Pathways for the sustainable intensification of wheat production under current and future climate change scenarios in the Mediterranean region

MSc internship report by Davide Tita

February 12, 2024

Soil Physics and

Land Management Group

Pathways for the sustainable intensification of wheat production under current and future climate change scenarios in the Mediterranean region

Master internship report Soil Physics and Land Management Group submitted in partial fulfillment of the degree of Master of Science in Resilient Farming and Food Systems at Wageningen University, the Netherlands

Study program:
MSc Resilient Farming and Food Systems

Student registration number:
1155686

SLM70224

Supervisors:
WU Supervisor: Dr. Karrar Mahdi
Host supervisor: Krishna Devkota, Mina Devkota

Examinator:
Prof. Luuk Fleskens

Date:
12/02/24

Soil Physics and Land Management Group, Wageningen University

Contents

Abstract

This scientific inquiry delves into the far-reaching implications of global warming and the continuous emission of anthropogenic greenhouse gases into the Earth's atmosphere. With a primary focus on the semi-arid regions of Morocco, the study broadens its perspective to conduct a comparative analysis of similar challenges faced by Spain, Egypt, Italy, Jordan, Turkey, and Iran. The paper aims to illuminate the intricate interplay between climate change and agriculture, underscoring the imperative for sustainable practices to alleviate the detrimental impacts on food security and economic stability. The methodology employed centers around the utilization of the DSSAT (Decision Support System for Agrotechnology Transfer) model, a reliable tool for simulating yield across different seasons. This study evaluated the performance of wheat varieties in MENA (Middle East and North Africa) regions and some in the Mediterranean area. Optimal yields were observed under treatments involving sprinkler or furrow irrigation of 60-140 mm and nitrogen application ranging from 60 to 120 kg/ha, resulting in an average yield trend of around 6 t/ha. The identified optimal seeding date was the 1st of November, with conservation or adaptation practices demonstrating superior outcomes. This finding was further validated by climate change projections, estimating yields of up to 6.4 t/ha in Spain and a slight increase in Morocco and in one of the sites in Jordan, alas a reduction of 20% in Italy and up to 88% in Iran at the end of the century. The study's significance lies in its evaluation of nutrient and water trends in the MENA and Mediterranean regions. It offers farmers and policymakers valuable insights to guide a sustainable transition, both economically and ecologically.

Keywords: *Sustainable intensification, CERES Wheat, Climate Change, Mediterranean Agriculture, Adaptation Strategies*

1. Introduction

The undeniable reality of global warming, as emphasized by the Intergovernmental Panel on Climate Change (IPCC) in its 2023 report, brings forth a cascade of consequences for environmental systems worldwide (IPCC, 2023). In Morocco, a nation heavily dependent on agriculture, the historical burden of extreme weather events, such as severe droughts and floods, has led to suboptimal agricultural yields (Brouziyne et al., 2018; Bouignane, 2010). This vulnerability prompted some government in the MENA region, like the Moroccan government to introduce the Green Morocco Plan from 2008 to 2020, or the European Green Deal, in the case of the Mediterranean context, with the core objective of enhancing the sustainability of farmer incomes amidst multifaceted agricultural challenges (Sikora, 2021; MAPM, 2013; Moragues et al., 2006).

The impending climate projections for the Mediterranean context paint a grim picture, indicating a projected 1.3 °C increase in the annual mean temperature and an 11% decline in average yearly rainfall by 2050 (Balaghi and Dahan, 2015). Historical severe droughts in 1994/1995 and 1998/1999 resulted in a staggering 60% reduction in cereal production, underscoring the profound impact on agricultural GDP in MENA region, but also on rural areas in Mediterranean countries i.e. Spain and Italy (Bouignane, 2010; Lorite et al., 2023).

The agricultural landscape is dominated by rainfed smallholder farms, mainly cultivating cereals, legumes, and livestock. Barley, a resilient cereal crop well-suited for arid and semi-arid environments, holds particular significance (Cammarano et al., 2019, Amiri et al., 2021). The practices of these small-scale farmers are intricately tied to annual rainfall patterns, with deficits directly impacting the nation's economy (Saidi & Diouri, 2017(Gharous & Boulal, 2016)). Market-oriented agriculture, representing approximately 15% of agricultural land, relies on irrigation. Thus, the agricultural production per unit area in MENA countries is about 2.3 t ha^{-1} which is far below the world average of 4.0 t ha^{-1} (FAOSTAT, 2020; Pala et al.,2011).

Spatial variability in annual rainfall patterns categorizes regions into distinct precipitation levels, posing unique challenges (Barbour et al., 2024). An example, Morocco's water resources face a significant challenge, with per capita water availability among the lowest in arid regions, even less than that of Egypt, at just 730 m^3 per person per year. Approximately 1.5 million hectares of land are designated for irrigation, primarily relying on gravity systems (47%) compared to sprinkler (9%) or localized (10%) systems (MAOM, 2009).

Similar challenges are observed globally in semi-arid regions. Spain contends with water scarcity, soil erosion, and rising temperatures, impacting agricultural productivity (Lorite et al., 2023). In Egypt, reliance on the Nile for irrigation, almost the 98%, presents challenges amidst increasing demands and soil fertility depletion (Fouad et al., 2023). Italy faces altered precipitation patterns, affecting crop growth and pest dynamics, alongside socio-economic challenges in rural areas (Dettori et al., 2017). Jordan grapples with severe water scarcity, necessitating a delicate balance between water conservation and food production (Al-Bakri et al., 2011). Turkey experiences vulnerabilities to drought, soil erosion, and deforestation, requiring resilient agricultural practices(Yeşilköy & Şaylan, 2021). Iran confronts water scarcity, salinity in soils, and rising temperatures, demanding sustainable water management and adaptive agricultural strategies(Deihimfard et al., 2018; Eyshi Rezaie & Bannayan, 2012). Traditional water management practices in the MENA region, such as Khettaras in Morocco, qanat in Iran (foggara in North Africa), and acequia in Spain, pose maintenance challenges but could be included as sustainable practices (Lightfoot, 1996).

Therefore, the region is considered as the most water-stressed in the world, where two-thirds of countries continue to use groundwater at rates exceeding the renewable internal freshwater resources. The region has the lowest water prices in the world, and spending about 2% of GDP on water subsidies, and has considerable low water productivity, i.e., only half the world average (WB, 2018, (Abu-hashim et al., 2021; Gatti et al., 2023).

This comprehensive study aims to unravel the intricate dynamics of climate change and its impact on agriculture across semi-arid regions, providing insights into the challenges faced and fostering a foundation for sustainable solutions. Hence, the principal aim of this study are i) Identify and analyse the key factors influencing the cultivation of staple crops like wheat in the semi-arid conditions of the Mediterranean; ii) Examine how water productivity and nitrogen availability content evolve over time in the context of wheat cultivation in arid conditions, iii) Investigate the potential impacts of climate change on the shift towards more sustainable agro-ecological systems, considering the broader picture of the MENA and Mediterranean basin.

The existing literature employs various models, including Agriculture Production Simulator (APSIM), Soil and Water Assessment Tool (SWAT), Decision and Support System Agriculture Tool (DSSAT), and ACQUACROP, a crop growth model developed by FAO (Badora et al., 2022; Halima et al., 2021). The focus is particularly on water productivity and the agricultural system's capacity to manage and replenish water resources in semi-arid and arid regions. Given the study areas, future climate scenarios may present significant challenges regarding water availability (Nisa et al., 2022). Therefore, the primary focus should centre around efficient water utilization and proactive measures to mitigate potential cascading effects resulting from water shortages (Devkota et al., 2021).

The DSSAT model has been applied in the Mediterranean and WANA contexts to assess wheat management options and anticipate crop yield expectations in the studied locations. The model was utilized to explore diverse management strategies across various study locations, with pivotal factors such as sowing date, cultivar selection, irrigation, and nitrogen fertilizer rate considered. The DSSAT model, serves as a comprehensive tool for simulating crop growth, development, and yield within a single land unit. It responds to various factors, including weather conditions, management practices, and changes in soil water, carbon, and nitrogen over time within cropping systems (Jones et al., 2003). As of the latest version, 4.8.2, the DSSAT model accommodates simulations for over 42 crops. Each crop module necessitates specific inputs such as daily weather data, initial soil conditions, detailed soil profile characteristics, comprehensive crop management details, and cultivar coefficients.

In their assessment of the model's predictive capabilities for the growth and yields of wheat genotypes, Waffa and Benoit (2015) found it to be effective. The model demonstrated proficiency in simulating potential wheat yield production, particularly in relation to irrigation scheduling and nitrogen fertilization, as highlighted by Gameh et al., (2020). Consequently, this study considered different climate change horizons and utilized varied weather data to evaluate changes in yield across the studied locations.

Staple crops such as wheat and barley could be substantially impacted by climate change scenarios. The literature includes numerous analyses conducted using DSSAT to assess yield characteristics in various locations across the Mediterranean basin and the MENA region (Malik & Dechmi, 2019; Cammarano et al., 2019; Kheir et al., 2021; Waffa & Benoit, 2015). Leveraging DSSAT, the study aims to evaluate the impact of different climate change scenarios on various genotypes of wheat and barley, as well as their resilience in prolonged adverse conditions (Devkota et al., 2022; Mamassi et al., 2023; Ishaque et al., 2023). Pala et al. (2011) highlighted a gap in the yield of wheat production in the MENA region due to constraints such as the progressive decrease of rainfall. The example of Egypt is crucial, given its reliance on the Nile delta watershed and extensive use of nitrogen fertilizers, with increasing challenges in nutrient use efficiency (NUE) (Elrys et al., 2019,).

As Mrabet has suggested, future studies in this region should prioritize research on plant nutrition, fertilization recommendations, residue management, and irrigation practices to enhance water efficiency under conservation agriculture practices (Kheir et al., 2019; Mrabet et al., 2012; Govind et al., 2021). This research adopts a holistic perspective, considering not only crop-related indices but also their broader implications for the country's watershed. Mediterranean and MENA region countries already grapple with water scarcity issues and challenges in efficient water utilization, exacerbated by erosion reducing crop yields over time.

2. Methodology

2.1 Experimental data collection

All experimental data required for the calibration and validation of DSSAT model were gathered from a comprehensive literature review of the papers on wheat input (water, fertilizer, planting date, variety and their interaction) for closing yield gap in MENA and Mediterranean regions. The review collected data were selected on a baseline of twenty a paper among the others, by searching keywords such as climate change, impact on wheat yield and crop modelling in MENA or Mediterranean region. Those data extracted were based on yield and yield components, such as top weight, leaf area index (LAI), days to emergence, days to flowering, and days to maturity. Also, other information as required in DSSAT model such as amount of initial residue retained, no. of irrigation, amount of water applied, type, and time of fertilizer application, soil type and soil nutrient conditions, as required for model calibration and evaluation (Jones et al., 2003; University of Florida, USA et al., 2019; White et al., 2011; Table 3) were reviewed and collected. The major data collected had the comparison of rainfed and irrigated systems with zero or different fertilization rate compared. The soil data were provided some from the literature (Dettori et al., 2017; Devkota et al., 2022; Dokoohaki et al., 2015; Kheir et al., 2021; Malik & Dechmi, 2019; Yeşilköy & Şaylan, 2021) and were also cross referenced with the ISRIC world soil database (https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/a2379a76-4919-44c1-863e-90504b76ee10). Soil data collected from the reviews or from encompass properties like soil water content, wilting point, field capacity, saturation percentage, drainage and runoff factors, root growth factor, evaporation, and soil albedo.

2.2 Conceptual framework

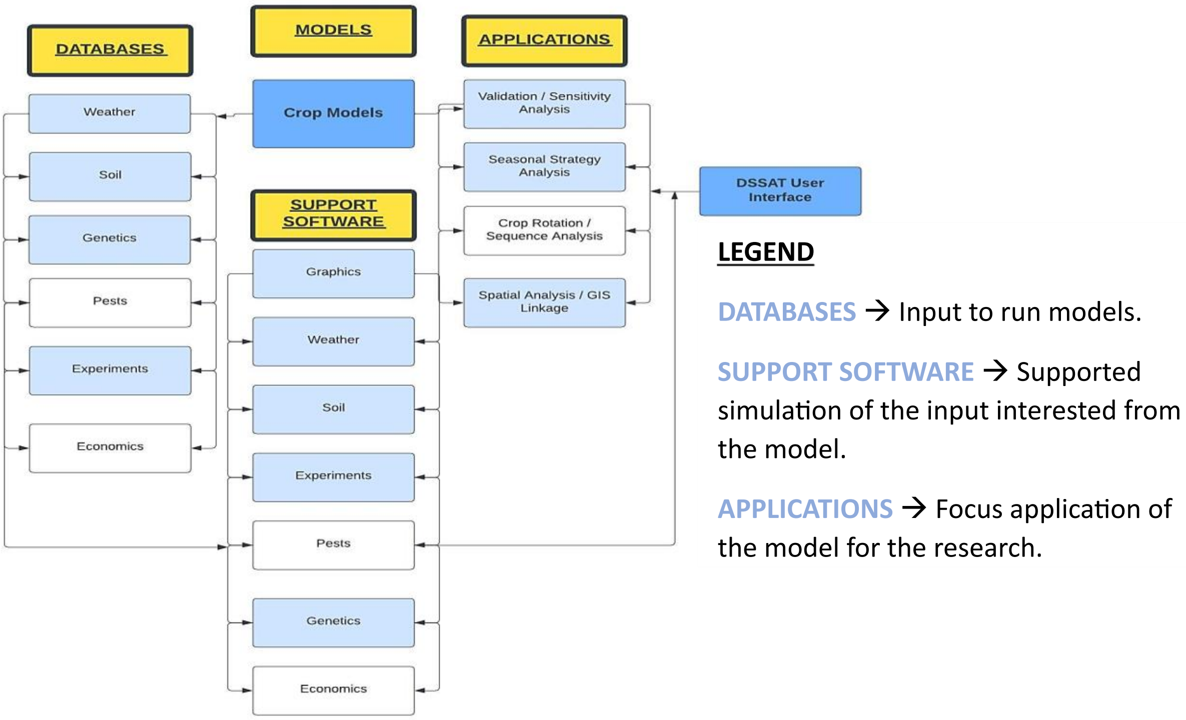


Figure 1 - Diagram of database, application, and support software components and their use with crop models for applications in DSSAT v3.5 (Jones et al., 2003).

