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CLIMATE RESILIENT AGRICULTURE: TRANSLATING DATA TO POLICY ACTIONS

Case Study of AquaCrop Simulation in Jordan

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Overview

Within the framework of an initiative supported by the Swedish International Development Cooperation Agency (Sida) on "Promoting food and water security through cooperation and capacity development in the Arab region", ESCWA prepared reports on the impact of changing water availability due to climate change on agricultural production in selected Arab countries.

A technical country team[1] was established and trained by ESCWA, the Food and Agriculture Organization (FAO) and the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) to assess the impact of projected climate change, expressed in terms of water availability, temperature and carbon dioxide (CO_2) changes, on selected crops and locations in Jordan. The assessment findings, derived from a national case study report[2], are used as a baseline to recommend adaptation measures to key actors in promoting water and food security under changing climate.

The assessments used the AquaCrop simulation programme developed by FAO. The assessments were carried out on selected irrigated and rainfed crops to identify the impact of climate change on crop productivity. The programme used the climate-variable projections of the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR)[3], while soil, yield and crop data were acquired from national sources. The climate change projections correspond to representative concentration pathways (RCP), i.e., greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change, of two levels: RCP 4.5: generally describing a moderate-emissions scenario; and RCP 8.5: generally describing a high-emissions or 'business-as-usual' scenario. In a way, RCP 4.5 and RCP 8.5 correspond to a more 'optimistic' and more 'pessimistic' scenario, respectively. The time horizons for the two RCPs consider the periods 2020-2030 (represented by 2025) and 2040-2050 (represented by 2045). Furthermore, to analyse the effect of elevated CO_2 on crop yield loss, two sets of projected CO_2 concentration changes, for each of the RCP scenarios, were simulated: one which considered the effects of increasing CO_2 concentrations; and another which kept CO_2 concentrations at the baseline level.

The present case study provides a general background of the assessment, and the main findings of the AquaCrop simulation undertaken to identify a variety of country-specific recommendations on adaptation measures in the agricultural sector.

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1. Country Background

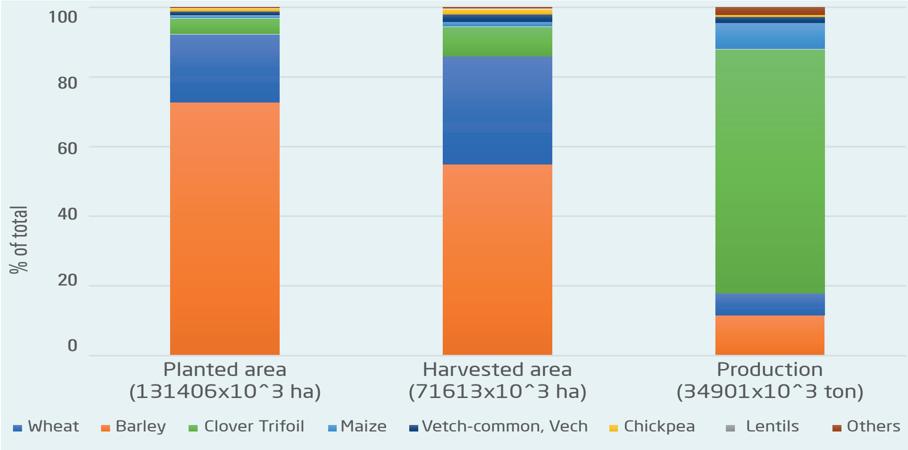
The total area of Jordan is about 8.9 million hectares of which about 10% are arable. Cultivated land in 2015 accounted for 30% of the arable area and 3% of the total area of Jordan. In 2016, the cultivated area with field crops reached around 135 thousand hectares, vegetables 50.5 thousand hectares, and fruit trees 86.7 thousand hectares.

There are three main climatic geographic zones in Jordan, the Jordan valley, the highlands, and the Badia. The Jordan Valley is the most fertile area in the country and has the advantage of early vegetables and fruits production with irrigation mainly practiced in the area. The highlands extend from north to south in the western part of Jordan, separating the Jordan Valley from the Badia region. The highlands have relatively higher level of rainfall. Badia, an arid and semiarid area, covers 88% of the total area of Jordan where the rainfall rate does not exceed 100 mm/year.

The agricultural sector is an essential part of the Jordanian export sector, amounting to 21% of Jordan's total exports and employs around 80,000 families in rural areas. Due to the challenges faced by the agricultural sector, its contribution to the GDP at the current market prices was around 6.2% in 2006 and decreased to 4% in 2017.

The sector faces several challenges, primarily seasonal rainfall fluctuations, occasional successive years of drought, scarcity of water resources, fragmentation of property and small production units. The challenges are most severely felt by women and youth as shown in Box 1.

