coconut	*Cocos nucifera*	C3	
Teff	*Eragrostis tef*	C4	These plants use the C4 carbon fixation pathway, which is more efficient in hot, sunny environments.
Purslane	*Portulaca oleracea*	C4	
Sweet sorghum	*Sorghum bicolor*	C4	
Prickly pear	*Opuntia ficus-indica*	CAM	Crassulacean acid metabolism plants open their stomata at night to reduce water loss in arid conditions.

Jatropha

Among the unutilized crops, jatropha has emerged as a promising candidate because of its adaptability to harsh conditions, economic potential, and versatility. It has a deep root system that helps access water from deeper soil layers (Figure A4.1). This study evaluated its suitability for the emirate, focusing on specific criteria such as temperature tolerance, rainfall requirements, soil salinity tolerance, pH range adaptability, soil texture preferences, chilling hour requirements, and economic value.

Figure A4.1. Field production of jatropha

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Temperature tolerance

Jatropha demonstrates strong adaptability to a broad range of temperatures, making it particularly suited to the emirate’s arid and high-temperature environment. The optimal temperature range for its growth is between 20 °C and 28 °C, with the ability to tolerate extremes as low as 5 °C and as high as 49.4 °C (Khalid *et al*., 2021; Singh, Vatsal and Verma, 2014). This high-temperature resilience is especially valuable in the emirate, where ambient temperatures frequently exceed 45 °C during the summer. The capacity of the crop to sustain growth and productivity under thermal stress ensures its viability across seasons, supporting continuous biomass production. This trait also enhances jatropha’s potential role as a stable biofuel feedstock, contributing to the national objectives for renewable energy and sustainable agriculture.

Rainfall requirements

One of the most critical factors for crop selection in the Abu Dhabi Emirate is water usage, given the country's limited rainfall and scarce water resources. Jatropha requires minimal rainfall, with an optimal range of 900–1 200 mm per year (Neupane *et al*., 2021). Although this requirement seems high compared to the emirate average annual rainfall of 37.5 mm, it has shown remarkable drought tolerance and can survive in semi-arid regions with supplemental irrigation (Rao *et al*., 2012).

The deep root system of the crop allows access to water from deeper soil layers, reducing the need for frequent irrigation. Drought tolerance is a significant advantage for cultivation in the emirate, where water conservation is a priority.

Soil salinity tolerance

Soil salinity is a prevalent issue in the Abu Dhabi Emirate and poses a challenge for many crops. However, jatropha demonstrates moderate tolerance to soil salinity, with optimal growth in soils with salinity levels between 1.5 dS/m and 6 dS/m (Yang *et al*., 2023). This tolerance makes the crop a viable option for areas with saline soils, where conventional crops may struggle to survive.

The ability to grow in saline conditions not only expands the potential cultivation areas within the emirate but also contributes to soil rehabilitation by reducing salinity levels over time. This characteristic enhances the sustainability of agricultural practices in the region.

pH range adaptability

Soil pH in the Abu Dhabi Emirate varies widely, necessitating crops that can adapt to different pH levels. Jatropha is adaptable to a wide pH range of between 5.5 and 8.5 (León-Villanueva *et al*., 2022). This adaptability ensures that the crop can be cultivated in various soil types across the emirate, from slightly acidic to alkaline soils.

This flexibility in pH tolerance allows farmers to utilize land that may otherwise remain underutilized because of unsuitable pH levels for other crops. The ability to grow under diverse soil conditions further support the widespread adoption of the plant in the emirate.

Soil texture preferences

The predominant soil type in the Abu Dhabi Emirate is sandy, with minimal organic matter and clay content. Jatropha prefers well-drained soils, making it compatible with the sandy soils found in the emirate (Leapheng, Effendi and Helmy, 2019). The ability to grow in sandy soils without significant soil amendments is an essential advantage.

Moreover, the preference for well-drained soil helps prevent waterlogging, which can be detrimental to many crops. This characteristic ensures that the plant can be cultivated with minimal soil preparation, thereby reducing the costs and labour associated with soil management.

Chilling hour requirements

Chilling hours are essential for breaking dormancy and initiating growth in some crops. However, the Abu Dhabi Emirate has fewer than 200 chilling hours annually, which can be a limiting factor for many crops. Jatropha does not require chilling hours for its growth cycle, making it perfectly suited to the emirate's warm climate (Zheng *et al*., 2009).

The lack of chilling hour requirements means that the plant can grow continuously throughout the year without seasonal interruptions. This continuous growth cycle ensures a consistent supply of raw materials for biofuel production and other applications.

Economic value

Jatropha's economic potential lies primarily in its use as a biofuel. Its seeds contain a high percentage of oil, which can be converted into biodiesel, making the plant a renewable energy source that can help reduce dependence on fossil fuels and greenhouse gas emissions (Maghuly and Laimer, 2013). Additionally, jatropha has other economic uses, including the production of soap, cosmetics and fertilizers. The by-products of oil extraction can be used as organic fertilizers, contributing to soil health and reducing the need for chemical fertilizers. The cultivation of jatropha can also create employment opportunities in rural areas, contributing to economic development and poverty alleviation. The establishment of jatropha plantations can provide jobs in planting, maintenance, harvesting, and processing, thereby supporting local economies.

Castor bean

Among potential crops, castor bean stands out because of its adaptability and economic potential. It has a robust root system that can access deep water sources (Figure A4.2).

