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CLIMATE RESILIENT AGRICULTURE:
TRANSLATING DATA TO POLICY ACTIONS

Case Study of AquaCrop Simulation in Yemen
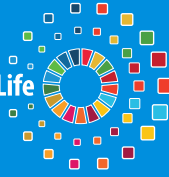
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CLIMATE RESILIENT AGRICULTURE: TRANSLATING DATA TO POLICY ACTIONS

Case Study of AquaCrop Simulation in Yemen

UNITED NATIONS
Beirut

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", the United Nations Economic and Social Commission for Western Asia (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 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 and temperature and carbon dioxide (CO_2) changes) on selected crops and locations in Yemen. The assessment findings, derived from a national case study report, are used as a baseline to recommend adaptation measures to key actors in order to promote water and food security under a changing climate.

The assessments used the AquaCrop simulation program developed by FAO to identify the impact of climate change on the productivity of selected irrigated and rainfed crops. The program 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), while soil, yield and crop data were acquired from national sources. The climate change projections correspond to representative concentration pathways (RCP), i.e., two greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change: RCP 4.5: generally describing a moderate-emissions or 'optimistic' scenario; and RCP 8.5: generally describing a high-emissions or 'business-as-usual' and 'pessimistic' scenario. These two RCPs are each considered for two time horizons: 2020–2030 (represented by 2025) and 2040–2050 (represented by 2045). Furthermore, to analyse the effect of elevated CO_2 on crop yields, two sets of projected CO_2 concentration changes were simulated for each of the RCP scenarios: 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 in order to recommend a variety of country-specific adaptation measures in the agricultural sector.

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1. Country Background

Yemen covers an area of 45.55 million ha, with an estimated 1.6 million ha of agricultural land divided between rain-fed (51 per cent), irrigated from wells (31 per cent), irrigated from floods (10 per cent), irrigated from dams (6 per cent) and irrigated from springs (2 per cent).[1]

Agriculture in Yemen is diverse due to large local variation in rainfall, temperature, humidity and topography. This has resulted in a diversity of agro-ecological zones producing a variety of different plants.

Yemen's population is estimated at 28 million people, most of whom live in rural areas and depend on agriculture to survive. Agriculture constitutes the main source of income for 73.5 per cent of the population of the Republic and contributes 14.5 per cent of GDP. Cereals are the dominant crop type, accounting for 57.1 per cent of area (figure 1). However, the cultivated area has decreased from 1,500,973 ha in 2012 to 1,172,185 ha in 2015 due to poor rains and the ongoing conflict in the country, which has adversely impacted the agriculture sector. This situation has also affected the quantity of cereals produced, particularly wheat, production of which decreased from 715,000 tons in 2008 to 100,000 tons in 2015.

Figure 1. Distribution of crop types in Yemen (by area)

Legumes 3%
Other 11%
Cash crops 6%
Fruits 6%
Vegetables 6%
Feed and Khat 11%
Cereals 57%
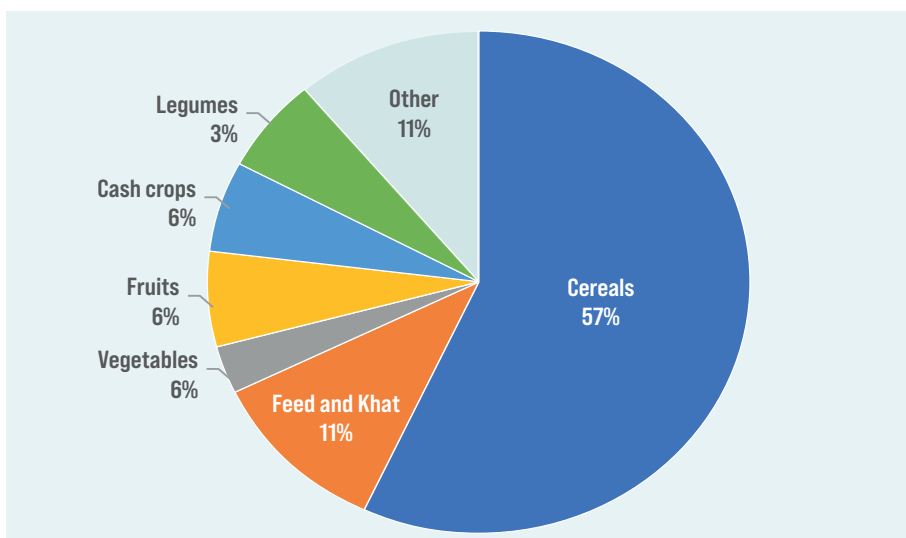
Source: Ministry of Agriculture and Irrigation, 2016.