Figure 1. Percentage distribution of total planted and harvested areas, and production for different crops in Jordan (adopted from Jordan General Statistics Department, 2015).



2. Selected Crops and Areas for AquaCrop Simulations

For this study, two major cropping systems were selected:

(1) Irrigated tomatoes in Mafraq region, Dafayana area, the north-eastern part of the Hashemite Kingdom of Jordan
(2) Rainfed wheat in governorate of Madaba

Mafraq region has a desert climate, with hot summer and extreme cold in the winter. It is characterized as an agricultural area and is famous for cereal cultivation, especially wheat and barley and vegetable crops of which tomatoes. Average tomato production in the Mafraq region is around 106,630 tons/year and accounts for 36% of the entire vegetable crop production in the governorate. The cultivation of tomatoes in Mafraq area relies on drip irrigation from groundwater sources, and are grown over two main periods; summer (March to August) and winter (October to March) with 80% of the seasonal rainfall occurring through the months of December to March[4].

The governorate of Madaba is characterized by the diversity of its terrain, as it is famous for its wide, flat plains, which provide Jordan with ample quantities of cereals, and represents just 7% of the cultivated area in Jordan.

Box 1. Women and youth empowerment

In 2016, Jordan ranked 134 in the Global Gender Gap Index, and second last in female labour force participation reaching 15%. According to Jordan Vision 2025 estimates, increasing women's participation in labour market to 24% may increase Jordan's annual GDP by 5% (UN women, 2016).

Women in rural areas of Jordan are the most vulnerable to climate change as their livelihoods depend on threatened natural resources. In addition, women face many social, economic, and political barriers that hinder their empowerment. Nonetheless, Jordan was the first MENA country to mainstream gender issues in its National Climate Change Policy, identifying women as main contributors to agricultural sector (farmers, livestock herders, workers, and entrepreneurs) and yet the most impacted by climate change (UN women, 2016). The Government of Jordan has further strengthened its commitment gender equality and women's social and economic empowerment through Jordan's Renaissance Plan 2019-2020 (WB,2020).

In June 2020, a Memorandum of Understanding was signed by the ILO, Jordan's Ministry of Labor, and the Vocational and Technical Skills Development Commission to improve youth employment in the agricultural sector. Six agricultural guidance and support offices were established in Jordanian districts (Mafraq, Irbid, Zarqaa and Balqaa) that aim at providing employment services to employers and employees and assistance in access to social security coverage. This initiative is expected to enhance the employment of 500 young Jordanians who have completed the "Khedmat Watan" program; a government-led initiative, providing vocational training opportunities for the youth (aged 18-27) (ILO,2020)

Source: UN Women Jordan, 2016, Rural women and climate change in Jordan
World Bank, 2020. Women's economic empowerment in Jordan
https://openknowledge.worldbank.org/handle/10986/33587
ILO report, 2020. https://www.ilo.org/beirut/media-centre/news/WCMS_746962/lang--en/index.htm

3. Assessment methodology

The assessment aimed to evaluate the impacts of climate change on agriculture productivity using the AquaCrop simulation program (version 6)[4], and the climate-variables projections of the RICCAR Initiative on Climate Change in the Arab Region, led by ESCWA, to assist in shaping evidence based agricultural strategies.

The steps involved in the use of AquaCrop were as follows:

- **Data collection** was required for climate, soil, and crop types. The required daily climate data inlcuded maximum and minimum temperatures, wind speed, relative humidity, solar radiation and rainfall. In the Mafraq study area, climatic data recorded in the meteorological station were used covering the period of 2007-2016 (the period for which climate data are available) and summer cultivation season was from 20 March to 9 August for irrigated tomato crop. For Madaba area, daily climatic data were retrieved from the weather station at the Ministry of Water and Irrigation that covers the period 1998 -2014 based on data availability. Soil data for both areas were collected from the National Soil Survey Project at the Ministry of Agriculture (1993).
- **Calibration** of AquaCrop to simulate the productivity of the two selected crops under local conditions, using 10 years of field data (from 2007-2016) in Mafraq area and 12 years of field data (1998-2014) in Madaba area, including soil characteristics, groundwater depth, irrigation scheduling, main farm-management practices, climate data and crop yield. The objective of such calibration was to provide the model with actual parameters that can simulate the actual productivity of the three crops within an acceptable accuracy range. The calibrated model was then used to simulate the crop yield under future climate change .
- **Simulation** of the impacts of climate change on the productivity of two crops using the prediction of the RICCAR project for two periods: the 2020 -2030 (represented by 2025) and the 2040-2050 (represented by 2045) and for two scenarios RCP 4.5 and RCP 8.5. The reference period is the 1986-2005. Moreover, two sets of projected changes were implemented: one which considered the effects of both CO_2 concentrations and associated climatic changes (temperature and water); and one which considered temperature and water changes only and no change in CO_2 concentrations (i.e., keeping CO_2 concentrations at the baseline level). This allowed to disaggregate the mitigating effect of increased CO_2 on yield losses derived by adverse impacts of temperature rise and water scarcity, and account for related uncertainties.
- **Testing adaptation measures** to overcome the impacts of reduced water availability due to climate change by using one deficit irrigation measure: reducing irrigation for tomato crop by 17 % of the allocated irrigation amount for both RCP scenarios and both periods.