The Decision Support System for Agrotechnology Transfer (DSSAT) version 4.8, CERES-wheat model (Hoogenboom et al., 2019a, 2019b), It seamlessly integrates databases for soil, weather, and crops to simulate multi-year outcomes of diverse crop management scenarios (Fig. 1). One notable aspect is the interactive consideration of the effects of crop choices, soil conditions, weather variations, and management strategies. This allows users to pose hypothetical questions through virtual simulation experiments on a desktop computer, saving considerable time compared to the extensive efforts required in field experiments.

2.2.1. Model inputs

The primary inputs for running the models such as soil properties, daily weather data, cultivar name and characteristics, and crop management practices were collected from the reviewed literatures. Essential weather data include maximum and minimum temperatures, solar radiation, rainfall, and the geographical coordinates of the weather station (latitude and longitude). For calibration purposes, distinct genetic parameters in the genotype file, such as vernalization, photoperiod, thermal time, kernel number per unit, kernel growth rate, maximum stem dry weight, and phyllochron interval were utilized.

Crop management factors involve details regarding irrigation treatments (rates and dates), fertilization (doses, rates, and dates), planting information (date, depth, and density), and initial soil water and nitrogen levels, either measured or estimated.

There were to be evaluated different type of irrigation (i.e., furrow, sprinklers, etc.,) based on (reference). Every option is utilized with two irrigation treatments (i.e., furrow and sprinkler) and four applications through the years.

Long-term simulations for the locations representing the Marchouch, El Rehamna, Ankara, Edirne, Zagros, Ussana, North Sinai, Tanta, Irbid, El Mashuqqer, Violada District basin was performed using the calibrated model (CERES) and the two different irrigation treatments (i.e., furrow and sprinkler) based on the needs based on the historical precipitation data.

To better assess the efficiency of the treatments on the crop, we computed the coefficient of crop water productivity (Chai et al., 2014) and expressed as kg ha^{-1} mm^{-1} ET.

$$\text{Crop Water Productivity (CWP)} = \frac{GY}{10*\text{ET}} \quad \text{(I)}$$

Thereafter, based on the simulated grain yield (GY, kg ha^{-1}), and ET (kg ha^{-1} mm^{-1} ET) irrigation water use efficiency (kg ha $^{-1}$mm $^{-1}$Irri) (Chai et al., 2014; Kheir et al., 2021; Malik & Dechmi, 2019).

$$\text{WUE}_{\text{Irri}} = \frac{GY}{Total\ water\ applied} \quad \text{(II)}$$

The total water applied is the sum of simulated irrigation water applied under a specific treatment, and the total rainfall over the growing season.

Table 1 - List of genetic of coefficients of wheat cv. calibrated for CERES-Wheat (Jones et al., 2003).

Model	**Parameter**	**Parameter Definition**
CERES Wheat	**P1D**	Photoperiod sensitivity coefficient
	P1V	Vernalization sensitivity coefficient
	P5	Thermal time from onset of linear grain filling to maturity
	G1	Kernel number per unit stem plus spike weight at anthesis (kernel weight $^{-1}$)
	G2	Maximum kernel size under optimum conditions (mg)
	G3	Maximum stem and spike weight when elongation ceases (g)
	PHINT	Thermal time between the appearance of leaf tips (◦Cd)

2.2.2. Study location, soil and climatic characteristics

2.2.2.1 Morocco

In this comprehensive study, multiple fieldwork was conducted across diverse geographic locations to assess the impact of various factors on wheat production. The first set of experiments took place at the ICARDA experimental field in Marchouch, Morocco (33°36'41" N, 6°42'45" W, 390 m above sea level). This location, approximately 75 kilometres east of Rabat, experiences an average annual rainfall of 392 mm over the 47-year period from 1974 to 2020, with variations ranging from 181 mm to 665 mm and a coefficient of variation (CV) of 31%. The mean annual air temperature is 18°C, with monthly minimum and maximum temperature ranges of 10–12°C and 20–24°C, respectively. The soil at this site is classified as a Vertisol with a clay-loam texture, comprising 47.6% clay and 41% silt content, with medium soil organic carbon (1.25–1.65%) and a soil pH range of 7–7.9.

Table 2. Site, soil and climatic characteristics in the study sites

Country	Site	Lat. e Long.	Annual rainfall ± CV (mm)	Annual T(°C)	Avg. Tmax. (°C)	Avg. Tmin. (°C)	Soil class (FAO Taxonomy)	Sand (%)	Silt (%)	Clay (%)	SOC (%)	Soil pH
Morocco	Marchouch	33.61N-6.71W	141 ± 0.31	19 °C	26	12	Vertisol	11.4	41.00	47.60	1.13	7.6
	El-Rehamna	32. 3 N-7.97W	87 ± 0.37	21 °C	28	14	Eutric Regosol	59.8	18.5	21.75	0.77	8.5
Egypt	North Sinai	30.95N-29.66E	122 ± 0.96	21 °C	26	16	Calcaric Regosol	34.3	39.65	26.1	0.32	8
	Tanta	30.8N-31.1E	74 ± 0.9	23 °C	30	15	Vertisol	34.1	21.4	44.4	0.7	7.8
Turkey	Ankara-Ikizce	39.36N-32.40E	379 ± 0.36	11 °C	18	5	Cambisols	12.1	37.7	50.1	0.48	8.2
	Edirne	41.68N-26.55E	571 ± 0.29	14 °C	20	8	Cambisols	44.7	24.28	31	0.67	6.9
Jordan	Irbid	32.64N-35.57E	318 ± 0.35	21°C	29	13	Vertisol	8	45.98	53	0.37	8.1
	El-Mashuqqer	31.77N-35.80E	195 ± 0.37	22 °C	29	14	Chromic Luvisol	8.8	36.8	54	0.96	7.9
Iran	Zagros	32.20N-50.14E	299 ± 0.40	16 °C	22	10	Calcaric Regosol	15	30	55	0.96	8
Spain	Violada	42.04N-0.40E	441 ± 0.24	14 °C	20	8	Gypsic Haploxerept	31.5	40.3	28.3	0.56	7.8
Italy	Ussana	39.24N-9.5E	433 ± 0.29	18 °C	20	16	Vertic Cambisol	56.4	21.5	22.1	0.83	7.9

Moving on, the study extended to the Marrakech Safi region in Central Morocco, covering an area of 41,404 km2, with a focus on the Rehamna province. This province, representing 16.81% of Morocco's farmland, experiences variable climate conditions(Briak & Kebede, 2021.). Over a 7-year analysed in Briak & Kede (2021) study period from 2013 to 2019, the mean annual rainfall in Rehamna is 168 mm, with precipitation concentrated in November (42.24 mm) and minimal in July (0.2 mm). The annual average daily maximum and minimum temperatures are 27.03 °C and 19.12 °C, respectively. The soil in Rehamna is predominantly sandy clay loam, reddish-brown in colour, with alkaline pH and moderate levels of nitrogen and CEC.

2.2.2.2 Spain

From Malik & Dechmi, (2019) the Violada Irrigation District in northeast Spain was considered. It is located in the Ebro River basin, covers an area of 5231 ha. The Mediterranean climate is characterized by concentrated precipitation in spring and autumn, with mean annual precipitation and evapotranspiration values recorded at the meteorological station of Tardienta (2005–2017) being 361 mm and 1272 mm, respectively. The mean temperature for the period was 14 °C, with the hottest month being July (mean temperature of 38 °C) and the coldest month December (mean temperature of −5.6 °C). Soils in the Violada Irrigation District were classified into 13 soil units, with Typic Xerofluvent fine-silty and Gypsic Haploxerept fine-silty being predominant.

2.2.2.3 Italy

Continuing the research, Ussana, within the experimental farm of San Michele in Southern Sardinia, Italy, were studied. The Mediterranean climate in this durum wheat growing area exhibits warm and dry summers and mild winters (Dettori et al., 2017). The Ussana site, located in a hilly area, features sandy clay loam soil with a percentage of sand exceeding 50%.

2.2.2.4 Turkey

Therefore, in Edirne, Northwestern Turkey, the study focused on the growing seasons of winter wheat between 2014 and 2018. The region experiences an average temperature of 13.6 °C and annual precipitation of 601.8 mm. The predominant soil in Edirne is clayey with 1.49% soil organic matter (Yeşilköy & Şaylan, 2021).Moving to Central Turkey, the study utilized agrometeorological simulation model DSSAT-CSM CERES-Wheat for wheat yield estimation. Field trials were conducted at the Ankara-İkizce Research Farm, revealing clayey soil with 1.49% soil organic matter (Aydoğdu et al., 2023).

2.2.2.5 Jordan

Additionally, a field experiments in the Mushaqqer Agricultural Research Station Southwest Amman (31°46'24.7'' N, 35°47'47.3'' E, 800 m above sea level) and in Jordan's part of the Yarmouk River basin considered the semi-arid Mediterranean ecosystem. The region experiences variable rainfall and temperature gradients, with mean annual minimum and maximum temperatures ranging from 9.3 °C to 24.0 °C (Al-Bakri et al., 2011, 2021; Elgadi, 2019).

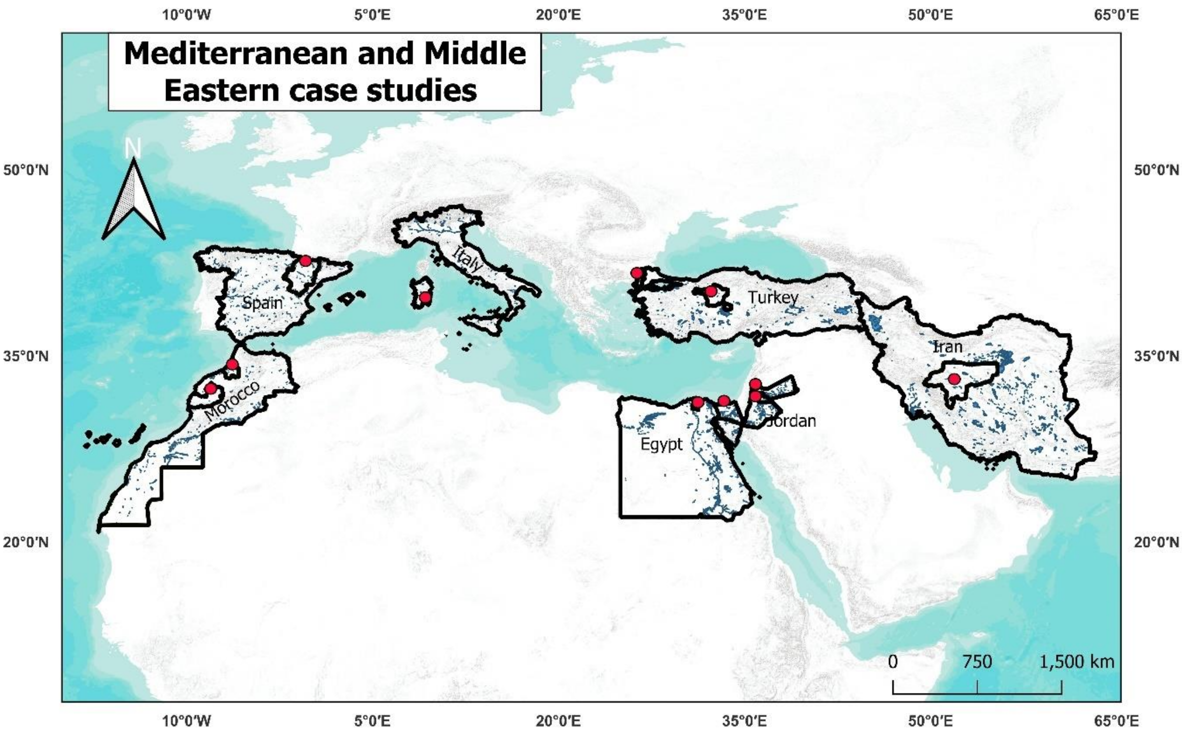
2.2.2.6 Egypt

Further investigations were carried out at the experimental farm of Suez Canal University in North Sinai, Egypt (31°08'04.300 N, 33°49'37.200 E), and in the middle delta of Egypt, Tanta (30.8 N, 31.0 E) (Fayed et al., 2015; Kheir et al., 2021). The Suez Canal University experiments aimed to evaluate four bread wheat cultivars, while the Tanta location, featuring clay soil, was chosen for its high water-holding capacity (Kheir et al., 2021)

2.2.2.7 Iran

The final leg of the study took place in southwest Iran, specifically in Zagros (Dokoohaki et al., 2015). The field experiment for model calibration occurred in a research centre, while the evaluation covered 69 points in 16,500 ha of the undulating area of the region. The mean elevation of the evaluation site was approximately 2400 m above sea level, with transversal slopes of 10–20%. The long-term average annual precipitation in this area is 1400 mm, mainly falling in winter and spring months.

A)



B)

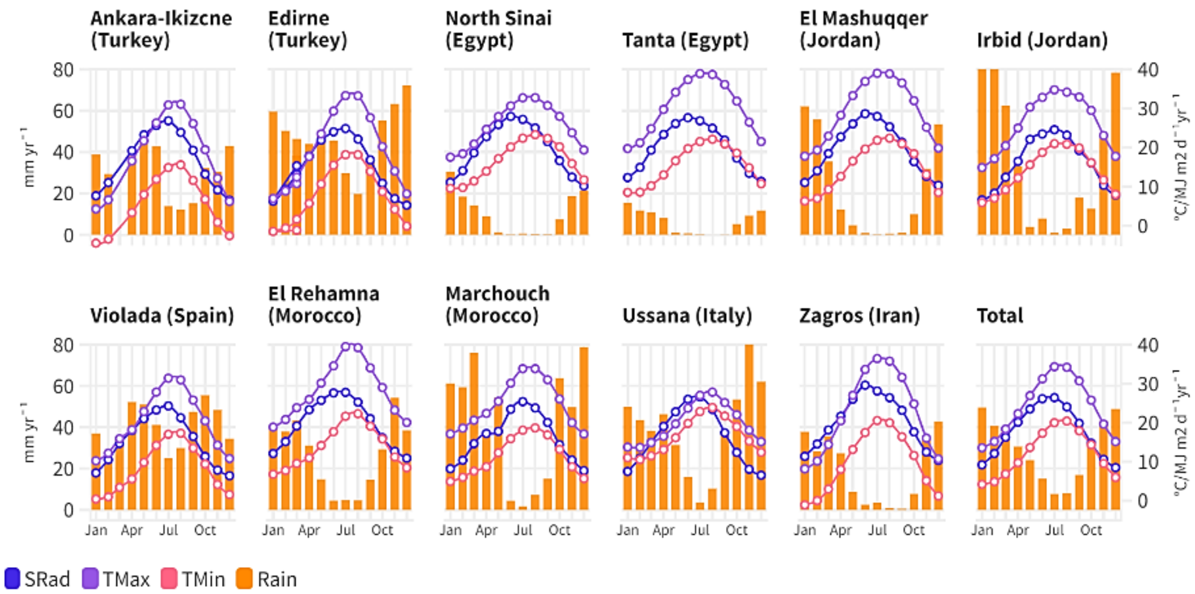


Figure 2 –A) Geographical overview of the case studies spatial distribution; B) Climate graph showing the amount of Rainfall, the maximum temperature (T max), and minimum temperature (T min), and solar radiation through the year.