2. Selected crops and areas for AquaCrop simulations

The present study applied the AquaCrop simulation model to identify the impact of climate change on crop productivity for the following six major crops in three areas of Yemen:

Rainfed wheat with supplementary irrigation in Sana'a area, northern highlands region.

1. Rainfed sorghum with supplementary irrigation in Sana'a area, northern highlands region.
2. Rainfed wheat in Dhamar Governorate, central highlands region.
3. Rainfed sorghum in Dhamar Governorate, central highlands region.
4. Irrigated maize in Al Khoud, Abyan Governorate.
5. Irrigated sesame in Al Khoud, Abyan Governorate.

The northern highlands region is one of the main territories where rainfed agriculture is concentrated and is in a critical situation as a result of the impacts of climate change on rainfall and groundwater availability.

Both Sana'a (representing the northern highlands) and Dhamar (representing the central highlands) depend on supplementary irrigation. The cultivated area in Sana'a is estimated at 133,310 ha, with around 40–50 per cent of the area being rainfed and with cereals planted in 32 per cent of the rainfed cultivated area. The cultivated area in Dhamar governorate is around 85,101 ha, also with around 40–50 per cent of the cultivated area being rainfed and with cereals cultivated in 59 per cent of the rainfed cultivated area.[2]

Al Khoud (Abyan Governorate) is a coastal region in southern Yemen and is characterized by a hot and arid climate and limited water resources, with agriculture reliant on spate or groundwater irrigation. Total arable land in the governorate totals 38,973 ha, of which only 16,883 ha is cultivated.

Box 1. Women's empowerment

In Yemen, 2 million children and 1 million women are currently acutely malnourished. Furthermore, less than 1 per cent of agricultural landholders in Yemen are female whereas women provide 60 per cent of labour in farming, 90 per cent in livestock rearing and 10 per cent of wage labour. Women are at greater risk of food insecurity due to their limited work opportunities and reduced access to productive resources, services and rural institutions. Moreover, women are generally excluded from economic transactions in local markets and are not significantly involved in decision-making, thus not able to fully participate in activities aimed at empowering women, especially in rural areas.

The FAO Yemen Plan of Action (2018–2020) aimed at strengthening the resilience of agricultural livelihoods considering the specific needs of women and young people. One pillar of the plan provides emergency support to the most vulnerable rural households, including cash-based transfers for the development of infrastructure on farms and in rural communities at large and distribution of agricultural kits, with gender taken into consideration when selecting beneficiaries, acknowledging the fact that war disproportionately impacts women.

Source:

Food and Agriculture Organization, Yemen, Plan of Action – Strengthening resilient agricultural livelihoods (2018–2020).

World Food Programme, Yemen: Responding to coronavirus in the world's worst humanitarian crisis.

3. Assessment methodology

The assessment evaluated the impacts of climate change on agriculture productivity using the FAO AquaCrop simulation program (version 6) and the RICCAR climate variables projections.

The following steps were involved in the use of AquaCrop:

- **Data collection** was required for climate, soil and crop types. The required daily climate data included maximum and minimum temperatures, wind speed, relative humidity, solar radiation and rainfall. Daily climatic data (2003–2012) were collected from the Sana'a International Airport meteorological station, and from the weather station affiliated with the General Authority for Agricultural Research and Extension located at the Dhamar research farm. For Sana'a and Dhamar, wheat (2003–2012) and sorghum (2003–2012) yield data were collected from technical reports of the Regional Station for Agricultural Research in Sana'a and the central highlands specialized research centre in Dhamar. Crop data for both maize (1998–2008) and sesame (1999–2008) in Al Khoud were also taken from technical reports and previous studies including Binsalim and others (2004)[6] and Abed (2016).[7] The sesame crop file was adapted from a similar crop file as it was not included in the AquaCrop database.