4. Description of Assessment Findings

Overall, the assessment clearly shows a decrease in the projected irrigated tomato yields in both periods and scenarios, with fixed CO_2 concentration, is indicative effects of rising max. and min. temperatures and variation in rainfall. In case of changing CO_2 concentration, the increase in the projected irrigated tomato yield in both periods and scenarios is an indication of the positive effect of this increase on photosynthesis and biomass production which outweighs the negative impact of climate on tomato yield in Mafraq area.

The increase in the simulated rainfed wheat yield in the 2025 and 2045 periods, in both scenarios, with fixed CO_2 concentration, is due to the shift in rainfall towards the mid-wheat growing season and thereafter (i.e., during the flowering, reproduction and grain-filling phases). This has led to an increase in wheat yield and water productivity in Madaba region.

Shortening of the length of the growing season for tomatoes and wheat in both periods and scenarios under fixed and changing CO_2 concentration (compared to the reference period-1986-2005) is due to the anticipated higher temperatures leading to a reduction in operational costs in the field.

- **MAFRAQ SITE FINDINGS**

Rainfall projections show inconsistent patterns, in both climate change scenarios (RCP 4.5 and RCP 8.5) and both periods (2025 and 2045). The annual average production rate for tomatoes is 4.25 ton/ha. The results of the crop model productivity simulations showed that actual and simulated values differ averagely by 0.05 ton/ha with Pearson correlation coefficient of about 0.7.

Climate variable projections

For the irrigated tomato planted in the summer season in the Mafraq region, RCP 4.5 simulations indicate a slight increase in seasonal rainfall during the 2025 period in both the CNRM (5.4mm) and EC-Earth (2.8mm) models, and a decrease in seasonal rainfall in the GDFL (-3.9 mm) model. For the 2045 period, seasonal precipitation in all climatic models is slightly reduced. The RCP 8.5 simulations indicate a decrease in seasonal rainfall during the 2025 period in both CNRM (-7.9mm) and EC-Earth (-0.8mm) models, and an increase in seasonal rainfall in the GFDL (2.1 mm) model. For the 2045 period, seasonal precipitation increases in CNRM (3mm) and GFDL (4.8mm) models and decreases in the EC-Earth (5.2 mm) model.

Regarding temperature, there is an increase in max and min values for both RCP and periods.

Crop productivity

The yield of irrigated tomato is expected to insignificantly decline for both periods and scenarios in case of fixed CO_2 concentration. The apparent slight decrease in productivity for irrigated tomato culture, is mainly due to the shortening of the crop cycle duration, as compared to the reference period, due to the expected increase in temperature. In case of changing CO_2 concentration, productivity increases significantly for both periods and scenarios.

This is an indication of the positive effect of this increase on photosynthesis and biomass production which outweighs the negative impact of climate on tomato yield in Mafraq area. Further impacts of the model in comparison to the reference period (1986-2005) are addressed in box 2.

- **MADABA SITE FINDINGS**

In Madaba area, under both scenarios, RCP 4.5 and RCP 8.5, increase in max. and min. temperatures are projected and a shift in rainfall towards the mid-wheat growing season and beyond. The results of the crop model productivity simulations showed that the actual and simulated annual average production rate of rainfed wheat differ averagely by 0.05 ton/ha with a correlation coefficient of about 0.7 (reference production of 0.07 ton/ha for rainfed wheat).

Climate variable projections

RCP 4.5 simulations indicate a slight increase in seasonal rainfall during the 2025 period under all climatic models. For the 2045 period, seasonal precipitation decreases in the CNRM (-8.2mm) and GFDL (-15.9mm) models and increases in the EC-Earth (52.4mm) model. The RCP 8.5 simulations indicate a decrease in seasonal rainfall during the 2025 period in CNRM (-4.2mm) model and increase in seasonal rainfall in the GFDL (2.3 mm) and EC-Earth (38.6mm) models . For the 2045

Box 2. Main Findings of AquaCrop Simulation in Mafraq

- Under the RCP 4.5 scenario:

The length of the growth season for irrigated tomatoes decreases by 2 and 4 days for the 2025 and 2045 periods, respectively.

The productivity of irrigated tomato decreases by 1 and 3.1 % for 2025 and 2045 periods, respectively, in case of fixed CO_2. In case of changing CO_2, productivity increases significantly by 12.8 and 17.6%, for the 2025 and 2045 periods, respectively.