Figure A4.2. Field production of castor beans

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Temperature tolerance

Castor bean is highly adaptable to a wide range of temperatures, making it suitable for the extreme climate of the Abu Dhabi Emirate. It thrives optimally between 20 and 30 °C (Ramos *et al*., 2013), but can tolerate temperatures up to 40 °C. The ability to withstand high temperatures is crucial for the emirate, where summer temperatures can exceed 45 °C. Furthermore, the castor bean has a minimum temperature tolerance of 0 °C, ensuring that it can survive occasional cold spells (Mahr, 2024).

This temperature resilience ensures that castor bean can maintain growth and productivity throughout the year in the Abu Dhabi Emirate despite significant temperature fluctuations. The crop's ability to endure both high and low temperatures without significant loss in yield makes it an ideal candidate for the emirate's diverse climates.

Rainfall requirements

Water scarcity is a critical issue in the Abu Dhabi Emirate, necessitating crops that require minimal amounts of water. The castor bean has moderate water requirements, with an optimal annual rainfall of 250 to 750 mm (Patel *et al*., 2016). Although the emirate's average annual rainfall is only approximately 37.5 mm, the castor bean can be cultivated with supplemental irrigation. Its deep root system allows it to access water from the deeper soil layers, further reducing the need for frequent irrigation.

The moderate water requirements and drought tolerance of the castor bean make it a viable option for the Abu Dhabi Emirate, where water conservation is a priority. This crop can thrive under efficient irrigation practices to ensure sustainable water use.

Soil salinity tolerance

Soil salinity is a prevalent issue in the Abu Dhabi Emirate that affects the growth of many conventional crops. The castor bean exhibits moderate tolerance to soil salinity, thriving in soils with salinity levels between 1.5 and 6 dS/m (Zhang *et al*., 2016). This tolerance allows the castor bean to grow in areas with high soil salinity.

The ability to tolerate saline conditions not only expands the potential cultivation areas within the Abu Dhabi Emirate but also contributes to soil reclamation efforts. By reducing soil salinity over time, the castor bean can improve overall soil health, making it more suitable for subsequent crops.

pH range adaptability

Soil pH varies widely across the Abu Dhabi Emirate, necessitating crops to adapt to different pH levels. Castor bean is adaptable to a pH range between 6 and 8, making it suitable for both slightly acidic and alkaline soils (Mustapha *et al*., 2021). This adaptability ensures that castor bean can be cultivated in various regions across the emirate, regardless of soil pH.

The wide pH tolerance range of castor bean allows farmers to utilize land that might otherwise remain underutilized because of unsuitable pH levels for other crops. This flexibility supports the widespread adoption of castor bean in the Abu Dhabi Emirate.

Soil texture preferences

The predominant soil type in the Abu Dhabi Emirate is sandy, with low organic matter and clay content. Castor bean prefers well-drained soils, which align with the sandy soils found in the emirate (Sakure, Dhaduk and Mehta, 2012). The ability to grow in sandy soils without significant soil amendments is a critical advantage.

Moreover, the preference for well-drained soils helps to prevent waterlogging, which can be detrimental to many crops. This characteristic ensures that castor bean can be cultivated with minimal soil preparation, reducing costs and labour associated with soil management.

Chilling hour requirements

The Abu Dhabi Emirate has less than 200 chilling hours annually, which can be a limiting factor for many crops. Castor bean is sensitive to cold and does not require chilling hours for its growth cycle, making it perfectly suited to the emirate’s warm climate (Mahr, 2024).

The lack of chilling hour requirements means that castor bean can grow continuously throughout the year without seasonal interruptions. This continuous growth cycle ensures a consistent supply of raw materials for industrial use, thereby contributing to the sustainability of agricultural practices.

Economic value

Castor bean has significant economic value because of its various industrial applications. The primary product is castor oil, which is used in the manufacture of lubricants, pharmaceuticals, cosmetics, and biodiesel (Kumar *et al*., 2023). The high oil content and unique chemical properties of castor oil make it a valuable commodity for the global market. Additionally, castor bean can contribute to the economy by creating employment opportunities in rural areas. The cultivation, harvesting, and processing of castor bean provide jobs and support local economies. Furthermore, by-products of oil extraction can be used as organic fertilizers, contributing to soil health and reducing the need for chemical fertilizers. The versatility and economic potential of castor bean make it an attractive crop for the Abu Dhabi Emirate. Its cultivation can diversify the agricultural sector, improve food and energy security and create new economic opportunities.

Camelina

Camelina, commonly known as false flax or gold-of-pleasure, is an oilseed crop that has gained attention for its adaptability to various climatic conditions and economic potential (Figure A4.3). Originating from eastern Europe, Central Asia, and Southwest Asia, camelina is cultivated for its oil, which is used in biofuels, food and feed applications (Radišek *et al*., 2014). It has a short growing season, which helps avoid the most intense periods of drought.

Figure A4.3. Field production of camelina

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Temperature tolerance

Camelina demonstrates significant adaptability to a wide range of temperatures, making it a suitable candidate for extreme climates in the Abu Dhabi Emirate. The optimal temperature range for camelina is 5 to 30 °C (Carmo-Silva and Salvucci, 2012). While the minimum temperature requirement is relatively low, camelina can tolerate high temperatures of up to 30 °C, which is beneficial for surviving in the hot summers of the emirate.

The crop's ability to endure both low and high temperatures without significant loss in yield makes it an ideal candidate for the Abu Dhabi Emirate diverse climate.