2.2.3. Agronomic data collection

In the implementation of conservation Agriculture (CA), no-till method with Wintersteiger Plotseed XXL planter was used, directly planting seeds and fertilizers into undisturbed soil, avoiding soil tillage. Crop rows were spaced 25 cm apart, with seed rates adjusted to 300 seeds m^2, spaced 16 cm apart. Sowing occurred from December 15 to 20 yearly. Basal fertilizer of 50:22:42 kg of N, P, and K ha–^{1} was applied during precipitation events to aid nutrient uptake. In Marchouch, irrigation ranged from 55 to 100 mm ha^{-1} via sprinkler and furrow methods, while in Rehamna, it was 120 to 200 mm ha^{-1} using the same methods. Harvest was on June 1st in both locations in Morocco (Briak & Kebede, 2021; Devkota et al., 2022).

In Violada Irrigation District (VID), northeast Spain, irrigation management was evaluated by comparing actual farmer practices with optimal scenarios. The Alfalfa study in VID during 2015 and 2016 provided crucial data for scenario application. Fertilization rates were based on common agronomic knowledge, with a sowing density of 560 seeds m^2 spaced 5 cm apart. Harvest was on June 21st, using no-tillage practices (Briak & Kebede, 2021). In Ussana (Italy), durum wheat agronomic management data from 1973–2004 were sourced from Italian Durum Wheat Variety Trials. Seeding rate was 350 seeds density spaced by 18 cm, planting on December 4th, and harvest on June 30th (Dettori et al., 2017). Nitrogen application doses in Ankara (60 and 120 kg/ha) were compared to the optimum of 120 kg/ha, with 50% reduced (60 kg/ha) fertilizer application. Field trials at Ankara-İkizce Research Farm used DAP as a base fertilizer and ammonium nitrate top fertilizer at different doses in April. Planting occurred on October 24th in Ankara and October 20th in Edirne, with a density of 400 seeds m^2 spaced by 16 cm, and harvest on June 20th (Aydoğdu et al., 2023; Yeşilköy & Şaylan, 2021).

Table 3. Crop management practices in the reviewed papers

Country	Site	Experimental year	Variety	Planting date	Planting density	Fertilizer rate (kg/ha)	Irrigation	Harvesting date	Reference
Morocco	Marchouch	2014	Arihane	15-Dec	300	120	120 mm	01-Jun	Devkota et al., 2022, 2023
	El-Rehamna	2014	Arihane	04-Dec	300	120	120 mm	01-Jun	Briak & Kebede, 2021
Egypt	North Sinai	2011	MISR1	15-Dec	300	200	120 mm	23- Apr	Fayed et al., 2015
	Tanta	2017	GIZA 171	15-Nov	300	180	120 mm	15- May	Kheir et al., 2021
Turkey	Ankara-Ikizce	2017	Bayraktar	24-Oct	400	110	120 mm	20-Jul	Aydoğdu et al., 2023
	Edirne	2014	Bayraktar	20-Oct	400	120	120 mm	20-Jun	Yeşilköy & Şaylan, 2021
Jordan	Irbid	2007	Deiralla6	04-Feb	300	120	120 mm	20- Jun	Al-Bakri et al., 2011
	El-Mashuqqer	2016	CHAM1	16-Nov	300	100	120 mm	20-Jun	Elgadi, 2019
Iran	Zagros	2009	Sardari	11-Nov	300	80	120 mm	13-May	Dokoohaki et al., 2015 Moradi et al., 2022, Deihimfard et al., 2018
Spain	Violada	2014	Maris Fundin	29-Nov	560	100	100 mm	21-Jun	Malik & Dechmi, 2019

Italy	Ussana	2016	Creso	04-Dec	350	90	120 mm	30-Jun	Dettori et al., 2017 Martiniello, 2012

In Jordan, crop yield data for Irbid governorate spanning 1996–2006 were obtained from the Department of Statistics of Amman. Seeding density was 300 seeds m^2 spaced by 16 cm, with El Mashuqqer planted on November 15th and Irbid on February 1st. Harvest date recorded was June 20th for both locations (Al-Bakri et al., 2011; Elgadi, 2019). In Egypt, seeding rate was 300 seeds m^2 for both North Sinai and Tanta. Harvest dates were April 23rd and May 15th, respectively (Fayed et al., 2015; Kheir et al., 2021). In Iran, the calibration site involved wheat cultivation in a level field with adequate water and nitrogen. Fertilization rates ranged from 60 kg to 120 kg ha^{-1} with DAP and split doses of DAP and ammonium nitrate. Seeding density was 300 seeds m^2 spaced by 15 cm on November 11th, with harvest on July 20th (Deihimfard et al., 2018; Dokoohaki et al., 2015; Moradi et al., 2022). Crop production and management practices are summarized in Table 3.

2.3. Climatic data

The daily climatic data (sowing – harvest) of the experimental location consisted of maximum and minimum temperatures, solar radiation and rainfall were collected from a nearby EC station and averaged over the growing season. The daily weather data of 37 years (1986–2023) for all other locations represent the Northern Morocco, Spain, Italy, Jorda, Egypt, Turkey, Iran area was collected from NASA, AgCFSR climate dataset. The dataset used hereinafter for long term simulation by the DSSAT model.

The climate change projections for the experimental locations were based on a 37-year analysis, considering key indicators such as temperature, solar radiation, and rainfall. Data for the simulations were sourced from the MARKSIM DSSAT weather file generator, a CGIAR tool used to create weather files for the DSSAT model. The chosen Representative Concentration Pathways (RCPs) for assessment were RCP 4.5 and 8.5 from the MIROC5 pathway (Model for Interdisciplinary Research on Climate, version 5) developed by University of Tokyo.

2.4. Model calibration and validation

Model calibration and evaluation involve adjusting genetic coefficients for both models and cultivars to align with measured outputs in the study area. The dataset from the initial growing season is used for model calibration under non-stress treatments, while data from subsequent seasons are employed for evaluation. Calibration focuses on genetic parameters related to crop growth, phenology, yield, and yield components (Table 1).

After calibration, model performance is assessed using three statistical indices: determination coefficient (R2), root mean square deviation (RMSD), and Wilmott index of agreement (D). These indices provide a comprehensive evaluation of the models' predictive accuracy.

In this study, the CERES-Wheat model (Hoogenboom et al., 2017) for crop growth and development was employed due to its flexibility in handling diverse agricultural systems, including plant litter decomposition. The model was specifically utilized for wheat simulations, requiring calibration with seven genetic coefficients (P1V, P1D, P5, PHINT, G1, G2, and G3), as outlined in Table 1. The coefficients P1V, P1D, and P5, influencing the timing of development, growth, and yield components, were subjected to the influence of G1, G2, and G3 (Table 5)..

The 'trial and error' or manual calibration method, commonly employed with the DSSAT model (Seidel et al., 2018), was used until a satisfactory match between measured and simulated crop parameters (grain yield and vegetative biomass) was achieved. Additional tools within the model, such as GENCALC (Genotype Coefficient Calculator) and GLUE (Generalized Likelihood Uncertainty Estimation), were also employed to refine phenological outputs (Jha et al., 2022).

Sequentially, cultivar genetic coefficients were obtained, beginning with phenological development parameters related to flowering and maturity dates, followed by crop growth parameters concerning kernel filling rate and kernel numbers per plant. The outcomes were subsequently used for validation and management scenario simulations.

Crop management practices for model calibration and evaluation were derived through a comprehensive literature review. Irrigation doses and timing were extracted from remote database registrations, particularly from the FAO Country profiles. The calibrated model for each crop underwent further evaluation for growth milestones (anthesis and physiological maturity), yield components (grain and vegetative biomass yields), nitrogen uptake (grain and vegetative biomass), and residual nitrogen in the soil. To ensure the scientific rigor and reliability of the model outcomes firstly, the root means square error (RMSE) between the simulated and observed values was computed as:

$$\mathrm{RMSE} = \frac{\sqrt{\sum(yi-xi)^2}}{n} \quad \text{(III)}$$

Therefore, the normalized RMSE (nRMSE) was expressed as the ratio between the RMSE and the average of the observed data. The model simulations were considered excellent, good, fair, and poor based on the nRMSE values of < 10%, 10–20%, 20–30%, and > 30%, respectively, which were proposed by (Kadiyala et al., 2015).

$$nRMSE = \frac{RMSE}{\bar{x}} \times 100 \qquad \text{(IV)}$$

Finally, the index of agreement or d statistic (d; Willmott, 1982) was computed as follows:

$$d = 1 - \frac{\sum(yi-xi)^2}{\sum((|yi-\bar{x}|+|xi-\bar{y}|)^2} \quad \text{(V)}$$

The coefficient of determination (R^2) of the linear regression was calculated between the simulated x - observed values y. The index of agreement can detect additive and proportional differences in the observed ($\bar{x}$) and simulated means ($\bar{y}$) and variances (Legates & McCabe, 1999). The Index of Agreement (d) developed by Willmott (1981) as a standardized measure of the degree of model prediction error and varies between 0 and 1. A value of 1 indicates a perfect match, and 0 indicates no agreement at all (Willmott, 1981).

2.5. Scenario analysis

Twenty-three climate change scenarios, representing the possible average climatic conditions around year 2100 (MoEnv, 2009). According with the literature we selected three climate horizons were suggested as potential scenarios of climate change by year 2100 (i.e., 2010-2040, 2040-2070, 2075-2100). Those three scenarios (Table 2) were based on the monthly temperature and precipitation projections from the following coupled ocean–atmosphere general circulation models (GCMs) MIROC5 Model for Interdisciplinary Research on Climate, version 5 developed at centre for Climate System Research (CCSR) at the University of Tokyo, Japan in which temperature changes of +1.5 °C (RCP 4.5) and more than +2.5°C (RCP 8.5). Changes in rainfall of 10%, and 20% were incorporated in combinations with each level of the temperature increase. Outputs of these GCM were retrieved and extracted from the MARKSIM DSSAT weather file generator (https://gisweb.ciat.cgiar.org/MarkSimGCM/#). More details on the models, scenarios and variables for which climatology are available can be found at (http://www.ipcc-data.org/ ar5/gcm_data.html). In this study, the monthly temperature and precipitation from the GCM were used to simulate the current conditions (CO_2)

and were compared with observed data of daily air temperature and precipitation for the period 1986-2023. Models' outputs were in good agreement with mean monthly air temperatures of the study areas. Outputs from the models, adjustment statistics for temperature and precipitation (Table 2), were used in DSSAT to predict yield of wheat.

2.6. Statistical analysis

The R software's model function was employed for conducting calculations related to model calibration and evaluation indices. The dataset encompassing simulated yield (GY) and its associated attributes, such as water use efficiency (WUE), irrigation, evapotranspiration (ETc), and nutrient balances across various irrigation and fertilization treatments, underwent analysis through principal component analysis (Addinsoft, 2015). This analytical approach was utilized to gain a comprehensive understanding of the correlations among all factors.

3. Results and Discussions

3.1 Characterization of wheat production

The analysis of wheat crop data, as reviewed in the literature spanning from 2010 to 2019, reveals a consistent cropping pattern across consecutive seasons. Table 3 presents the average yield values for the mentioned crop seasons. Notably, the literature, including studies by Al-Bakri et al. (2011), Aydoğdu et al. (2023), Briak & Kebede (2021), Devkota et al. (2022, 2023), Fayed et al. (2015), Kheir et al. (2021), Yeşilköy & Şaylan (2021), Dettori et al. (2017), Dokoo-haki et al. (2015), Elgadi (2019), Malik & Dechmi (2019), and Moradi et al. (2022), indicates an average yield under rainfed and irrigated conditions. This trend is observed to be comparable to conventional methods, particularly in regions such as Jordan and Egypt, with a notable emphasis on the North Sinai location (Table 3).

Examining experimental data, the highest yields were reported in Ussana, Italy, and Rehamna, Morocco, employing contrasting agricultural practices. In Morocco, minimum tillage coupled with the application of 120- or 200-mm ha^{-1} of water per year resulted in optimal yields. Conversely, in Italy, the absence of tillage was considered, and fertilization rates ranged from 60 kg ha^{-1} to 120 kg ha^{-1} at maximum. It is noteworthy that the irrigation amounts were generally consistent, except for Italy, Spain, Turkey, and Marchouch in Morocco, where lower water application was employed, considering the local rainfall patterns. These locations were selected for comparative analysis with others requiring higher water application and fertilization, such as Jordan, Egypt, Iran, and the central-south region of Morocco.