Crop water productivity of irrigated tomatoes decreases from 0.91 kg/m^3 to 0.89 kg/m^3 in 2045 period. In case of changing CO_2, crop water productivity increases from 0.94 kg/m^3 to 1.06 and 1.11 kg/m^3 for both periods, respectively.

- Under the RCP 8.5 scenario:

The length of the growth season for tomatoes decreases by 2 days for the two periods.

The productivity of irrigated tomato decreases by 2.1 and 2.6%, respectively, for 2025 and 2045 periods, respectively in case of fixed CO_2. In case of changing CO_2, productivity increases significantly by 13.1 and 21.3% for both periods, respectively.

Crop water productivity of irrigated tomatoes decreases insignificantly from 0.91 Kg/m^3 to 0.90 Kg/m^3 for the 2025 period and decrease significantly for the 2045 period reaching 0.88 Kg/m^3. In case of changing CO_2, crop water productivity increases significantly from 0.94 to 1.08Kg/m^3 and 1.13 kg/m^3 during the two periods, respectively.

period, seasonal precipitation increases in CNRM (7mm) and EC-Earth (36.6mm) models whereas it decreases in the GFDL (-15.9mm) model.

Regarding temperature, the increase in max. values is projected between 0.5 °C - 1.3 °C, while the min. temperature is expected to increase by 0.3-0.9 °C.

Crop productivity

The yield of rainfed wheat is expected to increase for periods and scenarios with higher yield expected for RCP4.5 (increase by 34% in 2025 period and by 48% in 2045 period), as compared to the reference period in case of fixed CO_2 concentration. Similarly, water productivity is expected to increase for both periods and scenarios with fixed CO_2 concentration. These observed yield increase for rainfed wheat are explained by the shift in rainfall towards the mid-wheat growing season and thereafter (i.e., during the flowering, reproduction and grain-filling phases). Further impacts of the model in comparison to the reference period (1986-2005) are addressed in box 3.

Box 3. Main Findings of AquaCrop Simulation in Madaba

- Under the RCP 4.5 scenario:

  The length of the wheat-growing season is reduced by 3 and 5 days for 2025 and 2045 periods, respectively. In case of changing CO_2, length of the season is insignificantly reduced by 2 and 4 days for both periods, respectively.

  Productivity of rainfed wheat increases by about 33.77 and 48.26% for 2025 and 2045 periods, respectively. In case of changing CO_2, productivity increases by 53.53 and 81.59%, respectively, for both time periods.

  Crop water productivity of rainfed wheat increases from 0.18 Kg/m^3 to 0.22 and 0.25 Kg/m^3 for 2025 and 2045 periods, respectively. In case of changing CO_2, crop water productivity increases to 0.26 and 0.31 Kg/m^3 for both periods, respectively.

- Under the RCP 8.5 scenario:

  The length of the wheat-growing season is reduced by 2 and 6 days for 2025 and 2045 periods, respectively. In case of changing CO_2, length of the season is reduced by 3 and 5 days for both periods, respectively.

  The productivity of rainfed wheat increases by 32.1 and 36.5% for the 2025 and 2045 periods, respectively. In case of changing CO_2, productivity increases by 42.4 and 73.9% for both periods, respectively.

  Crop water productivity of rainfed wheat increases from 0.17 Kg/m^3 during the reference period to 0.21 and 0.23 kg/m^3, respectively, for 2025 and 2045 periods. In case of changing CO_2, crop water productivity increases to 0.24 and 0.29 Kg/m^3 for both periods, respectively.

- **Applying deficit irrigation**

Simulations for deficit irrigation application were undertaken by decreasing irrigation of tomato crops by approximately 17%. This method was used as an adaptation measure to improve the productivity of irrigated tomato. Further impacts of the model in comparison to the reference period (1986-2005) are addressed in box 4.

Box 4. Main Findings of Applying deficit irrigation

- Under the RCP 4.5 scenario:

  Tomato crop productivity reduced significantly by around 7.5 and 8.7%, for both periods, respectively, compared to its productivity in the reference period at full irrigation.

- Under the RCP 8.5 scenario:

  Tomato crop productivity reduced significantly by around 6.1 and 6.3% for both periods compared to its productivity in the reference period at full irrigation.

5. Analysis of Assessment Findings

The assessment study applied AquaCrop simulation model to identify the impacts of climate change on crop productivity for two major cropping systems in two regions of Jordon. The impact of rising temperatures observed in both climate change scenarios, and the uncertain decrease in rainfall for irrigated tomato, were found not to be significant. As the country's self-sufficiency in tomato production was around 337.4% in 2013, tomato exports can still be considered a good source of income, without jeopardizing food security. As such, minor reduction in the yield of tomato crops is unlikely to pose any concern for Jordan's agricultural sector.