Rainfall requirements

Water scarcity is a critical issue in the Abu Dhabi Emirate, necessitating crops that require minimal amounts of water. Camelina has moderate water requirements, with an optimal annual rainfall of 300 to 600 mm (Shukla, Dutta and Artz, 2002). Although the emirate’s average annual rainfall is only approximately 37.5 mm, camelina can be cultivated with supplemental irrigation. Its deep root system allows access to water from deeper soil layers, thereby reducing the need for frequent irrigation.

The moderate water requirements and drought tolerance of camelina make it a viable option for the Abu Dhabi Emirate, where water conservation is a priority. This crop can thrive under efficient irrigation practices that ensure sustainable water use.

Soil salinity tolerance

Soil salinity is a prevalent issue in the Abu Dhabi Emirate that affects the growth of many conventional crops. Camelina exhibits moderate tolerance to soil salinity and thrives in soils with salinity levels between 6 and 8 dS/m (Obeng *et al*., 2021). This tolerance allows it to grow in areas of high soil salinity.

The ability to tolerate saline conditions not only expands the potential cultivation areas within the Abu Dhabi Emirate but also contributes to soil reclamation efforts. Camelina can improve the overall soil health by reducing soil salinity over time, making it more suitable for subsequent crops.

pH range adaptability

Soil pH varies widely across the Abu Dhabi Emirate, necessitating crops to adapt to different pH levels. Camelina is adaptable to a pH range of 5.5 to 8 (Hazrati *et al*., 2024). This adaptability ensures that camelina can be cultivated in various regions across the emirate, regardless of the soil pH.

The wide pH-tolerance range of camelina allows farmers to utilize land that might otherwise remain underutilized because of unsuitable pH levels for other crops. This flexibility supports the plant’s widespread adoption in the Abu Dhabi Emirate.

Soil texture preferences

The predominant soil type in the Abu Dhabi Emirate is sandy, with low organic matter and clay content. Camelina prefers well-drained soils, which are aligned with the sandy soils found in the emirate

(Shukla, Dutta and Artz, 2002). The ability to grow in sandy soils without significant soil amendments is a critical advantage.

Chilling hour requirements

The Abu Dhabi Emirate has less than 200 chilling hours annually, which can be a limiting factor for many crops. Camelina does not require chilling hours for its growth cycle, making it perfectly suited to the emirate's warm climate (Soorni *et al*., 2022). The lack of chilling hours means that it can grow continuously throughout the year without seasonal interruption.

Economic value

Camelina has a significant economic value owing to its various applications. The primary product is camelina oil, which is used in the manufacture of biofuels, food products and animal feed (Soorni *et al*., 2022). The high oil content and unique chemical properties of camelina oil make it a valuable commodity in the global market.

Teff

Teff is a warm-season annual grass that has traditionally been cultivated in Ethiopia for its grain and is a staple food. Given its adaptability to various environmental conditions, teff is considered for cultivation in the Abu Dhabi Emirate (Figure A4.4).

Figure A4.4. Field production of teff

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Temperature tolerance

Teff exhibits a significant adaptability to a wide range of temperatures, making it suitable for the Abu Dhabi Emirate climate. The optimal temperature range for teff is 20 to 35 °C (Yu *et al*., 2023). Although it can tolerate temperatures as low as 5 °C, optimal growth occurs at warmer temperatures. This makes it particularly well suited to the emirate's hot summers.

Rainfall requirements

Teff has moderate water requirements, with an optimal annual rainfall of 200 to 800 mm (Lebot, 2020). Although the Abu Dhabi Emirate's average annual rainfall is only approximately 37.5 mm, it can be cultivated with supplemental irrigation. The efficient use of water and its ability to grow under rainfed conditions in regions with lower rainfall makes it a viable option.

The moderate water requirements and drought tolerance of teff make it suitable for the emirate, where water conservation is a priority. The crop can thrive under efficient irrigation practices that ensure sustainable water use.

Soil salinity tolerance

Soil salinity is a prevalent issue in the Abu Dhabi Emirate that affects the growth of many conventional crops. Teff exhibits moderate tolerance to soil salinity and thrives in soils with salinity levels between 2 and 4 dS/m (Kayasth *et al*., 2013). This tolerance allows it to grow in areas with higher soil salinity where other crops might fail.

pH range adaptability

Teff is adaptable to a pH range of 5 to 7.5 (Selassie *et al*., 2014). This adaptability ensures that the plant can be cultivated in various regions across the Abu Dhabi Emirate, regardless of the soil pH. The wide pH range tolerance of teff allows farmers to utilize land that might otherwise remain underutilized because of unsuitable pH levels for other crops. This flexibility supports its widespread adoption in the emirate.

Soil texture preferences

Teff prefers loam or sandy soils, which align with the sandy soils found in the Abu Dhabi Emirate (Lim *et al*., 2015). The ability to grow in sandy soils without significant soil amendments is a critical advantage. Moreover, the preference for well-drained soils helps to prevent waterlogging, which can be detrimental to many crops. This characteristic ensures that teff can be cultivated with minimal soil preparation, reducing the costs and labour associated with soil management.

Chilling hour requirements

Teff does not require chilling hours for its growth cycle, making it perfectly suited to the Abu Dhabi Emirate's warm climate (Cholakova *et al*., 2023).

Economic value

Teff has significant economic value owing to its various applications. The primary product is grain, which are used as a staple food in many cultures. Teff is highly nutritious, rich in fibre, iron and protein, as well as being gluten-free, making it popular among health-conscious consumers and those with gluten intolerance (Gizaw, 2018).

Research indicates that teff can also be a valuable forage option for livestock, with studies assessing its productivity in lactating dairy cows and horses (Saylor, Min and Bradford, 2018; Staniar *et al*., 2010).