- **Calibration** of AquaCrop to simulate the productivity of the selected crops under local conditions using 10 years of data for wheat and sorghum (2003–2012) in Sana'a and Dhamar and maize and sesame (1998–2008) in Al Khoud. Data included soil characteristics, groundwater depth, irrigation scheduling, main farm management, climate data and crop yield. The objective of this calibration was to provide the model with parameters simulating the actual productivity of crops within an acceptable accuracy range. The calibrated model was then used to simulate crop yields under future climate change.

- **Simulation** of the impacts of climate change on the productivity of crops were carried out based on the RICCAR project for two periods: 2020–2030 (represented by 2025) and 2040–2050 (represented by 2045) and for the two scenarios of RCP 4.5 and RCP 8.5. The reference period is 1986–2005. Moreover, two sets of projected changes were used: 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 for disaggregation of the mitigating effect of increased CO_2 on yield losses due to temperature rise and water scarcity.

4. Assessment findings

Overall, the assessment shows that rainfed agriculture is more vulnerable to climate change than irrigated agriculture. This is reflected in lower productivity of rainfed agriculture due to reduction and variability of rainfall, compared to higher productivity under irrigated agriculture and supplementary irrigation. Changes in CO_2 concentration benefited wheat production while sorghum yield witnessed a decline in productivity. This is because wheat is a C3 crop that benefits from increased CO_2 concentrations, while sorghum is a C4 crop that does not.

Sesame will not be affected by temperature increases up to 40°C, while maize will be affected by increased maximum temperatures during flowering, which is the most vulnerable phase of the maize crop's life cycle.

• Sana'a site findings

For wheat production in Sana'a, two to four irrigations are typically applied with an average of three, the first during canopy development, the second at flowering and the third during kernel formation and filling, depending on the amount of rainfall. Meanwhile, sorghum is grown using a rainfed system. The AquaCrop model performed well in projecting production for both wheat and sorghum. The coefficients of determination show a good correlation between actual and simulated yields after calibration for these crops (wheat R=0.92, sorghum R=0.748).

Climate variable projections

Three climate models were used (CNRM-CM5,[8] GFDL-ESM2M[9] and EC-Earth[10]) to project seasonal and annual precipitation and change in minimum and maximum temperatures. The GFDL-ESM2M predicts a sharp decrease in precipitation of around 22 mm in the 2025 period under both RCP scenarios. In the 2045 period, the model predicts a 24 mm decrease in precipitation under RCP 4.5 and 16 mm decrease under RCP 8.5.

Maximum temperatures are projected to increase by 0.75–1.55°C under RCP 4.5 and by 0.95–2.23°C under RCP 8.5. Minimum temperatures are also projected to increase by 0.35–0.88°C under RCP 4.5 and by 0.44–1.30°C under RCP 8.5.

Crop productivity

Average wheat productivity decreases under fixed CO_2 concentrations and increases under changing CO_2 concentrations. Sorghum productivity drops in all scenarios, but with a smaller decrease under changing CO_2 concentrations. Under RCP 4.5, it decreases somewhat in the 2025 period and to a larger extent in the 2045 period; under RCP 8.5, it suffers a large decrease. Further findings of the model in comparison to the reference period (1986–2005) are addressed in boxes 2 and 3.

Box 2. Main findings of the AquaCrop simulation in Sana'a for wheat

Under the RCP 4.5 scenario:

- Length of growing season decrease by 3 days in the 2025 and 2045 periods.

- Wheat productivity decreases by 4.24 and 6.11 per cent in the two periods under fixed CO_2. Under changing CO_2, yield increases by 8.33 and 12.56 per cent in the two periods, respectively.

- Crop water productivity decreases to 0.70 and 0.68 kg/m³ in the two periods under fixed CO_2. Under changing CO_2, crop water productivity increases to 0.82 and 0.85 kg/m³ in the two periods, respectively.

Under the RCP 8.5 scenario:

- Length of growing season decrease by 2.4 and 4.5 days in the two periods.

- Wheat productivity decreases by 3.81 and 7.62 per cent in the two periods under fixed CO_2. Under changing CO_2, yield increases by 13.12 and 10.25 per cent in the two periods, respectively.

- Crop water productivity decreases to 0.69 and 0.67 kg/m³ in the two periods under fixed CO_2. Under changing CO_2, it increases to 0.82 and 0.85 kg/m³ in the two periods.