There is a need to promote investments in irrigated areas for modernization of irrigation systems to increase land and water productivity, while establishing proper water accounting systems to monitor water resources availability and control water allocations to the irrigation sectors within sustainable limits of water consumption. For instance, the cultivation of tomatoes in Mafraq area relies on drip irrigation from groundwater sources. Groundwater sources are in fact facing many challenges of overexploitation in Jordan and there is a need to reduce stress on groundwater resources and enhance the use of surface water (Jordan River and its tributaries, Yarmouk and Zarga). There is also a need to find unconventional methods for irrigation such as expanding the use of treated wastewater in line with norms and standards of safety.

Further analysis and simulation using AquaCrop are required to compare and determine which species are most adapted to future climatic conditions. A number of strategic agricultural crops in Jordan and different regions require further research to better identify the impacts of climate change on crop productivity. For example, the areas of Mafraq and Madaba showed essential differences in the expected rainfall pattern. This difference resulted in a decrease in tomato yield in the case of fixed CO_2 concentration and increased wheat yield in both cases of fixed and changing CO_2 concentration. For this, data collection and availability are critical to enhance and expand the application of AquaCrop.

For the rainfed wheat, the results showed an increase in yield due to the shift in rainfall period to the mid of growing season and thereafter (i.e., during the flowering, reproduction, and grain-filling phases). The shortening of the growing-season duration, as well as the effect of high temperature on vegetation, might have a moderate impact on yield and its quality. Scaling up conservation-agriculture practices in rainfed areas, modifying seeding dates to account for shifting periods of rainfall, and using of resistent crop varieties are venues to explore for ensuring food security status in Jordan.

Further, application of supplemental irrigation when rainfall does not provide sufficient moisture through on-farm rainwater harvesting and management system may also reduce stress on rainfed agriculture.

Box 5. Economic Impact of Climate Change on Agriculture sector

The agricultural sector plays a clear role socially and economically, especially in rural communities where it employs around 80,000 families thus limiting migration to urban areas. The Jordanian statistics of foreign trade has indicated that between the years 2006-2015, the total value of agricultural exports increased from 451 million dinars to 1,010.03 million dinars, an increase of approximately 124%. Due to the challenges faced by the agricultural sector, the contribution of the agricultural sector to the GDP at the current market prices was around 6.2% in 2006 and decreased to 4% (1140.2 million dinars) in 2017.

Jordan reached 337.4% self-sufficiency in the production of tomato crops in 2013, and 70% of the agricultural products were exported to various international markets, notably the Gulf countries and Europe. In 2015, the average production of tomatoes reached 870 thousand tons, representing 42% of the total production of vegetable crops in Jordan, which amounted to 2 million tons of the same year.

In 2017, Jordan imported 902,496 tons of wheat, amounting to 190.705 million $, or 0.921% of the country's imports (FAOSTAT, November 2019). Wheat yield increase by more than 30% could improve the country's balance of trade position to a significant extent. In fact, a large increase in local production of wheat could help cover this import gap to a significant extent and help soften the burden of a big balance of trade deficit, estimated at 12.53 billion $ (Observatory of Economic Complexity, December 2019), amounting to roughly 31.27% of GDP.

Sources:

Food and Agriculture Organization of the United Nations, FAOSTAT Trade: crops and livestock products, November 2019, available at: www.fao.org/faostat/en/#data/TP

Observatory of Economic Complexity, Jordan country profile, December 2019, available at: https://oec.world/en/profile/country/jor/

6. Simulation of supplementary and deficit irrigation applications as adaptation measures

As part of the ESCWA project on "Enhancing resilience and sustainability of agriculture in the Arab region" further trainings were undertaken to enhance capacities of Jordanian officials on the use of the AquaCrop model for irrigation management (supplementary and deficit irrigation) as an adaptation measure. As a result, two case study were prepared for potatoes in Deir Alla/Balqaa and wheat in Naour using AquaCrop for simulating different irrigation management patterns (irrigation at 71%, 62% and 53%) together with impact of enhancing soil fertility levels of "near optimal" (79%) and non-limiting" 100% levels as compared to current irrigation pattern and fertility level (moderate at 61%).

- **Impact of supplementary irrigation on productivity of rainfed wheat in Naour**

The study was conducted for the 2009-2018 period for which a nearby weather station was used to account for missing climatic data (min and max temperatures) and to form relationships and identify missing inputs. Al-Mashqar Agricultural Research Station data (2009-2019) was used to input crop, soil, and management data. The calibrated model performed well with a RMSE of 0.23 and an r of 0.9 after removing outliers.