Purslane

Purslane is a succulent herb well known for its nutritional and medicinal properties (Figure A4.5). Originating from North Africa, southern Europe and the Near East, purslane has adapted to a variety of climatic and soil conditions, making it a potential candidate for cultivation in the Abu Dhabi Emirate.

Figure A4.5. Field production of purslane

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Temperature tolerance

Purslane exhibits remarkable adaptability to a wide range of temperatures, making it suitable for the climate of the Abu Dhabi Emirate. The optimal temperature range for purslane is between 10 and 40 °C (Hopen, 1972). This adaptability to high temperatures is particularly advantageous for the emirate, where summer temperatures can soar. The ability of purslane to thrive at such temperatures without a significant loss in yield ensures stable production.

Rainfall requirements

Purslane has moderate water requirements, with an optimal annual rainfall of 300 to 1 500 mm (Foran, Low and Strong, 1985). Although the Abu Dhabi Emirate's average annual rainfall is about 37.5 mm, purslane can be cultivated with supplemental irrigation. The efficient use of water and the ability to thrive under rainfed conditions in regions with lower rainfall make it a viable option. The moderate water requirements and drought tolerance of purslane make it suitable for the emirate, where water conservation is a priority. This crop can thrive under efficient irrigation practices that ensure sustainable water use.

Soil salinity tolerance

Purslane exhibits a high tolerance to soil salinity, thriving in soils with salinity levels between 5 and 10 dS/m (Bekmirzaev *et al*., 2023). This tolerance allows purslane to grow in areas with higher soil salinity, where other crops might fail. The ability to tolerate saline conditions not only expands the potential cultivation areas within the Abu Dhabi Emirate, but also contributes to soil reclamation efforts.

pH range adaptability

Purslane is adaptable to a pH range of 5 to 7.5 (Alyazouri *et al*., 2020). This adaptability ensures that purslane can be cultivated in various regions across the Abu Dhabi Emirate, regardless of soil pH. The wide pH range tolerance of purslane allows farmers to utilize land that might otherwise remain underutilized because of unsuitable pH levels for other crops. This flexibility supports widespread adoption of purslane in the emirate.

Soil texture preferences

Purslane prefers well-drained soils that align with the sandy soils found in the Abu Dhabi Emirate (Younis *et al*., 2023). Its ability to grow in sandy, loamy and clayey soils without requiring significant soil amendments is a critical advantage. This characteristic means that purslane can be cultivated with minimal soil preparation, reducing the costs and labour associated with soil management.

Chilling hour requirements

The Abu Dhabi Emirate has less than 200 chilling hours annually, which can be a limiting factor for many crops. Purslane does not require chilling hours for its growth cycle, making it perfectly suited to the emirate's warm climate (Corrêa *et al*., 2023).

Economic value

Purslane has significant economic value owing to its various applications. It is rich in omega 3 fatty acids, vitamins and minerals, making it a highly nutritious food source (Nafea, 2017). Additionally, purslane has medicinal properties, including antidiabetic and anti-inflammatory effects (Bai *et al*., 2016).

The economic potential of purslane extends beyond its nutritional value. It is used in traditional medicine as a hypoglycemic agent and has pharmaceutical applications in pharmaceuticals (Kinichenko *et al*., 2018).

Safflower

Safflower is an annual herbaceous plant in the Asteraceae family and has been historically cultivated for its oil, animal feed and natural dyes (Figure A4.6). Originating from the Near East, likely in present-day regions of Egypt and the Islamic Republic of Iran, safflower has spread worldwide owing to its versatility and adaptability. It has a deep taproot system that allows it to access water from the deeper soil layers.

Figure A4.6. Field production of safflower

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Temperature tolerance

Safflower exhibits a wide range of temperature tolerance, making it suitable for the Abu Dhabi Emirate's climate. The optimal temperature range for safflower growth is 15 to 25 °C (Bonfim-Silva *et al*., 2015). However, safflower can tolerate temperatures of up to 40 °C, which aligns with the summer temperatures of the emirate.

Its ability to withstand high temperatures without significant yield loss ensures that safflower can be successfully cultivated in the Abu Dhabi Emirate throughout the year.

Rainfall requirements

Safflower requires moderate water with an optimal annual rainfall range of 300 to 600 mm (Bonfim-Silva *et al*., 2015). While the Abu Dhabi Emirate's average annual rainfall is significantly lower, the high drought tolerance of safflower makes it a viable option with supplemental irrigation.

Efficient irrigation practices can support safflower cultivation in the Abu Dhabi Emirate, thereby ensuring water conservation and sustainable agricultural practices. The moderate water requirements and high drought tolerance of the crop make it suitable for the emirate's arid environment.

Soil salinity tolerance

Safflower exhibits moderate tolerance to soil salinity and thrives in soils with salinity levels of up to 4 dS/m (Bonfim-Silva *et al*., 2015). This tolerance allows safflower to grow in areas with higher soil salinity. The ability to tolerate moderate salinity expands potential cultivation areas within the Abu Dhabi Emirate and contributes to soil reclamation efforts. By reducing soil salinity over time, safflower can improve the overall soil health, making it more suitable for subsequent crops.

pH range adaptability

Soil pH varies widely across the Abu Dhabi Emirate, necessitating crops to adapt to different pH levels. Safflower is adaptable to a pH range of 6.5 to 7.6 (Bonfim-Silva *et al*., 2015). This adaptability ensures that safflower can be cultivated in various regions across the emirate, regardless of the soil pH.