Table 4 - Summary from elaboration of the literature review

Country	Location	TN	H_2O irr. (mm)	Fertilizer rates (kg/ha)	Planting date	Yield (kg ha^{-1} yr^{-1})	References
Morocco	Marchouch	T1	0	Leg. Residue	15-Dec	3000	Devkota et al., 2022, 2023
		T2	100 F	Leg. Residue	15-Dec	3100	
		T3	60 S	60	15-Dec	5250	
		T4	100 F	120	15-Dec	6410	
	El Rehamna	T1	0	Cereal Residue	4-Dec	4500	Briak & Kebede, 2021
		T2	120 F	Cereal Residue	4-Dec	4800	
		T3	120 S	60	4-Dec	7000	
		T4	200 F	120	4-Dec	10000	
	North Sinai	T1	0	Cereal Residue	15-Dec	5000	Fayed et al., 2015
		T2	140 F	Cereal Residue	15-Dec	5500	

Egypt		T3	140 S	Residue + 120	15-Dec	7000	
		T4	240 F	180	15-Dec	7500	
	Tanta	T1	0	Cereal Residue	15-Nov	3500	Kheir et al., 2021
		T2	140 F	Cereal Residue	15-Nov	4500	
		T3	140 S	C.Residue + 120	15-Nov	7000	
		T4	240 F	180	15-Nov	7500	
Turkey	**Ankara - Ikizcne**	T1	0	Cereal Residue	15-Nov	2000	Aydoğdu et al., 2023
		T2	100 F	Cereal Residue	15-Nov	3500	
		T3	55 S	60	15-Nov	5500	
		T4	100 F	120	15-Nov	6500	
	Edirne	T1	0	Cereal Residue	24-Oct	5000	Yeşilköy & Şaylan, 2021
		T2	100 F	Cereal Residue	25-Oct	5250	
		T3	55 S	60	25-Oct	5750	
		T4	100 F	120	25-Oct	7250	
Jordan	**Irbid**	T1	0	Leg. Residue	20 Oct	4500	Al-Bakri et al., 2011
		T2	140 F	Leg. Residue	20 Oct	5000	
		T3	140 S	L.Residue + 60	20 Oct	6110	
		T4	240 F	L.Residue + 120	20 Oct	7150	
	El Mashuqqer	T1	0	Leg. Residue	1 Feb	4000	Elgadi, 2019
		T2	140 F	Leg. Residue	1 Feb	4500	
		T3	140 S	Residue + 60	1 Feb	6000	
		T4	240 F	Residue + 120	1 Feb	7500	
Iran	**Zagros**	T1	0	Leg. Residue	11-Nov	2200	Dokoohaki et al., 2015 Moradi et al., 2022, Deihimfard et al., 2018
		T2	120 F	Leg. Residue	11-Nov	4250	
		T3	120 S	60	11-Nov	4750	
		T4	200 F	120	11-Nov	5250	
Spain	**Violada District (Aragon)**	T1	0	Leg. Residue	29-Nov	4350	Malik & Dechmi, 2019
		T2	100 F	Leg. Residue	29-Nov	5000	
		T3	55 S	60	29-Nov	6000	
		T4	100 F	120	29-Nov	7500	
Italy	**Ussana (Sardinia)**	T1	0	Leg. Residue	4 -Dec	3000	Dettori et al., 2017 Martiniello, 2012
		T2	100 F	Leg. Residue	4 -Dec	4500	
		T3	55 S	60	4 -Dec	5250	
		T4	100 F	120	4 -Dec	9000	

3.2 Model calibration and validation

The model's prediction of anthesis date exhibited high sensitivity to changes in P1V, aligning with findings by Rezzoug et al. (2008), who reported a 3-day delay in simulated anthesis date with a 1-day alteration in this parameter. Notably, Moradi et al., (2022), and Rezzoug et al. (2008; 2015) highlighted that P1V spans from 19 to 150 days, irrespective of climate type.

The photoperiod coefficient (P1D) was determined within the range of 2 to 48% for wheat varieties, a spectrum consistent with other studies that reported P1D values ranging from 30% to 70% (Rezzoug et al., 2008). Mirroring the sensitivity observed in P1V, the model's prediction of maturity date was notably responsive to variations in P1D (Moradi et al., 2022).

The grain-filling duration (P5) for wheat varieties ranged from 168 to 992 degree-days, while the coefficients for kernel number (G1) spanned from 17g to a maximum of 55g. Additionally, the kernel weight coefficient (G2) ranged from 10 to 80 mg day^{-1}, and the optimal value for the spike number coefficient (G3) was set within the interval of 1.5 to 8 g (Table 3). Comparisons with previous studies indicated variability in G1 values between 15 and 50 kg^{-1} globally, and G2 values reported by various authors ranged between 36 and 76 mg (Rezzoug et al., 2008). The optimum value for PHINT, representing plant height, fell within the range of 30 to 120 for the wheat varieties (Table 5).

The calibration results, detailed in Table 6 and supplementary statistics 1, showed that simulated values closely matched observed data, as indicated by r-square and d-stat (Willmott index). This suggests the model's suitability for evaluating undulating areas. Adjustments to genetic coefficients generally aligned with previous studies, except for higher days to vernalization (P1V) for spring-autumn wheat. The compensatory effect observed, where decreasing one coefficient increases another, underscores the complex relationship between these factors (Table 5).

Table 5. Genetic coefficients for wheat varieties determined under climate conditions Mediterranean and MENA basin after calibration.

Parameters	Arihane	Arihane	Violada	Sardari	Baykara ktar	Baykara ktar	Giza	Misr1	Deiralla6	Cham1	Creso
P1D	4.7	33	14	2.04	42	23	36	44	48	45	34
P1V	19	93	34	90	150	56	84	29	100	152	67
P5	702	590	878	440	986	993	484	168	799	536	286
G1	20	21	51	27	28	18	56	49	48	48	47
G2	60	10	80	65	36	37	80	80	71	76	61
G3	1.5	1.02	8	3.1	5.3	6.3	7.8	7.2	6.1	7.1	6.7
PHINT	95	95	91.5	90	95	120	90	58	30	50	100

The simulation of grain and vegetative biomass in eleven sites from 1986 to 2023 demonstrated strong linear relationships between simulated and observed yields. Vegetative biomass weight (VEG WT) showed higher R^2 (0.921) values and lower RMSE compared to grain yield (GY) (0.907). The NRMSE values were 7% for vegetative biomass and 6% for grain yield across all locations. Deihimfard et al. (2018), Moradi et al. (2022), and Waffa & Benoit (2015), reported successful simulation of wheat yield, with this study aligning closely with an RMSE of 540 kg ha^{-1} and an nRMSE of 7%. Discrepancies in results may arise from model calibration using literature review data and the amalgamation of diverse datasets from various studies and time spans.

DSSAT performed better in simulating vegetative biomass than grain yield, likely due to the latter being more influenced by climatic conditions. Comparing with previous studies, an improvement in DSSAT calibration was observed when using replicated experimental data to modify genotype coefficients. The RMSE for wheat grain yield decreased from 476 kg/ha to 413 kg/ha (Al-Bakri et al., 2011; Devkota et al., 2022). Trends in DSSAT and farmers' wheat grain yield were similar, with minor differences in standard deviations and coefficients of variation.

Differences between simulated and observed yields were expected, considering variations in soil and crop management practices. Simulated values from 1986 to 2023 captured variations in wheat yield, showing a general increasing trend. The lowest wheat yield occurred in the driest years (1999, 2000, 2002, 2008, 2009, 2014, 2017, 2019, 2021), while the wettest year (2015) in Spain recorded the maximum yield of 12610 kg/ha during 1986–2023.

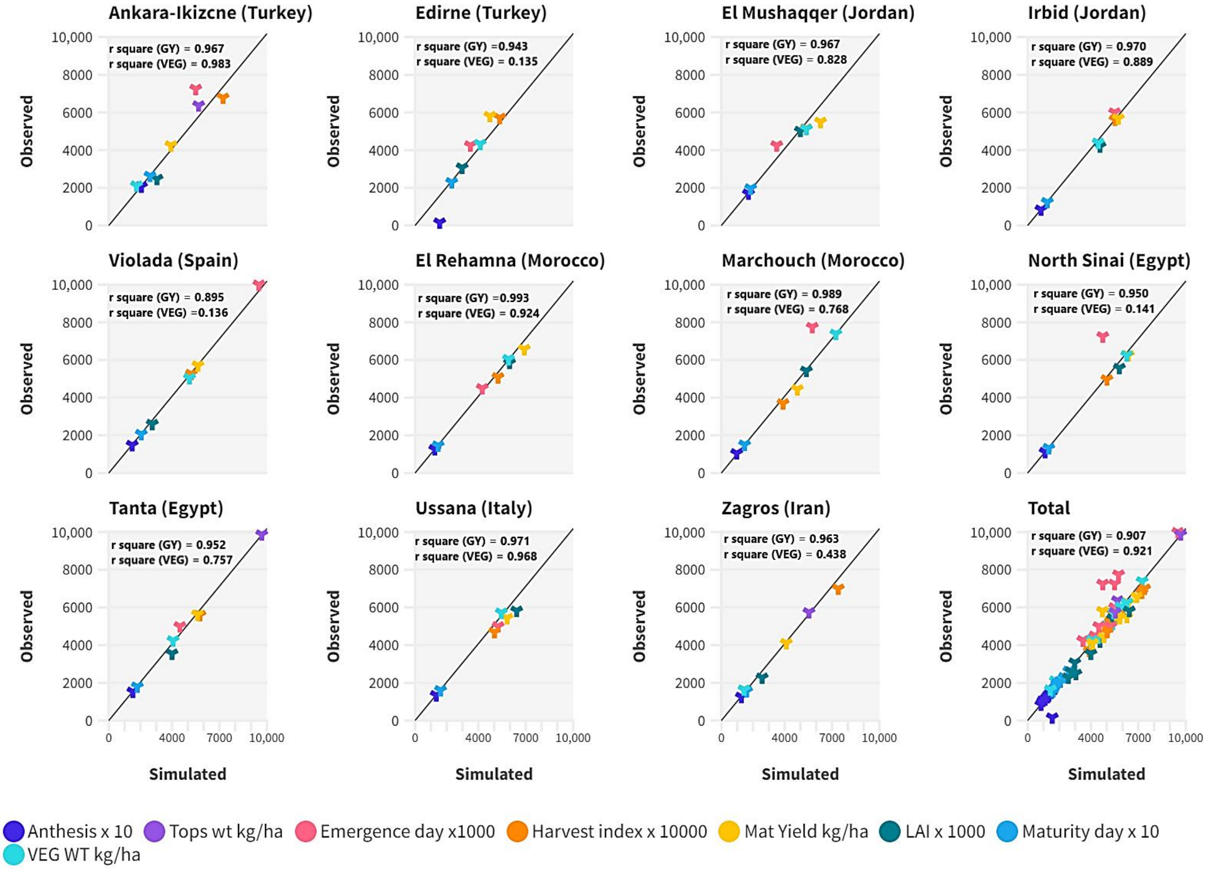


Fig. 3 - Results of the calibration and validation of the CERES-Wheat parameters

Table 6 – Summary of the calibration and validation from the simulation with DSSAT model (see supplementary 1).

		Mean		Std.Dev.									
Variable Name	Obs.	Sim.	Ratio	Obs	Sim.	R^2	Mean Diff.	Mean Abs.Diff.	RMSE	nRMSE	d-Stat.	Used Obs.	Tot Num Obs.
Anthesis day	**134**	**133**	1.012	26.53	27.27	0.990	-1.66	1.66	3.14	**4%**	**1.00**	44	44
Tops wt kg/ha	**10155**	**10104**	0.988	2896	3048	0.937	-51	597	771	**6%**	**0.98**	44	44
Emergence day	**7**	**6**	1.151	2.37	2.39	0.877	-5	5	1.18	**17%**	**0.93**	44	44
Harvest index	**0.541**	**0.555**	1.028	0.106	0.112	0.85	0.014	0.031	0.045	**10%**	**0.96**	44	44
Mat Yield kg/ha	**5400**	**5450**	1.015	1702.58	1762.34	0.907	50	413	540.6	**7%**	**0.98**	44	44
LAI maximum	**4.2**	**4.4**	1.058	1.50	1.63	0.892	0.2	0.40	0.585	**11%**	**0.97**	44	44
Maturity day	**177**	**176**	1.007	43.35	42.5	0.992	-1	1	4.049	**3%**	**1.00**	44	44

VEG WT kg/ha	**4755**	**4654**	0.959	1799.7	1845.8	0.921	-101	406	529.05	**6%**	**0.98**	44	44

3.3 Simulated potential yield.

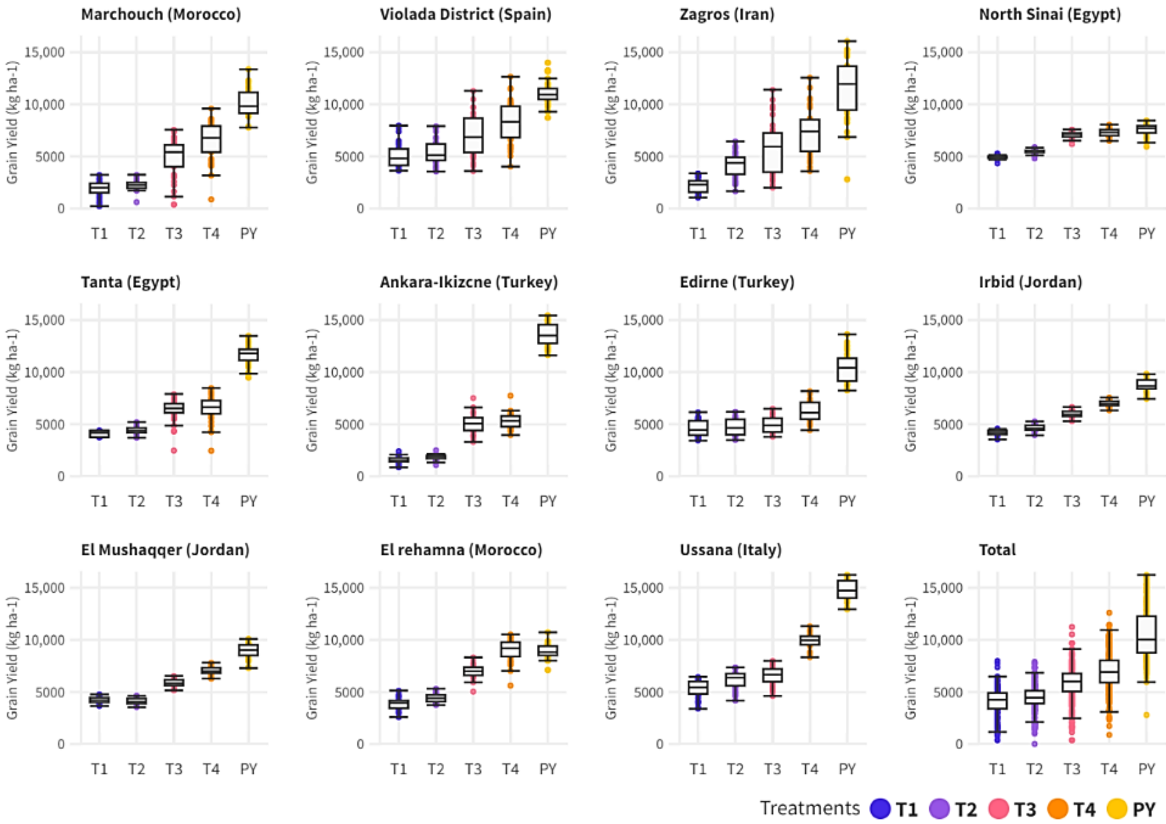


Figure 4 - Yield trend from 1986 to 2023 for each treatment, compared to potential yield.