Box 3. Main findings of the AquaCrop simulation in Sana'a for sorghum

Under the RCP 4.5 scenario:

- Length of growing season decrease by 4 and 7 days in the two periods.

- Sorghum productivity decreases by 6.71 and 11.93 per cent in the two periods under fixed CO_2. Under changing CO_2, productivity decreases by 3.05 per cent and by 6.03 per cent in the two periods, respectively.

- Crop water productivity decreases to 0.73 and 0.71 kg/m³ in the two periods under fixed CO_2. Under changing CO_2, crop water productivity increases to 0.77 and 0.76 kg/m³ in the two periods, respectively.

Under the RCP 8.5 scenario:

- Length of growing season decrease by 6 and 9 days in the two periods.

- Sorghum productivity decreases by 8.22 and 13.88 per cent in the two periods under fixed CO_2. Under changing CO_2, productivity decreases by 4.18 and 8.26 per cent in the two periods, respectively.

- Crop water productivity decreases to 0.73 and 0.71 kg/m³ in the two periods under fixed CO_2. Under changing CO_2, crop water productivity increases to 0.77 and 0.76 kg/m³ in the two periods, respectively.

- ## Dhamar site findings

In general, the AquaCrop model performed well in simulating wheat and sorghum production. The relationship between actual and estimated yields and the coefficients of determination reflect a good correlation between actual and estimated yields after calibration (wheat R=0.8, sorghum R=0.82).

Climate variable projections

Climate models show that the average seasonal precipitation in wheat-growing areas is expected to slightly increase in the 2025 period by 0.94 mm and decrease in the 2045 period by 5.07 mm under RCP 4.5. However, under RCP 8.5, seasonal precipitation is projected to increase by 21.16 and 10.79 mm in the 2025 and 2045 periods, respectively.

Average seasonal precipitation in sorghum-growing areas is expected to decrease by 27.97 and 51.54 mm in the 2025 and 2045 periods, respectively, under RCP 4.5. However, under RCP 8.5, it is projected to decrease by 20.1 and 38.68 mm in the 2025 and 2045 periods, respectively.

Maximum temperatures are projected to increase by 0.80–1.84 °C under RCP 4.5 and by 1.04–2.57 °C under RCP 8.5. Minimum temperatures are also projected to increase by 0.46–0.90 °C under RCP 4.5 and by 0.56–1.19 °C under RCP 8.5.

Crop productivity

Average wheat productivity is projected to decrease under fixed CO_2 and increase under changing CO_2. Sorghum productivity decreases in all cases except under changing CO_2 and RCP 8.5, where it increases slightly by 2.64 per cent in the 2025 period. Reduced sorghum productivity may be because the insufficient rainfall has a greater impact on productivity than rising CO_2 concentrations. Further findings of the model in comparison to the reference period (1986–2005) are addressed in boxes 4 and 5.

- ## Al Khoud site findings

In the Al Khoud study area, five irrigations were simulated for maize (one before planting and 4 after planting) and 2 irrigations were simulated for sesame (one before planting and one after planting). In general, the AquaCrop model performed well in projecting production for maize and sesame (maize R=0.728, sesame R=0.775). Fertilization levels were also calibrated to achieve the best possible match between actual and estimated yields, with a moderate fertilization level of 66 per cent for maize and near-optimal for sesame.

Climate variable projections

Under RCP 4.5, the CNRM-CM5 model projected a decrease in yearly precipitation of around 11 mm for both periods whereas the other two models (GFDL-ESM2M and EC-Earth) projected an increase of 54.58 mm for the 2045 period. Similarly, under RCP 8.5, the CNRM-CM5 model projected a decrease in yearly precipitation of around 11 and 0.5 mm for the 2025 and 2045 periods, respectively. Both GFDL-ESM2M and EC-Earth projected an increase in yearly precipitation, with a maximum increase of 40.69 for the 2025 period.

Maximum temperatures are projected to increase by 0.82–1.52 °C under RCP 4.5 and by 0.91–2.08 °C under RCP 8.5. Minimum temperatures are also projected to increase by 0.58–1.14 °C under RCP 4.5 and by 0.58–1.48 °C under RCP 8.5.