Soil texture preferences

Safflower prefers well-drained sandy loam soils, which aligns with the sandy soils found in the Abu Dhabi Emirate (Bonfim-Silva *et al*., 2015). Its ability to grow in sandy, loamy and clayey soils without requiring significant soil amendments is a critical advantage.

The preference for well-drained soils helps to prevent waterlogging, which can be detrimental to many crops. This characteristic ensures that safflower can be cultivated with minimal soil preparation, reducing the costs and labour associated with soil management.

Safflower does not require high levels of N fertilizer (which may be deleterious to livestock and oil quality). However, safflower is suitable for rotation with crops that require fertilizer. When sown after crop harvest, safflower benefits from N applied to the soil for the previous crop. Because of its taproot, safflower uses NO_3 leachates left in the groundwater and is thus considered environmentally friendly (Yau and Ryan, 2010).

Chilling hour requirements

Safflower does not require chilling hours for its growth cycle, making it perfectly suited to the Abu Dhabi Emirate's warm climate (Zimmerman, 1972). The lack of chilling hour requirements means that safflower can grow continuously throughout the year without seasonal interruption.

Economic value

Safflower has significant economic value because of its various applications. It is primarily cultivated for its oil, which is used in cooking, cosmetics and pharmaceuticals. Additionally, safflower is used as animal feed and a natural dye (Kammili *et al*., 2022). Both native and introduced bees, which are important pollinators, seek safflower pollen and nectar (Dajue and Mündel*,* 1996).

Jojoba

Jojoba is a perennial shrub belonging to the Simmondsiaceae family, native to the Sonoran Desert in the southwest of the United States of America and northwestern Mexico (Figure A4.7). Known as the "gold of the desert", jojoba is highly valued for its oil, which is used in cosmetics, pharmaceuticals and biofuel. Jojoba is extremely drought-tolerant and can survive long periods without water. Its deep root system helps to access water from deep underground areas.

Figure A4.7. Field production of jojoba

© Kenneth Bosma/Feedipedia

Temperature tolerance

Jojoba is well suited to the Abu Dhabi Emirate's hot climate, with an optimal temperature range of 15 to 40 °C (Al-Dossary *et al*., 2020). It can tolerate temperatures as high as 45 °C and as low as −5 °C, making it highly adaptable to extreme temperatures in the emirate.

Rainfall requirements

Jojoba is a drought-tolerant plant that requires minimal amounts of water. It thrives with annual rainfall of 100 to 400 mm (Al-Dossary *et al*., 2020). Given that the Abu Dhabi Emirate's average annual rainfall is approximately 37.5 mm, jojoba can be cultivated with minimal supplemental irrigation.

The low water requirements and high drought tolerance of plants are advantageous for the emirate, where water conservation is crucial. Efficient irrigation practices can support jojoba cultivation and ensure sustainable agriculture.

Soil salinity tolerance

Jojoba exhibits moderate tolerance to soil salinity, thriving in soils with salinity levels up to 2.5 dS/m (Mohasseb *et al*., 2020). The ability to tolerate moderate salinity expands the potential cultivation areas within the Abu Dhabi Emirate.

pH range adaptability

Soil pH varies widely across the Abu Dhabi Emirate, necessitating crops to adapt to different pH levels. Jojoba is adaptable to a pH range of 6.5 to 8.5 (Al-Dossary *et al*., 2020). This adaptability ensures that jojoba can be cultivated in various regions across the emirate, regardless of the soil pH.

Soil texture preferences

Jojoba prefers well-drained sandy soils, which aligns with the sandy soils found in the Abu Dhabi Emirate (Al-Dossary *et al*., 2020). The ability to grow in sandy soils without significant soil amendments is a critical advantage.

Jojoba plants have been used for afforestation in the arid areas of Mexico and Israel (Orwa *et al*., 2009a) and are also valuable due to their ability to regrow after a fire (Matthews, 1994).

Chilling hour requirements

The Abu Dhabi Emirate has less than 200 chilling hours annually, which can be a limiting factor for many crops. Jojoba does not require chilling hours for its growth cycle, making it perfectly suited to the emirate's warm climate (Milthorpe and Dunstone, 1989).

Economic value

Jojoba has significant economic value because of its various applications. It is primarily cultivated for its oil, which is used in cosmetics, pharmaceuticals and biofuels (Bala, 2022). The oil extracted from jojoba seeds is unique, resembling whale oil, and is highly sought after in various industries.

Jojoba produces palatable forage for livestock. Oil meal resulting from oil extraction can be used as fodder, but it contains antinutritional factors and first needs to be detoxified. Because of the limited expansion of the jojoba oil market, jojoba foliage and jojoba oil meal are currently not very important resources for livestock feeding.

Jojoba plants generally start fruiting around four years of age, achieve maximum yield by their tenth year, and may continue to bear fruit for a century or two. Notably, in Israel, some jojoba plantations have been documented to produce fruit as early as three years old (Feedipedia, 2025). Seed yield ranges from 2.5 to 4.5 t/ha. (Modise, 2007; Goodin and Northington, eds, 1979). The economic potential of jojoba extends beyond its oil. The versatility of the plant allows for multiple revenue streams, including animal-feed production and biofuel extraction.

Guayule

Guayule is a perennial shrub native to the arid regions of the Chihuahuan Desert in northern Mexico and the southwest of the United States (Figure A4.8). Guayule, known primarily for latex production, has been recognized as a potential alternative source of natural rubber. The shrub is highly drought-tolerant and well suited to arid and semi-arid environments.