The simulated long-term average yield potentials for wheat varied from 8.9 to 14.9 t/ha, revealing a significant water-nutrient limited yield gap, with Iran (8.1 t/ha), Italy (8.0 t/ha), and Turkey (7.7 t/ha). This emphasizes the substantial impact of treatment variability on overall yield gaps.

Multi-year simulations, aligned with experimental data, demonstrated increased grain yields for all wheat varieties with irrigation and higher fertilization rates, approaching the potential yield. The average long-term simulated potential grain yields surpassed treatments with high fertilization practices by 19% to 62%, indicating a potential reduction in attainable yield gaps for this major food crop.

It's noteworthy that in some countries, water constraints, such as in Egypt, Jordan, Morocco, and Southern Italy, seem to define the yield gap. In contrast, in Turkey and Iran, the trend suggests issues with management practices, as a reduction in irrigation and/or nutrients did not result in significant differences in attainable yield.

Long-term simulations assessing the impact of high or low fertilization rates on grain yield, nitrogen balance, crop water productivity, and water use efficiency were conducted for two major rotation systems: cereal-cereal (wheat-wheat) and cereal-legume, or, fallow period (wheat-lentil), aligning with case studies in the literature review.

3.3.1 Simulated yield under different irrigation and N management

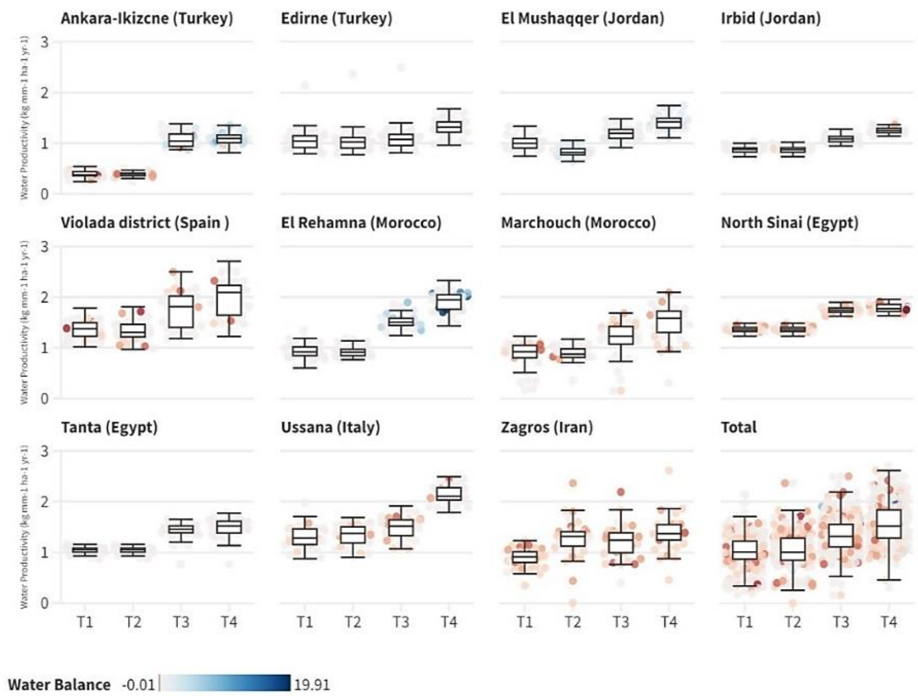
The thirty-seven-year average yields of the wheat varieties in rainfed conditions, as assessed in this study, are as follows: 3.06 t/ha (Turkey), 4.4 t/ha (Jordan), 5.13 t/ha (Spain), 3.51 t/ha (Morocco), 4.8 t/ha (Egypt), 5.29 t/ha (Italy), and 2.17 t/ha (Iran). Considering this, it is essential to examine their performance under irrigation treatments using the furrow system and no fertilization, except for leaving residue in some locations, as indicated in Table 3. The resulting yields are 3.26 t/ha (Turkey), 4.3 t/ha (Jordan), 5.45 t/ha (Spain), 4.09 t/ha (Morocco), 4.81 t/ha (Egypt), 6.16 t/ha (Italy), and 4.16 t/ha (Iran). The differences in yield are attributed to the rainfall patterns specific to these locations, as highlighted in the potential yield analysis.

Further confirmation is derived from the results of irrigation with a sprinkler and low fertilization, as well as irrigation with furrow and high fertilization. Notably, the results in Iran, Egypt, Turkey, and the comparison between two irrigation amounts in Morocco emphasize the significance of localized treatments and the management of water and nutrients on-site, rather than focusing solely on the total treatment amount and product quantities such as DAP or Ammonium Nitrate.

Examining the variance between treatments reveals that utilizing an application range of ammonia, urea, or nitrogen derivatives in the range of 60 to 120 kg/ha for Egypt leads to stable yields across the Mediterranean and Middle Eastern regions. Conversely, increasing fertilization rates may result in higher yields but introduces significant fluctuations from year to year, with a 21% variance across all locations. Therefore, solely applying water without enhancing nutrient management efficiency can contribute to even more fluctuations throughout the year, with a 34% variance. Above all, the timing and the localisation of the products applied to the different plot analysed in the study seems to be relevant to outline the path trajectory to close the yield gap that is currently present. Treatments in the whole MENA and Mediterranean locations considered in the study at 4.3 t/ha for rainfed conditions, 4.4 t/ha for only irrigation, 6 t/ha for sprinkler irrigation and low fertilisation rates and 6.9 t/ha for furrow irrigation and high fertilisation rates.

3.3.2 N and water balance

A)



B)

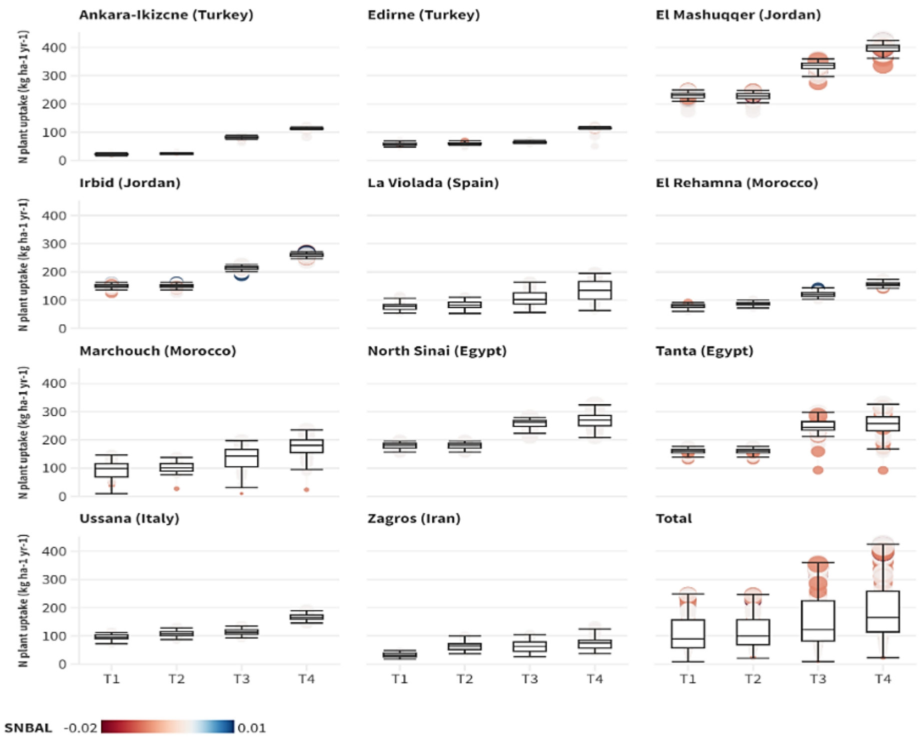


Fig. 5 - a) Seasonal crop water productivity and balance and b) nitrogen balance and trend from the period 1986-2023 of the different treatments considered in the study.

In the realm of sustainable water and nutrient management in agriculture, the objective is to align water availability and needs, both in terms of quantity and quality, spanning across space and time, while maintaining an acceptable environmental impact. The water balance results for the area a value of 0.34 mm ha^{-1} yr^{-1}. Figure 5a illustrates those treatments three and four, involving a minimum irrigation of 55 mm and a maximum of 200 mm applied in four instances, ensure a positive water balance that it is aligned Mateo-Sagasta et al., 2022).

It is noteworthy that even in rainfed conditions, a positive water balance of 0.001 mm ha^{-1} yr^{-1} was observed for the sites in Edirne (Turkey), El Rehamna (Morocco), and El Mushaqqer (Jordan). Conversely, Tanta (Egypt) and Irbid (Jordan) exhibited a neutral impact, while Ankara (Turkey), Ussana (Italy), and Zagros (Iran) experienced a severe negative impact on the water balance. Additionally, sites like Violada (Spain), Marchouch (Morocco), and North Sinai (Egypt) showed higher crop water productivity but had adverse effects on the overall water balance and water use efficiency.

Overall, rainfed conditions demonstrated better performance and less variability in crop water productivity compared to solely irrigated fields. The water use efficiency across the MENA and Mediterranean sites averaged at 13.69 mm ha^{-1} yr^{-1}, with a crop water productivity trend of 1.24 mm ha^{-1} yr^{-1}. The management of water slightly improved baseline conditions, particularly when applied through sprinkler and furrow methods. Notably, rainfall patterns played a crucial role, evident in the precipitation use efficiency (PUE) value of 29.70 mm ha^{-1} yr^{-1}.

On the nitrogen front, the balances showed a slight negative trend of 0.0011 kg ha^{-1} yr^{-1} over the past thirty-seven years, leading to challenges such as immobilization (32.72 kg ha^{-1} yr^{-1}) and mineralization (4.46 kg ha^{-1} yr^{-1}) over the years (Figure 5b). It's important to highlight those issues related to soil fertility or progressive nutrient erosion contributed to the imbalance, especially in countries with increased nitrogen application like

Jordan and Egypt. Interestingly, the third and fourth treatments exhibited varying impacts on nitrogen balances, with positive or neutral trends observed in Iran, Italy, Morocco, Spain, and Turkey between 80 to 120 kg ha. In gauging the impact of conservation agriculture on water and nutrient balances, the study provided a descriptive overview of the current state. However, precise estimates of nutrient leaching and runoff prove challenging due to the scarcity of national or localized data, echoing the sentiments of Malagó & Bouraoui (2023). They estimate a 15% negative balance, consistent with the study's findings but with specific locations such as Jordan, Egypt, and Turkey experiencing 10-12% reductions. Increased nitrogen application, as highlighted by Elrys et al. (2019) and Segurado et al. (2018), contributes to this dynamic.

3.3.2 Simulated yield under different seeding date

Following the analysis of potential yield and the diverse impacts of different treatments on nutrient and water balances, we investigated the optimal seeding times for each country considered in the studies. First and foremost, the ideal period for planting wheat varieties in Turkey, based on a yield of 4.26 t/ha and a variance of 40%, is the 15th of November.

Applying a similar approach, we determined that in Jordan, wheat can be seeded between the 1st and 15th of December, resulting in a corresponding yield of 5.9 t/ha and a variability of 19%. Furthermore, in Spain, considering a 25% variability across different seeding periods, wheat can be planted from the 1st of October to the 15th, guaranteeing yields ranging from 5 t/ha up to 5.6 t/ha, particularly for the 1st of October.

For Morocco, the optimal seeding times vary among different locations: the 1st of November for El Rehamna and the 15th of November for Marchouch. These timings ensure an average yield of at least 5.2 up to almost 5.6 t/ha, with respective variances of 35% and 38%. In Egypt, wheat varieties can be seeded from the datasets considered over the last 37 years, spanning from the 15th of November to the 1st of December, resulting in yields of 5.4 and 5.3 t/ha, with a variability of 20-23%.

Considering Italy, especially the unique situation and microclimate pattern in Sardinia Island, optimal planting can commence from the 15th of November, with a variability of 23% and an estimated yield of 6.4 t/ha. Nevertheless, the 1st of January also exhibits a positive average trend in yield, albeit with higher variability at 27%, owing to rainfall patterns.

The analysis of Iran has identified the optimal planting dates to be between the 15th of October and the 1st of November, considering a variability of 44%, resulting in average yields of 5 t/ha and 4.4 t/ha, respectively.

In the MENA and Mediterranean region, the overall trend indicates that the optimal seeding date in the area is projected to be the 1st of November, with a variability of 41% and an average yield of 4.8 t/ha.