Crop productivity

Maize is one of the most adaptable field crops to different environments and most responsive to different agricultural practices and parameters, hence enabling it to thrive in the country's climate. Under changing CO_2, there were no changes in productivity of maize except for a major decrease of 26 per cent under RCP 4.5 in the 2045 period.

The reduction in length of growing season attributed to higher temperatures leading to

Box 4. Main findings of the AquaCrop simulation in Dhamar for wheat

Under the RCP 4.5 scenario:

- Length of growing season decrease by 4 to 8 days in the two periods.

- Wheat productivity decreases by 7.02 and 14.57 per cent in the two periods under fixed CO_2. Under changing CO_2, productivity increases by 5.64 and 2.89 per cent in the two periods, respectively.

- Crop water productivity decreases to 0.39 and 0.37 kg/m^3 in the two periods, respectively, under fixed CO_2. Under changing CO_2, crop water productivity increases to 0.46 kg/m^3 in both periods.

Under the RCP 8.5 scenario:

- Length of growing season decrease by around 3.35 and 10.35 days in the two periods under fixed and changing CO_2.

- The productivity of wheat decreases by 5.21per cent and by 22.35 per cent in the 2025 and 2045 periods, respectively, under fixed CO_2. Under changing CO_2, productivity increases by 9.8per cent in the 2025 period and decreases by 3.96 per cent in the 2045 period.

- Crop water productivity decreases to 0.39 kg/m^3 and 0.32 kg/m^3 in the two periods, respectively (as compared to 0.41 kg/m^3 in the reference period) under fixed CO_2. Under changing CO_2, crop water productivity increases to 0.47 kg/m^3 in the 2025 period and decreases to 0.41 kg/m^3 in the 2045 period.

Box 5. Main findings of the AquaCrop simulation in Dhamar for sorghum

Under the RCP 4.5 scenario:

- Length of growing season decrease by 6 to 10.7 days in the two periods.

- Sorghum productivity decreases by 26.45 and 29.81 per cent in the two periods respectively, under fixed CO_2. Under changing CO_2, productivity decreases by 21.63 and 24.29 per cent in the two periods, respectively.

- Crop water productivity decreases to 0.27 kg/m^3 during the 2025 and 2045 periods under fixed CO_2. Under changing CO_2, crop water productivity decreases to 0.28 and 0.29 kg/m^3 in the two periods compared to 0.3 kg/m^3 in the reference period.

Under the RCP 8.5 scenario:

- Length of growing season decrease by 2.6 and 7.75 days in the two periods.

- Sorghum productivity decreases by 3.12 and 10.30 per cent in the two periods respectively, under fixed CO_2. Under changing CO_2, productivity increases by 2.64 per cent in the 2025 period and decreases by 2.47 per cent in the 2045 period.

- Crop water productivity increases to 0.32 kg/m^3 in the two periods under fixed CO_2. Under changing CO_2, crop water productivity increases to 0.34 and 0.35 kg/m^3 in the two periods.

early and faster ripening of crops, as well as to increased evaporation or droughts initiating early flowering and maturation. Sesame will not be affected by temperature increases up to 40°C, while maize will be affected by increased maximum temperatures during flowering, which is the most vulnerable phase of the maize crop's life cycle. Further findings of the model in comparison to the reference period (1986–2005) are addressed in boxes 6 and 7.

Box 6. Main findings of the AquaCrop simulation in Al Khoud for maize

Under the RCP 4.5 scenario:

- Length of growing season decrease by around 2 and 3 days in the two periods.
- Maize productivity decreases by 2.61 and 4.11 per cent in the two periods respectively, under fixed CO_2. Under changing CO_2, productivity does not change in the 2025 period and decreases by 26 per cent in the 2045 period.
- Crop water productivity decreases to 2.33 and 2.31 kg/m^3 during both periods under fixed CO_2. Under changing CO_2, crop water productivity increases to 2.46 and 2.47 kg/m^3 in the two periods.