Figure A4.8. Guayule shrub in the field, Maricopa, Arizona

© Edwin Remsberg/Alarmy Stock Photo

Temperature tolerance

Guayule thrives in a wide temperature range, from 5 to 40 °C, and can tolerate extreme down to −5 °C (Nakayama and Bucks, 1984; Sanchez *et al*., 2014). This temperature resilience makes it an excellent candidate for the harsh climate of the Abu Dhabi Emirate, where summer temperatures frequently exceed 40 °C.

Rainfall requirements

Guayule is highly drought-tolerant and requires annual rainfall between 200 and 600 mm (Ray *et al*., 2010). The Abu Dhabi Emirate's arid environment, characterized by low and irregular rainfall, can be supplemented with controlled irrigation to meet the plant's water needs. Drought tolerance is crucial for sustainable agriculture in water-scarce regions.

Soil salinity tolerance

Guayule can grow in soils with moderate salinity, tolerating salinity levels between 4 and 6 dS/m (Di Baccio *et al*., 2024). This adaptability allows guayule to be cultivated in areas where soil salinity poses a challenge to other crops. The ability to manage and mitigate soil salinity through appropriate agricultural practices would be beneficial for optimizing guayule production in the Abu Dhabi Emirate.

pH range adaptability

Guayule thrives in soils with a pH range of 6 to 8 (Hashemi and Estilai, 1992). This broad pH tolerance ensures that the guayule can be cultivated in various soil types across the Abu Dhabi Emirate, where the soil pH can vary significantly.

Soil texture preferences

Guayule prefers sandy and loamy soils, which are well-drained (Elshikha *et al*., 2023). These soil types are common in the Abu Dhabi Emirate and provide an ideal growing medium for guayule. Proper soil management, including ensuring adequate drainage and preventing waterlogging, will enhance the growth and productivity of guayule.

Chilling hour requirements

Guayule does not require chilling to initiate growth or flowering, making it suitable for regions with mild winters (Naqvi and Hanson, 1980). This characteristic aligns well with the Abu Dhabi Emirate's climate, where winter temperatures rarely fall below freezing and chilling hours are minimal.

Economic value

Guayule is primarily grown for its latex, which is a valuable alternative to natural rubber. The global demand for natural rubber, especially hypoallergenic latex, makes guayule economically viable. Latex extracted from guayule is free from proteins that cause latex allergies, providing a significant market advantage.

In addition to latex, guayule produces resins and biomass for industrial applications. Resins from guayule are used in the manufacture of adhesives, coatings and biopesticides (Dehghanizadeh *et al*., 2020). Biomass can be used for bioenergy production in addition to the economic potential of the crop.

Guayule's deep root system helps prevent soil erosion and improve soil structure. Its cultivation can contribute to soil conservation efforts in the Abu Dhabi Emirate and can enhance sustainable agricultural practices. Additionally, the ability of guayule to grow in marginal soils reduces the pressure on arable land and promotes land-use efficiency.

Sweet sorghum

Sweet sorghum (*Sorghum bicolor*) is an annual grass native to northeastern Africa, especially Ethiopia and the Sudan (Figure A4.9). Known for its versatility, it is utilized for biofuel, forage and food production.

Figure A4.9. Field production of sweet sorghum

© FAO/Mahmoud Shamrouk

Temperature tolerance

Sweet sorghum thrives over a wide temperature range, from 18 to 35 °C, with an optimal range between these temperatures (BassiriRad and Radin, 1992). This temperature resilience makes it an excellent candidate for the harsh climate of the Abu Dhabi Emirate, where summer temperatures frequently exceed 40 °C.

Rainfall requirements

Sweet sorghum requires an annual rainfall between 400 and 1 000 mm (Wortmann *et al*., 2010). Although the Abu Dhabi Emirate's arid environment receives much less rainfall, controlled irrigation can supplement water needs. Drought tolerance of this crop is crucial for sustainable agriculture in water-scarce regions.

Soil salinity tolerance

Sweet sorghum can grow in soils with high salinity and tolerating levels between 4 and 9 dS/m (Odilova, 2021). This adaptability allows it to be cultivated in areas where soil salinity poses a challenge to other crops. Appropriate agricultural practices are beneficial for optimizing sweet sorghum production in the Abu Dhabi Emirate.

pH range adaptability

Sweet sorghum thrives in soils with a pH range between 5.5 and 7.5 (Leible and Kahnt, 1991). This broad pH tolerance ensures that sweet sorghum can be cultivated in various soil types across the Abu Dhabi Emirate, where the soil pH can vary significantly.

Soil texture preferences

Sweet sorghum prefers well-drained soils with sandy and loamy textures (Malobane *et al*., 2018). These soil types are common in the Abu Dhabi Emirate and provide ideal growth media. Appropriate soil management, including ensuring adequate drainage and preventing waterlogging, will enhance its growth and productivity.

Chilling hour requirements

Sweet sorghum does not require chilling to initiate growth or flowering, making it suitable for regions with mild winters (Havaux, 1989). This characteristic aligns well with the Abu Dhabi Emirate's climate, where winter temperatures rarely fall below freezing and chilling hours are minimal.

Economic value

Sweet sorghum is primarily grown because of its high biomass and sugar content, which are ideal for biofuel production (Lauriault, Marsalis and VanLeeuwen, 2011). The global demand for sustainable biofuels has made it an economically viable crop. Juice extracted from stalks can be fermented to produce ethanol, providing a significant market advantage.