The real time simulation of impact of application of two different fertilization levels (near optimal and nonlimiting) from studied period on yield and water

Table 1. Application of supplementary irrigation on wheat yield at various fertilization level

Simulation Procedure*	Qty of water for irrigation (MM)	Change in Yield productivity %			Change in Water Productivity %		
		Moderate Fertility	Near Optimal Fertility	Non-Limiting Fertility	Moderate Fertility	Near Optimal Fertility	Non-Limiting Fertility
Rainfed	0	Reference	15	29	Reference	14	26
Supplementary irrigation	60	28	58	87	9	34	57

*All values are averaged over 2009-2018

Box 6. Proposed adaptation measures for Wheat production using supplementary irrigation

To study the economic feasibility of the two proposed options to assess applicability.

Application of supplementary irrigation without increasing fertility whereby we an increase in yield productivity by 28% and water productivity by 9% is registered.

Increasing the level of fertility without applying supplementary irrigation as this option increases productivity by 29% and water productivity by 26%.

productivity were compared to the reference moderate fertility levels used by farmers in the area. For each case, application of supplementary irrigation when the soil moisture in the root zone approaches 10 mm above the wilting point (except for year 2013-2017 that required two application of supplementary irrigation) was assessed to identify its impact on both yield and water productivity. Simulation results using different deficit irrigation scenarios are available in table 1 and related proposed adaptation measures by country team in box 6.

- **Impact of deficit irrigation on productivity of drip irrigated potato in Deir Alla/ Balqaa**

The study was conducted over the 2006-2015 period for which climatic data was available from the meteorological station in the Deir Alla region. Other data including crop yield, and soil management information were retrieved from the department of statistics (2015) and Ministry of Agriculture, respectively. The calibrated model performed well with a RMSE of 1.13 and an r of -0.88.

Table 2. Application of deficit irrigation on potato yield at various fertilization level

Simulation Procedure	Qty of water for irrigation (MM)	Change in Yield productivity %			Change in Water Productivity %		
		Moderate Fertility	Near Optimal Fertility	Non-Limiting Fertility	Moderate Fertility	Near Optimal Fertility	Non-Limiting Fertility
Full Irr	178						
Deficit Irr 71%	127	-1.23	23.3	33.61	7.75	29.89	40.59
Deficit Irr 62%	110	-7.6	10.1	16.29	5.17	22.14	29.15
Deficit Irr 53%	95	-18.69	-6.19	-2.47	-1.85	10.7	14.39

Three deficit irrigation scenarios (71, 62 and 53%) were investigated together with two fertilization levels "near optimal" 79% and "non-limiting" to determine their impact on crop productivity and water productivity. The values were compared to full irrigation (178 mm / season) and "moderate fertility" levels currently applied by farmers. While reducing volume of water used for irrigation under current fertility levels impacted negatively crop yield but to lesser extent water productivity. Simulation results using different deficit irrigation scenarios are available in table 2 and related proposed adaptation measures by country team in box 7.

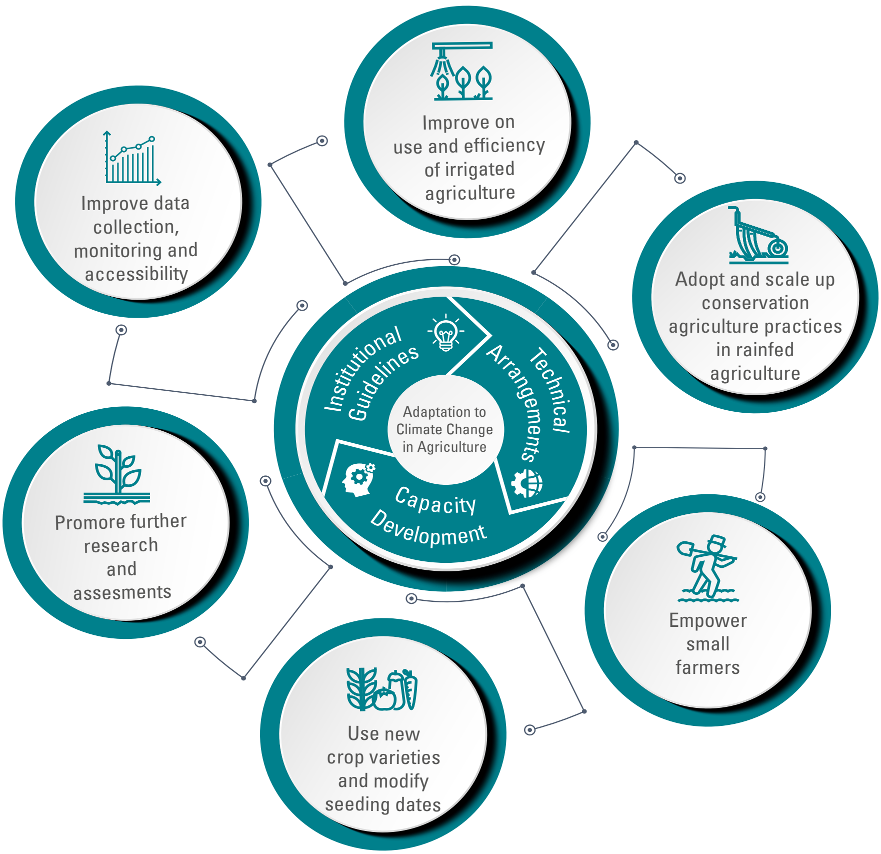
Box 7. Proposed adaptation measures for Potato production using deficit irrigation