Under the RCP 8.5 scenario:

- Length of growing season decrease by 2 and 5 days in the two periods.
- Maize productivity decreases by 2.35 and 5.57 per cent in the two periods, respectively, under fixed CO_2. Under changing CO_2, productivity is unchanged in the 2025 period and decreases by 1.41 per cent in the 2045 period.
- Crop water productivity decreases to 2.32 and 2.28 kg/m^3 in the two periods under fixed CO_2. Under changing CO_2, crop water productivity increases to 2.42 kg/m^3 in both periods

Box 7. Main findings of the AquaCrop simulation in Al Khoud for sesame

Under the RCP 4.5 scenario:

- Length of growing season decrease by 1 and 2 days in the two periods.
- Sesame productivity increases by 3.7 and 3.2 per cent in the two periods respectively, under fixed CO_2. Under changing CO_2, productivity increases by 7.48 and 14.79 respectively.
- Crop water productivity does not change in the 2025 period and increases to 0.45 kg/m^3 during the 2045 period under fixed CO_2. Under changing CO_2, crop water productivity increases by 0.47 and 0.50 kg/m^3 in the two periods.

Under the RCP 8.5 scenario:

- Length of growing season decrease by 1.33 and 2.33 days in the two periods.
- Sesame productivity decreases by 1.71 and 8.39 per cent in the two periods under fixed CO_2. Under changing CO_2, productivity increases by 9.78 and 11.78 respectively.
- Crop water productivity decreases to 0.41 and 0.39 kg/m^3 in the two periods, respectively, under fixed CO_2. Under changing CO_2, crop water productivity increases to 0.45 and 0.47 kg/m^3 in the two periods

5. Analysis

Rainfed agriculture, in general, is expected to be more vulnerable to climate change, with productivity falling due to the scarcity and variability of rainfall. Moreover, the summer rainy season is expected to shift by about a month, negatively affecting production of sorghum, which is usually cultivated before wheat. However, delaying sorghum planting could mitigate the negative impact of climate change, as could 50 mm of supplementary irrigation a month after planting. Revised planting dates and supplementary irrigation in periods of insufficient rain could improve cereal production and water productivity in the highlands.

Attention is needed to water losses from inefficient irrigation systems, as a significant volume of water (estimated at 50–65 per cent) is wasted. To this end, irrigation infrastructure and practices must be improved to provide a better supply of water for crops and preserve soil moisture during critical periods. Diversion dams to avoid overuse of irrigation and deficit irrigation are also recommended.

Extension programs are also needed to disseminate information on high yield varieties and agronomic techniques to improve rainfed agriculture. New and improved crop varieties (especially of cereals) that are adapted to harsh climate conditions could also be useful

as an adaptation measure. A survey of target species could leverage the genetic diversity of crops in Yemen to determine the best-adapted varieties. Conservation-agriculture practices should be adopted and scaled up in rainfed areas, such as enhancing soil water storage (mulching, tillage and crop rotation) which requires proper training and equipment.

Mechanisms are needed to maintain and develop agricultural land, which may include identifying the fertilizers needed for crops. Given the limited availability of suitable land and the scarcity of water resources, the productivity of maize may be increased by improving productivity per unit area and using appropriate fertilizers effectively to counter fertility stress. Appropriate measures should also be taken for maize in the southern coastal region to develop strains with short life cycles and suitability to the changing climate.

The changing climate is well suited to some crops, such as sesame, which is expected to see increasing yields. This will incentivize local farmers to invest in the cash crop, potentially increasing income and providing a better standard of living in the future. An economic assessment is therefore essential in order to assess the impacts of climate change on crop yields and the local and national economy.

Box 8. Economic impact of climate change on agriculture

The agriculture sector is one of the most important sectors in the Yemeni economy as it constitutes the primary source of income for about 73.5 per cent of the population. It also contributes 14.5 per cent of GDP, making it the largest single sector in the national economy. Since 2015, the Yemeni economy has shrunk severely and food prices have soared, around 73–178 per cent higher in 2018 than before the crisis (FAO and WFP, 2019) thus leaving more than 80 per cent of the Yemeni population under the poverty line (OCHA, 2018).

According to FAO statistics, the import requirement for cereals in 2014 was estimated at about 4.5 million tons, including 3 million tons of wheat, 0.7 million tons of maize and 0.4 million tons of rice (GIEWS 2015). The gap between cereal production and consumption is estimated at around 22 per cent, with the shortfall covered by rapidly increasing imports. The deficit in maize production has been covered by imported quantities, with 503,880 tons of maize imported in 2013 at a cost of 34,036 million Yemeni rials (Yemen, General Administration of Statistics and Agricultural Documentation).