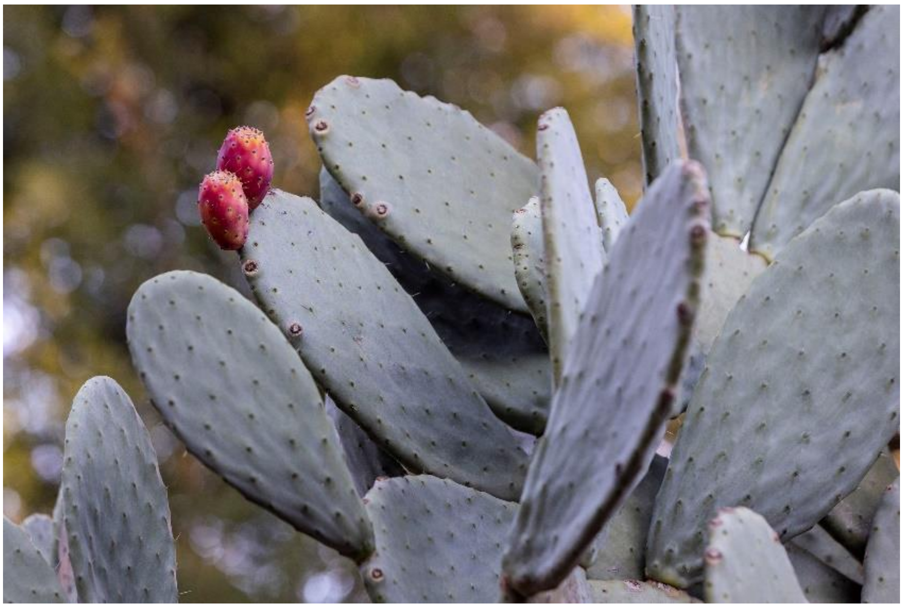
Sweet sorghum is also used as forage and provides high-quality feed for livestock (Godoy and Tesso, 2013). Its rapid growth and high biomass yield make it an excellent forage crop, especially in arid regions, where other forage crops may struggle.

The ability of sweet sorghum to grow in marginal soils and tolerate high salinity contributes to soil conservation efforts in the Abu Dhabi Emirate. Its cultivation can enhance sustainable agricultural practices by improving the soil structure and preventing erosion.

Prickly pear

Prickly pear is a perennial cactus native to Mexico (Figure A4.10). It is known for its adaptability to arid environments, high economic value and various uses, including food, medicine and fodder.

Figure A4.10. Prickly pear



© FAO/Riccardo De Luca

Temperature tolerance

Prickly pear is well suited to high temperature environments, with an optimal growth range of 10 to 45 °C (Shukla, Hailu and Kehsay, 2019). This wide temperature tolerance makes it ideal for the Abu Dhabi Emirate's climate, in which summer temperatures frequently exceed 40 °C.

Rainfall requirements

Prickly pear requires minimal rainfall, thriving in areas with annual precipitation between 150 and 600 mm (Orwa *et al*., 2009b). The Abu Dhabi Emirate's arid environment, with limited and irregular rainfall, is well-suited for prickly pear cultivation, supplemented by controlled irrigation when necessary.

Soil salinity tolerance

Prickly pear demonstrates a high tolerance to soil salinity, with optimal growth in soils with salinity levels between 5 and 9 dS/m (Dagar *et al*., 2006). This adaptability is advantageous for the Abu Dhabi Emirate, where soil salinity can be a significant issue, making it a suitable crop for such challenging conditions.

pH range adaptability

Prickly pear thrives in soils with a pH range of 5 to 7.5 (Orwa *et al*., 2009b). This broad pH tolerance ensures that it can be cultivated in various soil types across the Abu Dhabi Emirate, where soil pH can vary significantly.

Soil texture preferences

Prickly pear prefers well-drained sandy and loamy soils (Orwa *et al*., 2009a). These soil types are common in the Abu Dhabi Emirate and provide ideal growth media. Proper soil management, including ensuring adequate drainage and preventing waterlogging, will enhance its growth and productivity.

Chilling hour requirements

Prickly pear does not require chilling hours to initiate growth or flowering, making it suitable for regions with mild winters (Prisa, 2021). This characteristic aligns well with the Abu Dhabi Emirate's climate, where winter temperatures rarely fall below freezing and chilling hours are minimal.

Economic value

Prickly pear is widely consumed as a fruit, and its pads (cladodes) are used in various culinary dishes (Giraldo-Silva *et al*., 2023). The fruit is rich in vitamins, minerals and antioxidants, making it a valuable supplement to the diet and an attractive product for local and international markets.

It has numerous medicinal applications, including anti-inflammatory, antioxidant and anti-diabetic properties (Giraldo-Silva *et al*., 2023). Its use in traditional medicine and potential in modern pharmaceuticals have significant economic value.

Prickly pear is an excellent source of fodder for livestock, especially in arid regions where other forage crops may struggle (Orwa *et al*., 2009b). Its high water content and nutritional value make it a valuable feed resource during the dry season, thereby supporting sustainable livestock farming.

Its ability to grow in marginal soils and tolerate high salinity contributes to soil conservation efforts in the Abu Dhabi Emirate. Its cultivation can enhance sustainable agricultural practices by improving the soil structure, preventing erosion, and acting as a carbon sink.

Coconut

The coconut is a versatile perennial tree crop known for its economic and nutritional value (Figure A4.11). Originating in the Indo-Malayan region, the coconut palm has spread pan-tropically because of its adaptability and wide range of uses. It flourishes best close to the sea on low-lying areas a few feet above high water where there is circulating groundwater and ample irrigation. It can tolerate drought conditions, especially when grown in areas with access to groundwater or supplementary irrigation.