- In case of irrigation water is the limiting factor to increasing production, farmers can use the same amount of water currently used to irrigate one hectare (1,780 m^3), to cultivate and irrigate 1.4 hectares by applying deficient irrigation at 71%. This practice will thus produce with the same amount of water about 6.734 tons of potatoes from the 1.4 hectares when compared to 4.87 tons in one irrigated hectare.
- Enhancing soil fertility and using less amount of irrigation water also generates more yield and increase water productivity. Identifying the best fit scenario would also require a cost benefit analysis to determine the cost of increasing soil fertility as compared to the financial returns of higher productivity. Increasing fertility level to "near optimal" or "non-limiting" levels leads to an increase in crop and water productivity (5.98 t/ha and 6.48t/ha respectively).

7. Recommendations for enhancing the resilience of the Agriculture Sector

The main challenges of the agricultural sector in Jordan, include primarily: water scarcity (with per capita share of water less than 145 m^3/year), seasonal rainfall fluctuations; occasional successive years of drought; scarcity of water resources;

Figure 2. Framework for actions to adapt to climate change



fragmentation of property and climate change. Further estimates indicate a decline in per capita share of water resources reaching 90 m^3/year by 2025, which will constrain economic growth and endanger public health. The recent flux of refugees from politically instable countries has further exacerbated this situation.

Research also indicates increased intensity of droughts which will impact the ability of reservoirs to fill and groundwater's ability to recharge that would increase pressures on farmers. To this end, in 2017, Jordan developed its Green Growth Economy Plan, and launched the National Adaptation Plan (NAP) process, in the framework of the implementation of the Paris Agreement and the country's Nationally Determined Contribution, with the objective of integrating adaptation in its planning processes.

Table 3 lists the suggested actions for each key recommendation generated for this study in Jordan. Recommendations are identified based on the multiple dimensions they are connected to, including institutional, policy and financial arrangements, knowledge generation, and capacity development.

Table 2. Key Recommendations and actions for adaptation of agriculture to climate change

1. Improve on use and efficiency of irrigated agriculture

Institutional and Financial Arrangements:

- Establish proper water accounting systems to monitor water resources availability and control water allocations to the irrigation sector within sustainable limits of water consumption
- Enhance the implementation of comprehensive water strategies "Water for Life" that was updated in 2012 and focuses on effective water demand management, effective water supply operations, and institutional reform
- Promote collaboration between different research centres such as National Center for Agricultural Research and Extension (NCARE) that research irrigation and water use efficiency.
- Invest in modernizing irrigation systems such as localized irrigation technologies in irrigated areas to increase land and water productivity

Knowledge generation:

- Identify the water requirements of crops and schedule irrigation accordingly to reduce the depletion of irrigation water
- Evaluate irrigation water productivity and analyse the marginal benefit of water use for different crops and season

Technical Arrangements

- Expanding the use of treated wastewater in line with instructions and conditions for use of treated wastewater issued under Article (15/c) of the Agriculture Act No. (13) of 2015, as amended.

- Modernizing irrigation systems such as localized irrigation technologies in irrigated areas to increase land and water productivity.
- Optimizing the utilization of available water resources by using the most water-saving irrigation techniques such as identifying the water requirements of crops and scheduling irrigation

Capacity development

- Enable farmers to move to irrigated agriculture through participatory processes that identify best irrigation practices within sustainable consumption limits

2. Adopt and scale up conservation-agriculture practices in rainfed agriculture

Policy and Financial arrangements

- Develop comprehensive policies encouraging conservation practices such as reducing taxes and providing incentives to those farmers applying conservation agriculture practices/ technologies
- Provide social safety nets (equitable insurance schemes) for the most vulnerable farmers especially farmers relying on rainfed agriculture
- Ensure income is distributed fairly and channeled into financing development in rural areas.
- Increase investment in water harvesting infrastructure and techniques to provide the opportunity for farmers to adopt supplementary or deficit irrigation

Knowledge Generation

- Compare yields, soil properties development and plant growth phases, under the conditions of conservation agriculture and those of traditional agriculture and publish results

Technical Arrangements

- Develop water harvesting techniques to improve groundwater reserves and improve the use of surface water (Jordan River and its tributaries, Yarmouk and Zarga).
- Enhance information flow in both directions taking into consideration farmers' local initiatives and experiences to improve local ownership of management strategies
- Expand the use of treated wastewater in line with instructions and conditions for the use of treated wastewater issued under Article (15/c) of the Agriculture Act No. (13) of 2015, as amended.