Supplementary irrigation systems in the highlands region have been greatly affected by the increase in fuel prices and the scarcity of groundwater sources, thus increasing the costs of grain production under supplemental irrigation and decreasing the feasibility of growing cereals. It is projected that the production of wheat, sorghum and possibly other crops in those areas will be negatively impacted, compromising the food security of farmers in particular and the national economy in general. Production issues among crops in the highland region could further aggravate regional inequalities, which were at the core of the recent Yemeni Civil War.

Sources:

Food and Agriculture Organization and World Food Programme, Monitoring food security in countries with conflict situations, 2019.

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6. Recommendations

In addition to climate change, Yemen faces multiple challenges in improving its agricultural productivity. War has had an adverse effect on the agriculture sector in Yemen due to damages to agricultural areas and accompanying economic pressures in terms of high fuel prices and difficulties accessing agricultural inputs. This situation is further exacerbated by the reduced rainfall and decreased production in rainfed cultivated areas. Amid the production issues, securing the livelihoods of workers must also be a priority for any future economic policies related to the agricultural sector.

Figure 2. Framework for actions to adapt to climate change

Table 1 lists the suggested actions for each key recommendation generated for this study in Yemen. Recommendations are identified based on the multiple dimensions they are connected to, including institutional, policy and financial arrangements, knowledge generation and capacity development.

Table 1. Recommendations for Enhancing the Resilience of the Agriculture Sector

1. Increase the efficiency of irrigated agriculture

Institutional and financial arrangements:

- Establish proper water accounting systems to monitor water resource availability and keep water allocations for irrigation within sustainable limits.
- Coordinate between the various agencies involved in agricultural development and rural infrastructure development.
- Form collaborations between research centres and universities that perform research on irrigation and water use efficiency.
- Invest in modern irrigation systems such as localized irrigation technologies to increase land and water productivity.
- Develop and maintain irrigation infrastructure and build diversion dams to improve irrigation.

Knowledge generation:

- Identify the water requirements of crops and schedule irrigation accordingly to reduce the waste of irrigation water.
- Evaluate irrigation water productivity and analyse the marginal benefit of water use for different crops and seasons.
- Apply deficit irrigation and research crops that require less irrigation water while achieving the same yield.

Capacity development:

- Encourage farmers to move to irrigated agriculture through participatory processes that identify best irrigation practices within sustainable consumption limits.
- Run capacity-building programmes for farmers on water productivity and complexities, especially regarding different sources that can be used to satisfy water demand (surface water, groundwater, rainfall).

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

Policy and Financial arrangements:

- Develop comprehensive policies encouraging conservation practices such as incentives to farmers applying conservation agriculture practices/technologies.
- Provide social safety nets (equitable insurance schemes) for the most vulnerable farmers, especially farmers reliant on rainfed agriculture.
- Increase investment in water-harvesting infrastructure and techniques to facilitate farmers in adopting supplementary or deficit irrigation.

Knowledge generation and technical arrangements:

- Undertake and publish research to compare yields, soil development and plant growth phases between conservation agriculture and traditional agriculture.

- Improve the application of supplementary irrigation and support research on crops in terms of timing, quantity and economic feasibility.
- Apply organic fertilizers that have better water retention properties and increase use of fertilizers while ensuring they do not contaminate the water table or negatively impact health.

Capacity development:

- Facilitate farmers in adopting conservation agriculture practices through education and technical assistance, especially when conservation practices are profitable but farmers are unaware or do not have the necessary skills to implement them.

3. Empower Farmers

Institutional and financial arrangements:

- Equip rural workers with the skills needed for sound economic growth to mitigate potential negative effects of climate change on the local population.
- Support farmers who lost crops and pastures due to pests and climate shocks.
- Adopt a comprehensive policy with innovative measures to reduce and transfer risks through climate insurance and promote economic diversification at the local level through off-farm economic activities.
- Promote farmers' adoption of modern irrigation systems through provision of subsidies and support.
- Expand export opportunities by developing quality and safety standards and appropriate marketing systems.
- Develop farmer associations and organizations.

Capacity development:

- Implement targeted 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 partnerships between research institutions and universities to study other crops and regions and agricultural environments using the AquaCrop and RICCAR climate datasets.
- Identify a focal point/coordinator to follow up on the implementation of assessment programmes for different crop types and different regions in the country.