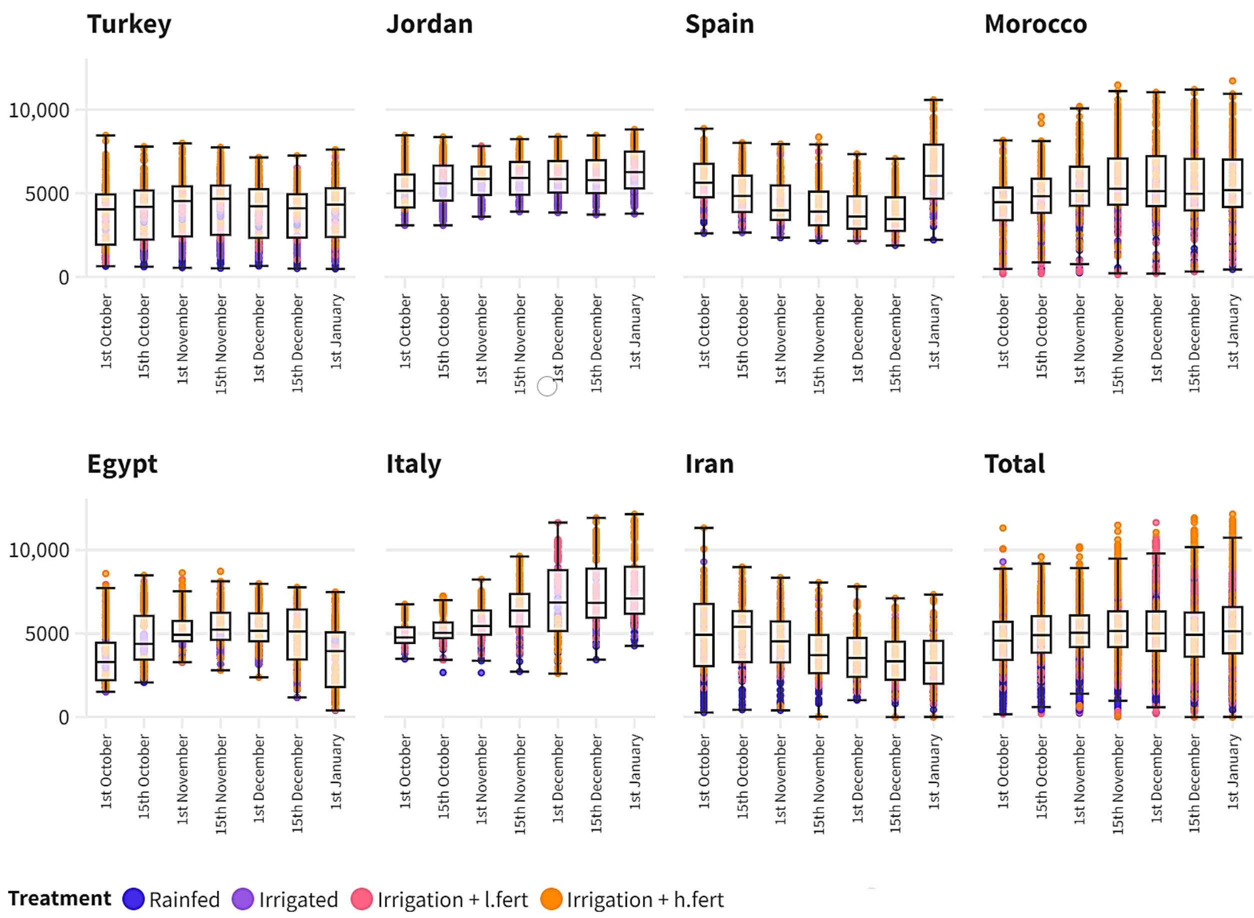


Figure 6 - Seeding date simulation from the aggregates weather data range 1986-2023

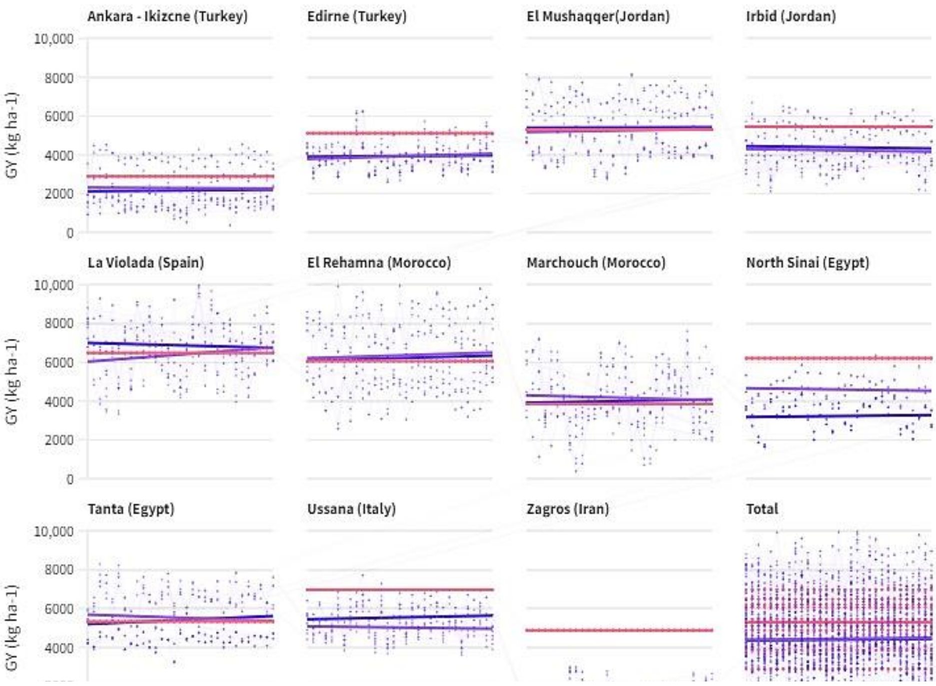
3.3.3 Wheat yield under different climate change situation

A climate change scenario analysis was conducted based on three distinct climate horizons: 2010-2040, 2040-2070, and 2075-2099, as documented in various studies in the region, including Al-Bakri et al. (2021), Deihimfard et al. (2018), Vanli et al. (2019), and Waffa & Benoit (2015).

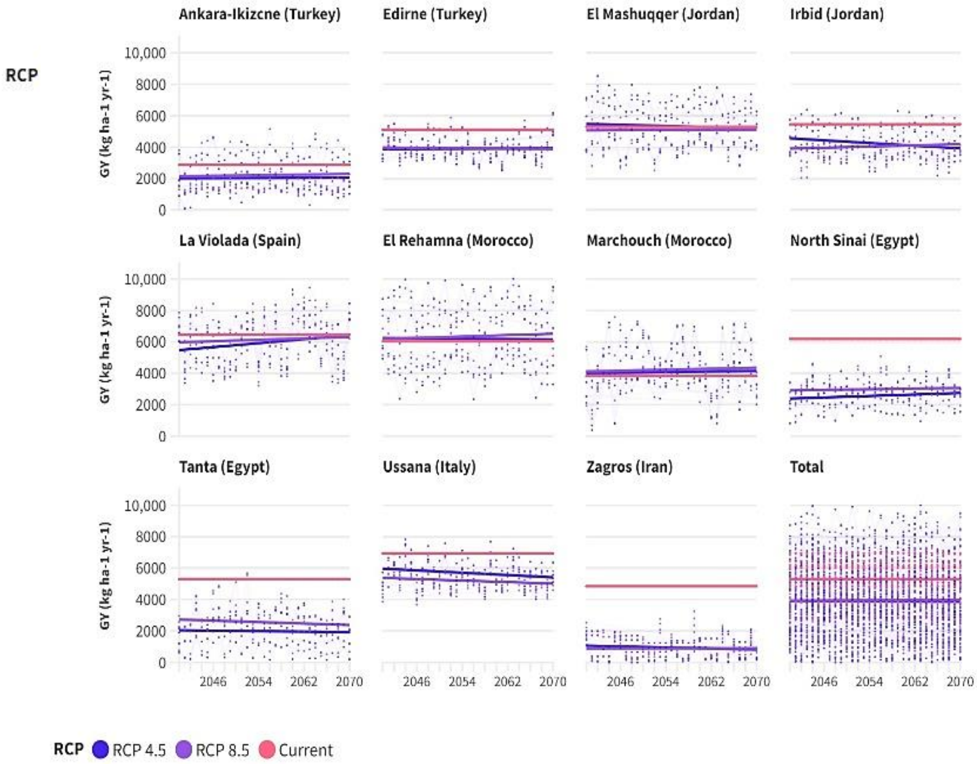
The findings suggest that climate change is poised to decrease crop yields across most locations in the next two decades and towards the end of the century. This reduction is attributed to rising temperatures, despite an overall increase in rainfall. Notably, the most significant yield reduction, 75% on average, was projected in Zagros, Iran, while Marchouch in Morocco and Viola District in Spain emerged as the least affected, with 8% and 6% yield increases, respectively, under both RCP 4.5 and RCP 8.5 (Figure 7a).

Across all locations, there is a consistent trend of higher yield decline under RCP 8.5, with a projected 20% average reduction by mid-century (Figures 7b and 7c). The MIROC5 model showed a greater reduction in yield under RCP 4.5 compared to RCP 8.5 for mid and end-century periods. In the MENA and Mediterranean regions, an average yield reduction of 27% (RCP 4.5) and 28% (RCP 8.5) was recorded for mid-century, while end-century projections indicated reductions of 30% (RCP 4.5) and 28% (RCP 8.5). In the case of Iran, mid-century yield reductions were alarming at 80% (RCP 4.5) and 86% (RCP 8.5), with end-century projections showing 88% (RCP 4.5) and 82% (RCP 8.5) reductions (Figures 7b and 7c).

The study concludes that implementing conservation agriculture practices, as observed in Jordan, Morocco, and Spain, could mitigate the average mean yield reduction. In these regions, a slightly positive trend was maintained under both RCP 4.5 and RCP 8.5, ranging from -1% to 6% in mid-century and 1% to 20% by the end of the century, particularly in Marchouch (Morocco) and Viola District (Spain) (Figures 7b and 7c). Notably, Violada District showcased an upper quartile range of yield around 6.4 t/ha by the end of the century, while Iran displayed a lower quartile of 0.5 t/ha. Conversely, Mediterranean countries like Egypt and Turkey experienced around a 40% reduction (RCP 4.5) in Ankara and 30% in Edirne by the end of the century (Figure 7c). In Egypt, substantial reductions of 68% (RCP 4.5) and 62% (RCP 8.5) were estimated in North Sinai, and 61% (RCP 4.5) and 63% (RCP 8.5) in Tanta by the end of the century. Finally, implementing no tillage or minimum tillage, such as conservation practices in Italy and Jordan, demonstrated a potential mitigation of yield reduction effects by the end of the century (Figure 7c).



B)



C)

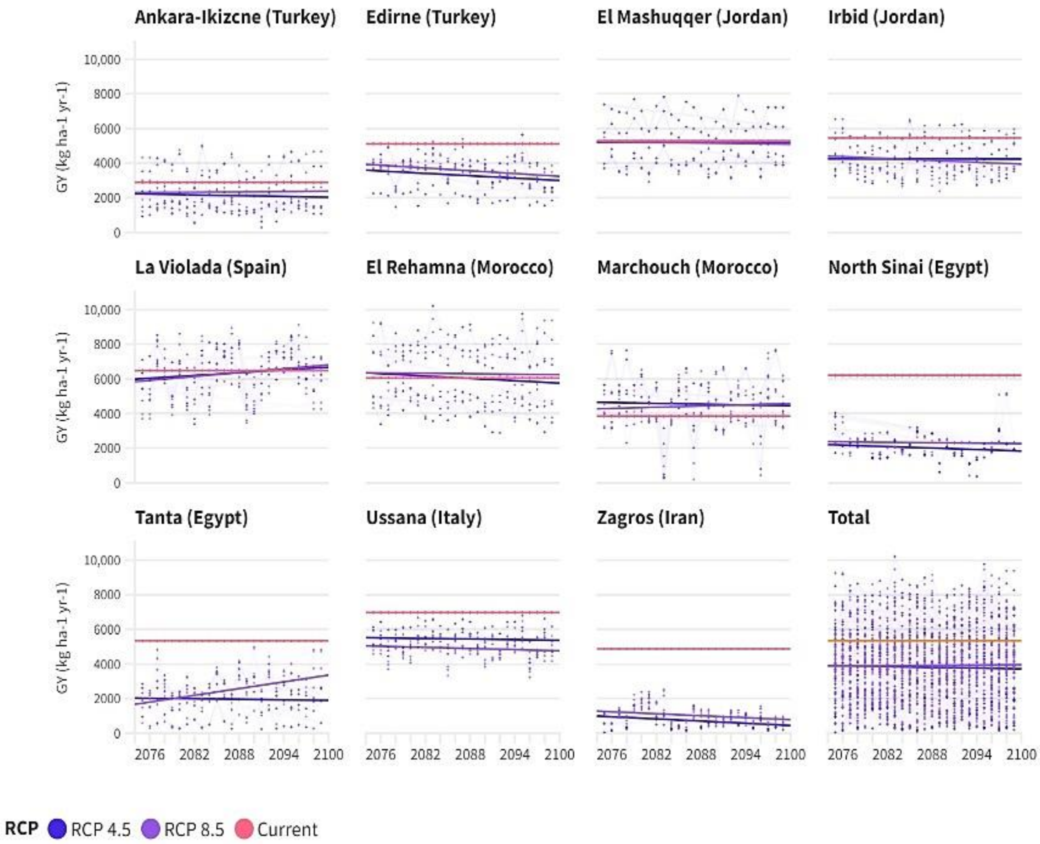


Figure 7 - Climate change scenarios through the climatic scenarios RCP 4.5 and RCP 8.5 from MIROC5 climatic projections a) 2010-2040, b) 2040-2070, c) 2075-2099.

The study concludes that future temperature increases are likely to decrease wheat yield by approximately 28% in mid-century and around 30% at the end of the century. This reduction is attributed to a shortened growth cycle due to increased temperatures, impacting grain size and weight. The call for further assessments involving different GCM models and the accuracy of various crop models, such as APSIM and AQUACROP, is crucial, especially in regions like Jordan and Egypt grappling with salinity issues in water content (Deihimfard et al., 2018; Halima et al., 2021).

4. Conclusions

The current assessment of yield gap indicates a missing overall potential ranging from 19% to 62% of attainable yield. Notably, high fertilization treatments, encompassing both water and nutrients, have demonstrated promising results in regions like North Sinai (Egypt), El Rehamna (Morocco), and El Mashuqqer (Jordan), with particularly close or equal outcomes observed in North Sinai. However, it's crucial to consider the potential consequences of excessive nitrogen or water applications in these areas, as they may lead to leaching, runoff, and soil erosion, especially evident in regions like Egypt and Jordan.

The study identifies the optimal seeding date in the region as falling between the 1st and 15th of November, resulting in an average yield of approximately 5 t/ha. This finding aligns with the historical trend observed from 1986 to 2023. While these results provide valuable insights, future climate projections should be considered to validate and adjust these seeding recommendations. The current findings, however, are consistent with existing literature on the subject.

In light of climate projections, regions implementing conservation or minimum disturbance practices, such as minimum or no tillage and localized irrigation (e.g., sprinkler systems in Morocco, Northern Spain, Italy), exhibit better performance and adaptation. It's noteworthy, though, that localized irrigation alone may not suffice to prevent leaching or runoff of nutrients in areas with high fertilization, as observed in Jordan, Egypt, and partially in Turkey (Ankara site). Effective management of residues and smart agricultural practices utilizing precipitation, as seen in Jordan, Violada District (Spain), and Ussana (Italy), can ensure satisfactory yields under rainfed conditions.