Capacity development

- Enable farmers to adopt conservation agriculture practices through education and technical assistance especially when conservation is profitable, but farmers are unaware of the technology and its profitability, nor do they have necessary skills to implement it.

3. Empower Farmers

Institutional and Financial arrangements

- Empower rural workers with the skills needed for sound economic growth to mitigate the negative effects climate change can have on the local population
- Adopt a comprehensive policy that includes innovations in measures to reduce and transfer risks through climate insurance and to promote economic diversification at local level through off-fam economic activities. This would provide a better buffer and safety nets for small scale famers more vulnerable to climate changes impacts

Technical Arrangements

- Distribute additional income due to increases in the yield of rainfed wheat fairly and channel into financing development in rural areas.
- Improve on application of deficit irrigation for different crops after field testing and simulations to ensure that crop yield is not affected

Capacity development

- Implement targeted farmers field schools to provide farmers with improved skills to enhance farm husbandry, including the use of new crop varieties, leading to higher adaptation capacity and enhanced farm resilience

4. Promote further research and assessments

Institutional arrangements:

- Encourage partnership between research institutes and universities to research impact on other crops and regions and agricultural environments
- Establish and join a Regional Network of AquaCrop practitioners and collaborate with the Near East and North Africa (NENA) Regional and Global Network of AquaCrop practitioners, established and managed by FAO

Knowledge generation and sharing

- Expand the scope of the study by applying AquaCrop on different strategic agricultural crops such as cereal, especially wheat and barley. Perform AquaCrop simulation and analysis on areas where rainfed agriculture/ irrigated crops are widespread with their various geographical features, climates, and soil types
- Assess optimization of water use in irrigation for the main crops in irrigated areas using AquaCrop model and analyze various irrigation methods and systems using AquaCrop model
- Encourage publication of research using AquaCrop model to provide more evidence-based adaptation measures for the agricultural sector under climate change conditions

Capacity development

- Training of trainers on the application of AquaCrop and Riccar Data sets through GIS for crop and water productivity assessments
- Training sessions and workshops at different institutions and universities that facilitate the use of AquaCrop and mainstream the AquaCrop simulation tool and methodology

- Develop training programs on the use of AquaCrop simulation tools (water deficit irrigation)
- Disseminate the training material and methodology developed in the project to encourage further research and applications

5. Improve data collection, monitoring and accessibility

Institutional arrangements

- Data monitoring and sharing between agencies and establish institutional coordination mechanisms to monitor the effects of climate change on different sectors and environments

Technical Arrangements

- Establish a database that provides reliable data required for calibrating and simulating AquaCrop model and allows for easy download and display of readily available data

Knowledge generation

- Develop tools to enhance weather station data monitoring, recording and data dissemination
- Produce interactive map using geographic information systems that represent the impacts of climate change on agriculture areas to display and download data as a tool to support and formulate future agricultural and food policies
- Downscale the vulnerability maps of agriculture for pertinent and informed adaptation policy and incorporate it into different topics and sectors
- Update the climate change data projections.

6. Use of new crop varieties and modify seeding dates

Institutional and Financial arrangements

- Promote coordination and collaboration between universities, research institutes (NCARE, National agricultural research centre) and technical centers to perform assessment studies
- Provide the necessary financial resources for research institutes to perform related studies. This may be through dedicating programs for adaptation in the agricultural sector
- Invest in promoting innovative approaches and technologies to develop use of new crop varieties and/or modify seeding dates

Knowledge Generation

- Test new crops with characteristics that could adapt more easily to expected climate changes
- Introduce drought-tolerant plant varieties with low water consumption and encourage field crop which requires less water than wheat such as barley
- Apply organic fertilizers that have better water retention properties and increase use of fertilizers on farms wile monitoring It has no negative effects on health and water table contamination
- Test the modification of seeding dates and crop sequence to account for shifting periods of rainfall
- Modify crop varieties, cropping pattern and crop calendar (planting and harvesting dates)

Endnotes

1. The country team comprised of experts from the Ministry of Agriculture
2. ESCWA. Assessing the impacts of changing water availability on agricultural production in Jordan, 2019 Available at https://www.unescwa.org/sites/www.unescwa.org/files/uploads/nationalassessment-report-jordan-arabic.pdf
3. ESCWA, RICCAR Arab Climate Change Assessment Report, 2017. Available at ww.unescwa.org/publications/riccar-arab-climate-change-assessment-report
4. Ministry of Foreign Affairs of Netherlands, 2018. Jordan Climate Change Profile.
5. Developed by FAO.

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