Knowledge generation and sharing:

- Expand the scope of the study by applying AquaCrop to different varieties of crops to study the impact of climate change on water productivity and agricultural production.
- Perform AquaCrop simulations and analyses on areas with rainfed/irrigated crops and various geographical features, climates and soil types.
- Identify best irrigation management strategies based on climate change scenarios and changes in rainfall.
- Assess water use in irrigation for the main crops in irrigated areas using the AquaCrop model and analyse various irrigation methods and systems.
- Encourage publication of research using the AquaCrop model to provide more evidence-based adaptation measures for the agricultural sector under climate change.

Capacity development:

- Train trainers on the application of the AquaCrop and RICCAR data sets through GIS for crop and water productivity assessments.

- Hold training sessions and workshops at different institutions and universities on the use of AquaCrop and mainstream the AquaCrop simulation tool and methodology.
- Develop training programmes on the use of simulation tools linked to AquaCrop (i.e. for 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:

- Implement data monitoring and sharing between agencies and establish institutional coordination mechanisms to monitor the effects of climate change on different sectors and environments.
- Develop tools to enhance weather station data monitoring, recording and data dissemination.
- Establish a database providing reliable data required for calibrating and simulating the AquaCrop model and allowing for easy download and display of data.
- Document and create a database covering the largest possible number of crops from different areas.

Knowledge generation:

- Produce an interactive map using geographic information systems to show the impacts of climate change on agriculture areas and display and download data, as a tool to support and help formulate future agricultural and food policies.
- Increase the granularity of agricultural vulnerability maps in order to inform relevant adaptation policies and incorporate them into different topics and sectors.
- Update the climate change data projection through cooperation between national, regional and international institutions.

6. Use of new crop varieties and modified planting dates

Institutional and financial arrangements:

- Promote coordination and collaboration between universities, research institutes and governmental agencies to perform assessment studies.
- Provide the necessary financial resources for research institutes to perform related studies. This may be through dedicated programmes on adaptation in the agricultural sector.
- Invest in promoting innovative approaches and technologies to develop the use of new crop varieties and/or modified planting 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 crops with lower water requirements than wheat, such as barley.
- Test modified planting dates and crop rotations to account for shifting periods of rainfall, for example delaying the planting date of sorghum.
- Modify crop varieties, crop rotations and the crop calendar, including planting and harvesting dates.
- Survey varieties of target species in the regions to leverage the genetic diversity of crops in Yemen and determine the best-adapted varieties.

Endnotes

1. The Country team is comprised of five experts from the Northern Highlands Regional Agricultural Research Station, Southern Highlands Research Station, Renewable Natural Resources Research Center and Al Khoud Research Station.

2. ESCWA, Assessment of the impacts of changing water availability due to climate change on agricultural production in Yemen, 2019. Available at https://archive.unescwa.org/sites/www.unescwa.org/files/uploads/national-assessment-report-yemen-arabic.pdf

3. ESCWA, RICCAR Arab Climate Change Assessment Report, 2017. Available at www.unescwa.org/publications/riccar-arab-climate-change-assessment-report.

4. Yemen, Ministry of Agriculture and Irrigation, 2016. Agricultural Statistics Book for 2015, the General Administration of Agricultural Statistics.

5. Ministry of Agriculture and Irrigation, 2016.

6. Binsalim, A.H.S. Sacran, S.S. and Ahmed, A.A. (2004). Effect of irrigation rate and scheduling on yield of maize (Zea mays L.) and its economic return. Yemeni Journal of Agricultural Research and Studies.

7. Al- Abed, A. (2016). Response of three maize cultivars (Zea maize L.) to sowing Dates andDeprive under Abyan Delta conditions. Ph.D thesis in Agriculture Science (Agronomy). Nasser's Faculty of Agriculture Science,University of Aden.

8. A version of the general circulation model CNRM-that contributes to phase 5 of the Coupled Model Intercomparison Project (CMIP5).

9. Earth System Model – Geophysical Fluid Dynamics Laboratory.

10. A global climate model system based on the use the world-leading weather forecast model of the ECMWF (European Centre for Medium-Range Weather Forecasts) in its seasonal prediction configuration as the base of the climate model.