In conclusion, the presented results underscore the potential of the DSSAT model to encourage farmers to enhance their irrigation practices. However, it's essential to continue considering soil properties to ensure production while advancing environmental sustainability. Policymakers in the region should collaborate with farmers, aiding in the transition and promoting the adoption of precision agriculture tools and modelling software. This support can empower farmers with enhanced precision in their practices, contributing to sustainable and efficient agricultural systems.
Finally, the consideration of increasing CO_2 concentrations through the time that might affect areas that showed a positive trend at the end of the century, which are based on temperature, solar radiation and rainfall pattern. However, the result is highlighting the importance of practices such as localised water application through sprinkler better than furrow and also an optimal dose highlighted in almost all the areas except Egypt can be still improved the dose and further assessment are required.

REFERENCES

[1] Abu-hashim, M., Khebour Allouche, F., & Negm, A. (Eds.). (2021). *Agro-Environmental Sustainability in MENA Regions*. Springer International Publishing. https://doi.org/10.1007/978-3-030-78574-1

[2] Al-Bakri, J., Farhan, I., Al-Qinna, M., Al-Karablieh, E., Bergouli, K., & McDonnell, R. (2021). Assessment of Climate Changes and Their Impact on Barley Yield in Mediterranean Environment Using NEX-GDDP Downscaled GCMs and DSSAT. Earth Systems and Environment, 5(3), 751–766. https://doi.org/10.1007/s41748-021-00238-1

[3] Al-Bakri, J., Suleiman, A., Abdulla, F., & Ayad, J. (2011). Potential impact of climate change on rainfed agriculture of a semi-arid basin in Jordan. *Physics and Chemistry of the Earth, Parts A/B/C*, *36*(5–6), 125–134. https://doi.org/10.1016/j.pce.2010.06.001

[4] Alderman, P. D. (2020). A comprehensive R interface for the DSSAT Cropping Systems Model. *Computers and Electronics in Agriculture*, *172*, 105325. https://doi.org/10.1016/j.compag.2020.105325

[5] Amiri, N., Lahlali, R., Amiri, S., El Jarroudi, M., Khebiza, M. Y., & Messouli, M. (2021). Development of an Integrated Model to Assess the Impact of Agricultural Practices and Land Use on Agricultural Production in Morocco under Climate Stress over the Next Twenty Years. *Sustainability*, *13*(21), 11943. https://doi.org/10.3390/su132111943

[6] Aydoğdu, M., Yildiz, H., Gürkan, H., Alsancak Sirli, B., & Tuğaç, M. G. (2023). Evaluation of Yield Prediction Performance of DSSAT CSM-CERES-Wheat Model in Some Bread Wheat Varieties. *International Journal of Environment and Geoinformatics*, *10*(1), 51–66. https://doi.org/10.30897/ijegeo.1087591

[7] Badora, D., Wawer, R., Nieróbca, A., Król-Badziak, A., Kozyra, J., Jurga, B., & Nowocień, E. (2022). Simulating the Effects of Agricultural Adaptation Practices onto the Soil Water Content in Future Climate Using SWAT Model on Upland Bystra River Catchment. *Water*, *14*(15), 2288. https://doi.org/10.3390/w14152288

[8] Balaghi, R., Dahan, R., 2015. Potentialités D'adaptation et D'atténuation au Maroc.

[9] Barbour, N. , Miller, . Susan Gilson , Brown, . L. Carl , Laroui, . Abdallah and Swearingen, . Will D. (2024, January 22). Morocco. Encyclopedia Britannica. https://www.britannica.com/place/Morocco

[10]Bouignane A., (2010). Sècheresse dans le Bassin versant de Sebou, état actuel et perspective. ABHS. 27p.

[11]Bouslihim, Y., Kacimi, I., Brirhet, H., Khatati, M., Rochdi, A., Pazza, N. E. A., Miftah, A., & Yaslo, Z. (2016). Hydrologic Modeling Using SWAT and GIS, Application to Subwatershed Bab-Merzouka (Sebou, Morocco). Journal of Geographic Information System, 08(01), 20–27. https://doi.org/10.4236/jgis.2016.81002

[12]Briak, H., & Kebede, F. (2021). Wheat (Triticum aestivum) adaptability evaluation in a semi-arid region of Central Morocco using APSIM model. Scientific reports, 11(1), 23173. https://doi.org/10.1038/s41598-021-02668-3

[13]Brouziyne, Y., Abouabdillah, A., Hirich, A., Bouabid, R., Zaaboul, R., & Benaabidate, L. (2018). Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under

projected climate change scenarios. Agricultural Systems, 162, 154–163. https://doi.org/10.1016/j.agsy.2018.01.024

[14]Chai, Q., Gan, Y., Turner, N. C., Zhang, R.-Z., Yang, C., Niu, Y., & Siddique, K. H. M. (2014). Water-Saving Innovations in Chinese Agriculture. In Advances in Agronomy (Vol. 126, pp. 149–201). Elsevier. https://doi.org/10.1016/B978-0-12-800132-5.00002-X

[15]Deihimfard, R., Eyni-Nargeseh, H., & Mokhtassi-Bidgoli, A. (2018). Effect of Future Climate Change on Wheat Yield and Water Use Efficiency Under Semi-Arid Conditions as Predicted by APSIM-Wheat Model. *International Journal of Plant Production*, *12*(2), 115–125. https://doi.org/10.1007/s42106-018-0012-4

[16]Dettori, M., Cesaraccio, C., & Duce, P. (2017). Simulation of climate change impacts on production and phenology of durum wheat in Mediterranean environments using CERES-Wheat model. *Field Crops Research*, *206*, 43–53. https://doi.org/10.1016/j.fcr.2017.02.013

[17] Devkota, K. P., McDonald, A. J., Khadka, A., Khadka, L., Paudel, G., & Devkota, M. (2015). Decomposing maize yield gaps differentiates entry points for intensification in the rainfed mid-hills of Nepal. Field Crops Research, 179, 81–94. https://doi.org/10.1016/j.fcr.2015.04.013

[18]Devkota, K. P., McDonald, A. J., Khadka, L., Khadka, A., Paudel, G., & Devkota, M. (2016). Fertilizers, hybrids, and the sustainable intensification of maize systems in the rainfed mid-hills of Nepal. European Journal of Agronomy, 80, 154–167. https://doi.org/10.1016/j.eja.2016.08.003

[19]Devkota, M., Devkota, K. P., & Kumar, S. (2022). Conservation agriculture improves agronomic, economic, and soil fertility indicators for a clay soil in a rainfed Mediterranean climate in Morocco. *Agricultural Systems*, *201*, 103470. https://doi.org/10.1016/j.agsy.2022.103470

[20]Devkota, M., Devkota, K. P., Karrou, M., & Nangia, V. (2023a). Genotype and agronomic management interaction to enhance wheat yield and water use efficiency in the Mediterranean rainfed environment of Morocco: I. Field data analysis. *European Journal of Agronomy*, *151*, 126972. https://doi.org/10.1016/j.eja.2023.126972

[21]Devkota, M., Devkota, K. P., Karrou, M., & Nangia, V. (2023b). Genotype and agronomic management interaction to enhance wheat yield and water use efficiency in the Mediterranean rainfed environment of Morocco: I. Field data analysis. *European Journal of Agronomy*, *151*, 126972. https://doi.org/10.1016/j.eja.2023.126972

[22]Devkota, M., Devkota, K. P., Paudel, G. P., Krupnik, T. J., & McDonald, A. J. (2024). Opportunities to close wheat yield gaps in Nepal's Terai: Insights from field surveys, on-farm experiments, and simulation modeling. Agricultural Systems, 213, 103804. https://doi.org/10.1016/j.agsy.2023.103804

[23]Devkota, M., Singh, Y., Yigezu, Y. A., Bashour, I., Mussadek, R., & Mrabet, R. (2022). Conservation Agriculture in the drylands of the Middle East and North Africa (MENA) region: Past trend, current opportunities, challenges and future outlook. In *Advances in Agronomy* (Vol. 172, pp. 253–305). Elsevier. https://doi.org/10.1016/bs.agron.2021.11.001

[24]Dokoohaki, H., Gheysari, M., Mehnatkesh, A., & Ayoubi, S. (2015). Applying the CSM-CERES-Wheat model for rainfed wheat with specified soil characteristic in undulating area in Iran. *Archives of Agronomy and Soil Science*, *61*(9), 1231–1245. https://doi.org/10.1080/03650340.2014.984696

[25]Elrys, A. S., Raza, S., Abdo, A. I., Liu, Z., Chen, Z., & Zhou, J. (2019). Budgeting nitrogen flows and the food nitrogen footprint of Egypt during the past half century: Challenges and opportunities. Environment International, 130, 104895. https://doi.org/10.1016/j.envint.2019.06.005

[26]Eyshi Rezaie, E., & Bannayan, M. (2012). Rainfed wheat yields under climate change in northeastern Iran. *Meteorological Applications*, *19*(3), 346–354. https://doi.org/10.1002/met.268

[27]FAOSTAT, 2020. United Nations Food and Agricultural Organisation. Statistics on CropProduction. http://www.fao.org/faostat/en/#data/QC.

[28]Farooq, A., Farooq, N., Akbar, H., Hassan, Z. U., & Gheewala, S. H. (2023). A Critical Review of Climate Change Impact at a Global Scale on Cereal Crop Production. Agronomy, 13(1), 162. https://doi.org/10.3390/agronomy13010162

[29]Fayed, T. B., El-Sarag, E. I., Hassanein, M. K., & Magdy, A. (2015). Evaluation and prediction of some wheat cultivars productivity in relation to different sowing dates under North Sinai region conditions. *Annals of Agricultural Sciences*, *60*(1), 11–20. https://doi.org/10.1016/j.aoas.2014.12.001

[30]Fouad, S. S., Heggy, E., Ramah, M., Abotalib, A. Z., Palmer, E. M., Jomaa, S., & Weilacher, U. (2023). Egypt's waterways conservation campaigns under growing intrinsic demand and Nile upstream damming. Journal of Hydrology: Regional Studies, 50, 101537. https://doi.org/10.1016/j.ejrh.2023.101537

[31]Gardi, M. W., Memic, E., Zewdu, E., & Graeff-Hönninger, S. (2022). Simulating the effect of climate change on barley yield in Ethiopia with the DSSAT-CERES-Barley model. *Agronomy Journal*, *114*(2), 1128–1145. https://doi.org/10.1002/agj2.21005

[32]Gatti, R., Lederman, D., Islam, A., Bennett, F., Andree, B. P. J., Assem, H., Lotfi, R., & Mousa, M. (2023). *Altered Destinies: The Long-Term Effects of Rising Prices and Food Insecurity in the Middle East and North Africa*. The World Bank. https://doi.org/10.1596/978-1-4648-1974-2

[33]Gharous, M. E., & Boulal, H. (2016). IPNI North Africa Challenges in Nutrient Management Under Rainfed Agriculture of Morocco. *Procedia Engineering*, *138*, 332–336. https://doi.org/10.1016/j.proeng.2016.02.093

[34]Godwin DC, Ritchie JT, Singh U, Hunt L. 1989. A user's guide to CERES-Wheat. Vol. v2:10. Muscle Shoals (AL): International Fertilizer Development Center.

[35] Government of Morocco, 2009. https://www.environnement.gov.ma/PDFs/EAU/STRATEGIE_EAU.pdf

[36] Govind, A., Wery, J., Dessalegn, B., Elmahdi, A., Bishaw, Z., Nangia, V., Biradar, C., Nisa, Z. U., Abay, K., Amarnath, G., Breisinger, C., Ibrahim, N. A., Kleinermann, C., Niane, A. A., & Thijssen, M. (2021). A Holistic Framework towards Developing a Climate-Smart Agri-Food System in the Middle East and North Africa: A Regional Dialogue and Synthesis. *Agronomy*, *11*(11), 2351. https://doi.org/10.3390/agronomy11112351

[37]Halima, O. I., Iaaich, H., Kerfati, A., Naaman, M., & Jnad, I. (2021). Application of FAO-AquaCrop model in evaluating climate change impact on wheat productivity in the rainfed Zaer area. . . *P.*

[38]Huang, W., Liu, Q., & Abu Hatab, A. (2023). Is the technical efficiency green? The environmental efficiency of agricultural production in the MENA region. *Journal of Environmental Management*, *327*, 116820. https://doi.org/10.1016/j.jenvman.2022.116820

[39]IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. (First). Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647

[40]*Irrigation management in Morocco*. (n.d.).