Figure A4.11. Coconut palm

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Temperature tolerance

The coconut palm thrives in warm climates, with an optimal temperature range of 21 to 32 °C (Zhong *et al*., 2017). The climate of the Abu Dhabi Emirate, characterized by high temperatures, aligns well with the tree's temperature tolerance. Additionally, it can survive at temperatures as low as 4 °C (Irawan, Antriyandarti and Laia, 2023), ensuring resilience during cooler months.

Rainfall requirements

The coconut palm requires substantial rainfall, with an annual optimal range of 1 000 to 2 500 mm annually (Nainanayake, Ranasinghe and Tennakoon, 2008). In the arid environment of the Abu Dhabi Emirate, this requirement can be met through efficient irrigation practices, including drip irrigation systems, which have proven to be effective in maintaining soil moisture and promoting healthy growth.

Soil salinity tolerance

The coconut palm has a moderate tolerance to soil salinity, with optimal growth in soils with salinity levels between 0 and 8 dS/m (Bañón *et al*., 2020). Given the Abu Dhabi Emirate's issues with soil salinity, the moderate tolerance of the coconut palm makes it a viable option, provided that soil management practices are implemented to maintain the salinity within acceptable limits.

pH range adaptability

The coconut palm can grow in soils with a pH between 5 and 8 (Irawan, Antriyandarti and Laia, 2022). This broad pH tolerance ensures that it can be cultivated in various soil types across the Abu Dhabi

Emirate, where the soil pH can vary significantly. Proper soil management, including the use of soil amendments, can enhance coconut palm growth under less than ideal soil conditions.

Soil texture preferences

The coconut palm prefers well-drained sandy and loamy soils (Epunam and Emebese, 2023). These soil types are common in the Abu Dhabi Emirate and provide ideal growth media. Ensuring adequate drainage and preventing waterlogging further enhances the tree's growth and productivity.

Chilling hour requirements

The coconut palm does not require chilling to initiate growth or flowering, making it suitable for regions with mild winters (Parthasarathy, Karun and Rajesh, 2007). This characteristic aligns well with the Abu Dhabi Emirate's climate, where winter temperatures rarely fall below freezing and chilling hours are minimal.

Economic value

Coconuts are widely consumed for their water, milk and flesh, which are used in a variety of culinary dishes and beverages (Xia, 2021). The nutritional benefits of coconut products, including high levels of essential vitamins and minerals, make them highly valued in both local and international markets.

Coconut oil is a versatile product used in cooking, cosmetics and industrial applications (Xia, 2021). Its health benefits, including antimicrobial properties and medium-chain fatty acids, enhance its market demand. The Abu Dhabi Emirate can leverage coconut oil production to reduce import dependency and boost local production.

Coconut husks are processed into coir, which is used in making ropes, mats and brushes (Muchtar *et al*., 2022). The production of coir products provides an additional revenue stream and supports the development of sustainable industries in the Abu Dhabi Emirate.

The coconut palm is often used in landscaping and as an ornamental plant, adding aesthetic value to urban and rural areas (Muchtar *et al*., 2022). its presence in public spaces and resorts enhances the appeal of these areas and contributes to the tourism industry.

It contributes to soil conservation efforts by preventing erosion and improving the soil structure, while its deep root systems enhance soil stability, making it suitable in regions prone to soil degradation. Additionally, the coconut palm acts as a carbon sink, contributing to C sequestration and climate change mitigation.

A4.2.2. Uncultivated crop suitability summary

This analysis evaluates the eleven selected crops: jatropha, castor bean, camelina, teff, purslane, safflower, jojoba, guayule, sweet sorghum, prickly pear, and coconut, based on their adaptability to the Abu Dhabi Emirate's arid environment, focusing on heat tolerance, water use efficiency, salinity tolerance, soil and pH adaptability, and economic value.

Best adaptability for the Abu Dhabi Emirate: Purslane, prickly pear, jatropha, and jojoba are the most suitable crops for the Abu Dhabi Emirate due to their high-temperature tolerance, low water requirements and good salinity tolerance.

Moderate adaptability: Guayule, sweet sorghum, safflower, and castor bean show good temperature tolerance and adaptability to moderate water and salinity conditions, making them moderately suitable for Abu Dhabi Emirate.

Lower adaptability: Teff and coconut are less ideal for the Abu Dhabi Emirate due to higher water requirements and lower salinity tolerance, which limits their potential in the arid and saline environments of the region.

Crop yield modelling supporting the Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate

The United Arab Emirates faces significant agronomic challenges due to its hyper-arid climate, poor soil fertility and limited water resources, requiring data-driven approaches for sustainable agriculture. The Abu Dhabi Agriculture and Food Safety Authority (ADAFSA) in collaboration with the Food and Agriculture Organization of the United Nations (FAO), the International Center for Agricultural Research in the Dry Areas (ICARDA), and the International Institute for Applied Systems Analysis (IIASA), have therefore conducted a comprehensive study under the Master Plan for Sustainable Agriculture in the Abu Dhabi Emirate. Using advanced crop-modelling tools, this study integrates crop yield simulations and suitability mapping to optimize resource allocation and land-use planning.

Covering 181 sites across the Abu Dhabi Emirate, the study assesses the potential and attainable yields of 51 crops – including annuals, fruit trees, and perennial grasses and shrubs – along with a crop sensitivity analysis of key growth-limiting factors across open field, greenhouse and shade house production systems.

The findings have been incorporated into a national crop suitability mapping database, supporting evidence-based decision-making and contributing to the development of a decision support tool (DST) to enhance sustainable agricultural practices in the Abu Dhabi Emirate.

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