[41]Ishaque, W., Osman, R., Hafiza, B. S., Malghani, S., Zhao, B., Xu, M., & Ata-Ul-Karim, S. T. (2023). Quantifying the impacts of climate change on wheat phenology, yield, and evapotranspiration under irrigated and rainfed conditions. *Agricultural Water Management*, *275*, 108017. https://doi.org/10.1016/j.agwat.2022.108017

[42]Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., Wilkens, P. W., Singh, U., Gijsman, A. J., & Ritchie, J. T. (2003). The DSSAT cropping system model. *European Journal of Agronomy*, *18*(3–4), 235–265. https://doi.org/10.1016/S1161-0301(02)00107-7

[43]Kheir, A. M. S., Alrajhi, A. A., Ghoneim, A. M., Ali, E. F., Magrashi, A., Zoghdan, M. G., Abdelkhalik, S. A. M., Fahmy, A. E., & Elnashar, A. (2021). Modeling deficit irrigation-based evapotranspiration optimizes wheat yield and water productivity in arid regions. *Agricultural Water Management*, *256*, 107122. https://doi.org/10.1016/j.agwat.2021.107122

[44] Kheir, A.M.S., El Baroudy, A., Aiad, M.A., Zoghdan, M.G., Abd El-Aziz, M.A., Ali, M., Fullen, M.A., 2019. Impacts of rising temperature, carbon dioxide and sea level on wheat production in North Nile delta. Sci. Total Environ. 651, 3161–3173.https://doi.org/ 10.1016/j.scitotenv.2018.10.209

[45]Lightfoot, D. R. (1996). Moroccan khettara: Traditional irrigation and progressive desiccation. Geoforum, 27(2), 261–273. https://doi.org/10.1016/0016-7185(96)00008-5

[46]Lorite, I. J., Castilla, A., Cabezas, J. M., Alza, J., Santos, C., Porras, R., Gabaldón-Leal, C., Muñoz-Marchal, E., & Sillero, J. C. (2023). Analyzing the impact of extreme heat events and drought on wheat yield and protein concentration, and adaptation strategies using long-term cultivar trials under semi-arid conditions. Agricultural and Forest Meteorology, 329, 109279. https://doi.org/10.1016/j.agrformet.2022.109279

[47]Malagó, A., & Bouraoui, F. (2023). Forty years of anthropogenic nutrient pressures: Agriculture and domestic nitrogen and phosphorus inventory in view of sustainable nutrient management. *Frontiers in Sustainable Food Systems*, *7*, 1062435. https://doi.org/10.3389/fsufs.2023.1062435

[48]Malik, W., & Dechmi, F. (2019). DSSAT modelling for best irrigation management practices assessment under Mediterranean conditions. *Agricultural Water Management*, *216*, 27–43. https://doi.org/10.1016/j.agwat.2019.01.017

[49]Mamassi, A., Balaghi, R., Devkota, K. P., Bouras, H., El-Gharous, M., & Tychon, B. (2023). Modeling genotype × environment × management interactions for a sustainable intensification under rainfed wheat cropping system in Morocco. *Agriculture & Food Security*, *12*(1), 22. https://doi.org/10.1186/s40066-023-00428-2

[50]Martiniello, P. (2012). Cereal-forage crop rotations and irrigation treatment effect on water use efficiency and crops sustainability in Mediterranean environment. *Agricultural Sciences*, *03*(01), 44–57. https://doi.org/10.4236/as.2012.31007

[51]Mateo-Sagasta, J., Al-Hamdi, M., & AbuZeid, K. (Eds.). (2022). *Water reuse in the Middle East and North Africa: A sourcebook*. International Water Management Institute (IWMI). https://doi.org/10.5337/2022.225

[52]Moradi, L., Siosemardeh, A., Sohrabi, Y., Bahramnejad, B., & Hosseinpanahi, F. (2022). Dry matter remobilization and associated traits, grain yield stability, N utilization, and grain protein concentration in wheat cultivars under supplemental irrigation. *Agricultural Water Management*, *263*, 107449. https://doi.org/10.1016/j.agwat.2021.107449

[53]Moragues, M., García Del Moral, L. F., Moralejo, M., & Royo, C. (2006). Yield formation strategies of durum wheat landraces with distinct pattern of dispersal within the Mediterranean basin. *Field Crops Research*, *95*(2–3), 182–193. https://doi.org/10.1016/j.fcr.2005.02.008

[54]Mrabet, R., Moussadek, R., Fadlaoui, A., & Van Ranst, E. (2012). Conservation agriculture in dry areas of Morocco. *Field Crops Research*, *132*, 84–94. https://doi.org/10.1016/j.fcr.2011.11.017

[55]Organisation des Nations Unies pour l'alimentation et l'agriculture (Ed.). (2014). *Climate-smart agriculture sourcebook*. FAO.

[56]Pala, M., Oweis, T., Benli, B., De Pauw, E., El Mourid, M., Karrou, M., Jamal, M., and Zencirci, N. (2011). Assessment of wheat yield gap in the Mediterranean: case studies from Morocco, Syria and Turkey. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. iv + 36 pp.

[57]Research Institute (Ifpri), I. F. P. (2018). *Agriculture and economic transformation in the Middle East and North Africa: A review of the past with lessons for the future* (0 ed.). International Food Policy Research Institute. https://doi.org/10.2499/9780896292956

[58]Segurado, P., Almeida, C., Neves, R., Ferreira, M. T., & Branco, P. (2018). Understanding multiple stressors in a Mediterranean basin: Combined effects of land use, water scarcity and nutrient enrichment. *Science of The Total Environment*, *624*, 1221–1233. https://doi.org/10.1016/j.scitotenv.2017.12.201

[59]Sikora, A. (2021). European Green Deal – legal and financial challenges of the climate change. ERA Forum, 21(4), 681–697. https://doi.org/10.1007/s12027-020-00637-3

[60]UnNisa, Z., Govind, A., Marchetti, M., & Lasserre, B. (2022). A review of crop water productivity in the Mediterranean basin under a changing climate: Wheat and barley as test cases. *Irrigation and Drainage*, *71*(S1), 51–70. https://doi.org/10.1002/ird.2710

[61]Vanli, Ö., Ustundag, B. B., Ahmad, I., Hernandez-Ochoa, I. M., & Hoogenboom, G. (2019). Using crop modeling to evaluate the impacts of climate change on wheat in southeastern turkey. Environmental Science and Pollution Research, 26(28), 29397–29408. https://doi.org/10.1007/s11356-019-06061-6

[62]Waffa, R., & Benoit, G. (2015). *SIMULATION OF CLIMATE CHANGE IMPACT ON WHEAT PRODUCTION IN THE TIARET REGION OF ALGERIA USING THE DSSAT*. https://eujournal.org/index.php/esj/article/view/5293

[63]Wheeler, T. R., Craufurd, P. Q., Ellis, R. H., Porter, J. R., & Vara Prasad, P. V. (2000). Temperature variability and the yield of annual crops. Agriculture, Ecosystems & Environment, 82(1–3), 159–167. https://doi.org/10.1016/S0167-8809(00)00224-3

[64]White, J. W., Hoogenboom, G., Kimball, B. A., & Wall, G. W. (2011). Methodologies for simulating impacts of climate change on crop production. *Field Crops Research*, *124*(3), 357–368. https://doi.org/10.1016/j.fcr.2011.07.001

[65] Willmott, C. J. (1982). Some comments on the evaluation of model performance. Bulletin of the American Meteorological Society, 63(11), 1309-1313. https://doi.org/10.1175/1520-0477(1982)063<1309:SCOTEO>2.0.CO;2

[66]Woli, P., Smith, G. R., Long, C. R., Rudd, J. C., Xue, Q., & Rouquette Jr., F. M. (2023). Exploring the Potential of Cowpea-Wheat Double Cropping in the Semi-Arid Region of the Southern United States Using the DSSAT Crop Model. Agricultural Sciences, 14(01), 35–57. https://doi.org/10.4236/as.2023.141004

[67]World Bank. (2018). *Beyond Scarcity: Water Security in the Middle East and North Africa*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1144-9

[68]Yeşilköy, S., & Demir, I. (2023). Crop Yield Prediction based on Reanalysis and Crop Phenology Data in the Agroclimatic Zones [Preprint]. Agriculture. https://doi.org/10.31223/X5BW8H

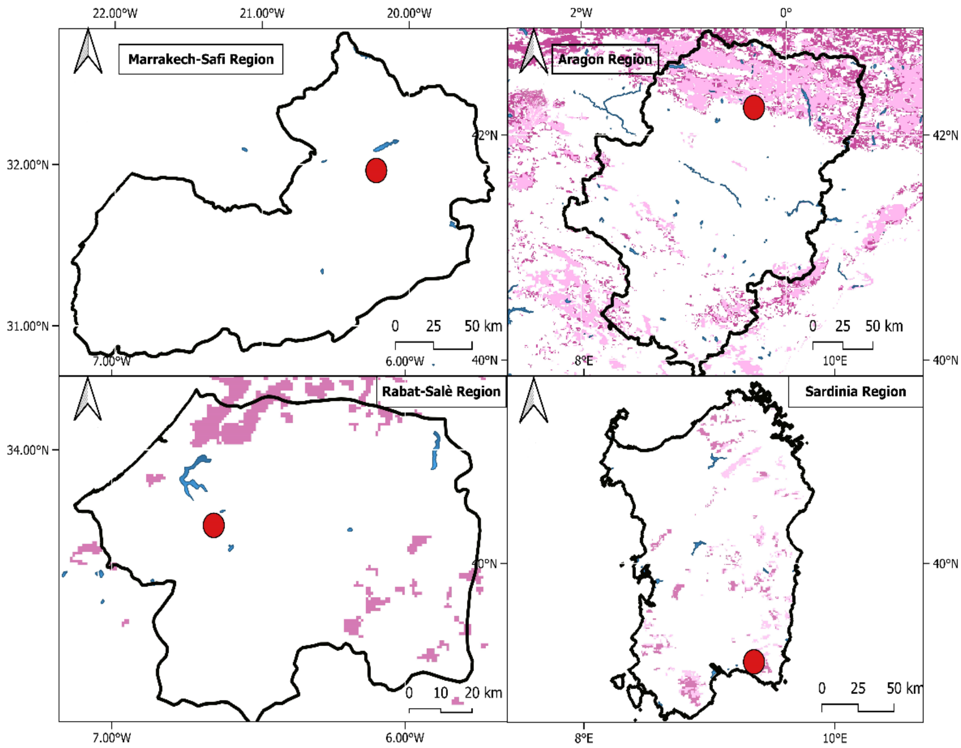
[69]Yeşilköy, S., & Şaylan, L. (2021). Yields and water footprints of sunflower and winter wheat under Different Climate Projections. *Journal of Cleaner Production*, *298*, 126780. https://doi.org/10.1016/j.jclepro.2021.126780

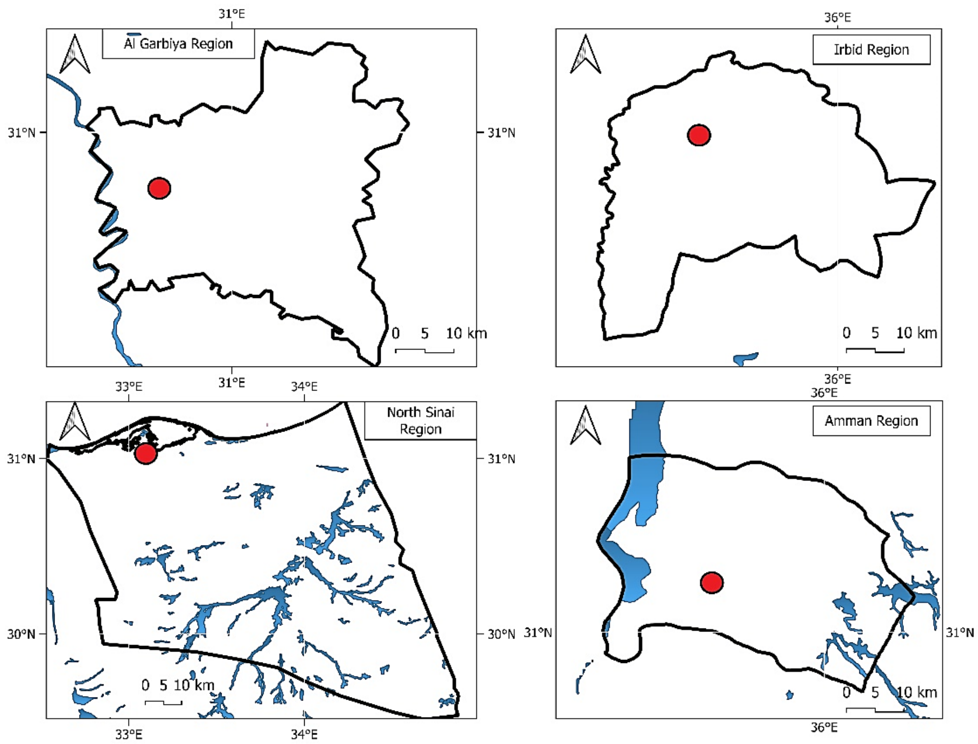
Annexes

Annex 1 - Research Planning

Phase	Duration	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Meeting
Orientation phase	1M before								1
Proposal writing	4-6 weeks								1
Proposal approval by examiner	Before start								1
Training DSSAT model	15 days								1-2
Meetings of the organisation									Once a week
Mid-term evaluation	-								1
Data collection	4-8 weeks								2
Data analysis	4-6 weeks								2
Report writing	6-8 weeks								1
Schedule colloquium	3-4 weeks								-
Final draft submission	2 w before								1
Corrected paper submission	1 w before								-
Examination	-								1

Annex 2 - Supplementary figures from the location of the selected areas





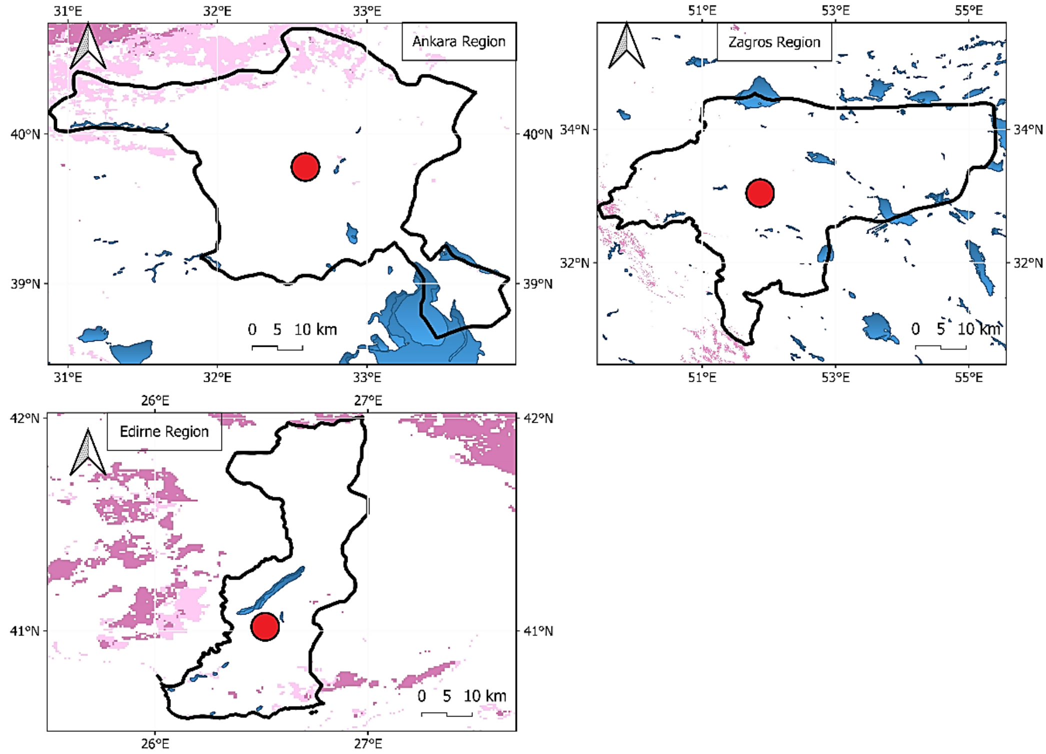


Figure 1. Case studies a) Morocco, Italy, and Spain case studies b) Egypt and Jordan case studies c) Turkey and Iran