Comprehensive review and situation analysis for rain fed cereal production in the Kingdom of Saudi Arabia

CRL/051/2021/1

Strengthening MoEWA's Capacity to implement its Sustainable Rural Agricultural Development Programme (2019-2025) (UTF/SAU/051/SAU)

Food and Agriculture Organization of the United Nations

Riyadh, Kingdom of Saudi Arabia

Table of Contents

Abbreviations and acronyms

C	Carbon
CCN	Cereal Cyst Nematodes
CFS	Council for Food Security
KAUST	King Abdulaziz University for Science and Technology
CIMMYT	International Maize and Wheat Improvement Center
CGIAR	Consultative Group of International Agricultural Research
CMS	Cytoplasmic male sterility
COVID	Corona virus
FAO	Food and Agricultura Organization
FAOSA	Food and Agricultura Organization, Saudi Arabia
FAOSTAT	Food and Agricultura Organization Statistical Database
Ha	Hectare
IBPGR	International Board for Plant Genetic Resources
ICRISAT	International Crop Research Institute for Semi-Arid Tropics
IDA	iron deficient anemia
IPPC	International Plant Protection Council
JARC	Jazan Agricultural Research Center
KACST-BGB	King Abdulaziz City for Science and Technology Botanical Gene Bank
KSU	King Saud University
KSA	Kingdom of Saudi Arabia
MT	metric ton
MoEWA	Ministry of Environment, Water and Agriculture
NARS	National Agricultural Research System
NAWRC	National Agricultural and Water Resources Center
PGR	Plant Genetic Resources
pH	power of hydrogen
SAGO	Saudi Grain Organisation
SAR	Saudi rial
SRAD	Sustainable Rural Agricultural Development
SWOT	Strengths, weaknesses, opportunities and threats analysis
UPOV	International Union for the Protection of New Varieties of Plants
USA	United States of America

USD	United States dollar
USDA FAS	United States Department of Agriculture Foreign Agricultural Service

Executive summary

The Kingdom of Saudi Arabia ranks 38 in Global Food Security Index considering food affordability, availability, quality and safety. This is above countries like Brazil or Russia with huge land resources and well-developed agriculture. The food security success in KSA originated from local production and effective management of the value chains including import. Dry and hot climate and lack of water for crops and animals represent a major challenge for domestic supply of major commodities such as wheat, barley, rice and maize. Saudi Vision 2030 very clearly defined the roadmap for the future with emphasis on food security through sustainable use of natural resources, rural development, enhancement of productivity, competitiveness of agricultural products, plant and animal health. Saudi Vision 2030 has been detailed in National Strategies for Agriculture, Water, Environment and Food Security. To attain the objectives of the strategies, ten programs were developed including Sustainable Rural Agricultural Development (SRAD) Program (2019-2025). Ministry of Environment, Water and Agriculture (MoEWA), in cooperation with the FAO, has developed this flagship program. The goal of the program is to achieve sustainable rural agricultural development and contribute to conservation and management of natural resources in the Kingdom of Saudi Arabia. The program covers nine components (rain-fed cereals, subtropical fruits, rose, fisheries, coffee Arabica, beekeeping and honey, livestock, natural resource management, value addition from smallholdings and rural activities) and six outcomes: 1) technologies and innovative practices to sustainably increase rural agriculture productivity; 2) innovative practices and technologies to restore and conserve natural vegetation; 3) capacity of rural agriculture institutions and small producers; 4) technical capacity of government and stakeholders; 5) capacity of public and private sector to develop rural agro-enterprises; and 6) information and knowledge products development and dissemination.

The program component on rainfed cereals targets sorghum, millet, sesame and wheat production in four regions situated in the southwest of the country: Makkah, Al-Baha, Aseer and Jazan. The region is blessed with relatively high precipitation due to Aseer mountain range stretching from southeast to northwest. This is densely populated region with relatively high share of rural population and less developed compared to the rest of the county. The country total number of farms with land exceeded 285,000 according to 2015 Agricultural Census. The four target regions had more than 162,000 farms or 57.1%. On the other hand, the four regions area under these farms was only around 252,000 ha or 7.4% of the total land. The land size per farm is below 1 ha in Aseer and Al-Baha. The four target regions having only 16% of all agricultural land employed more than 207,000 or 40% of permanent labor including 46% Saudi compared to 37% nationwide. This is indicative of relatively high labor-intensive farming system and low level of mechanization. Most importantly, cereals production is almost entirely rainfed without use of non-renewable underground water reservoirs.

The recent estimates of the area grown under rainfed crops: sorghum - 60,000 ha (continuous decline from year 2000); millet – 6,000 (on the rise in the last 5-7 years); sesame – 2,000 ha (continuous decline from year 2000); wheat – 6,000 ha (on the rise in the last 5-7 years). There are several factors affecting the production trends: demographic (migration from rural areas and aging of farming communities), technological (utilization of traditional varieties and cropping practices), financial (cost of production versus the profit, subsidies), access to labor, rural and agricultural services, shifting consumption patterns and possibly others. The study on this subject is well justified. Overall, there is great potential for all rainfed cereals crops expansion both in area and in productivity. The overall objective of the project for the rainfed crops is to increase production of sorghum by 15% to 190,000 t to approach self-sufficiency, millet by 50% to 7,200 t and sesame by 50% to 6,000 t to reduce the import volume. Jazan is the major producer of rainfed cereals followed by Aseer, Makkah and Al-Baha.

The region agroecology is very diverse depending on landscape, elevation, soils and climate. There are four clearly defined farming systems: rainfed without any irrigation, flood irrigation in lowlands; terrace farming in the highlands and supplementary irrigation in the lowlands. The key to improving crop production is more effective use of the scarce water resources. However, existing rainwater harvest infrastructure requires improvement and irrigation systems efficiency is only 35-40%. For all four crops, the farmers use conventional varieties and low input cultivation technologies with little if any inputs. There are no sources of new varieties. The seed system is informal with little distinction between grain and seed. The crops suffer from diseases and pests, weeds are common in some areas. Mechanization of the field operation represent one of the major challenges.

The farming community is diverse and dynamic responding to internal and external drivers and challenges. Rainfed cereals production is not the only source of income but contributes substantially to the rural livelihood. There is high degree of commitment to rainfed cereals production stemming from cultural traditions and rural values. Unfortunately, there is very limited support from adaptive research and extension. Lack of rural support and services as well as limited capacity to provide the services require substantial enhancement.

The main sector strengths are high priority given to rainfed cereals from MoEWA and SRAD project; committed and dynamic farming community; fast multiplication rate of rainfed crops allowing speedy multiplication; presence of Jazan Agricultural Research Center, Seed Center and MoEWA plans to develop agricultural research. Sorghum, millet and sesame grain possesses substances which positively affect human health. This is an opportunity in social environment where public is increasingly concerned about food health benefits. Several universities are involved in rainfed cereals research and can contribute to the project. The research on varieties and production technologies of sorghum, millet and sesame made tremendous progress globally and the outcomes can be used in the project through international cooperation with centers like ICRISAT or with national programs like in India, Sudan and Ethiopia.

The project interventions, activities and deliverables have been designed to address numerous challenges and build on strengths. These interventions have been aligned with MoEWA/SRAD initiatives and prioritized for implementation. The first priority themes include: Water, Mechanization, Demonstration farms, Strengthening of agricultural research and Establishment of selection program. The implementation methodology is based on focusing on pilot governorates and demo farms within these governorates. The consultation mechanism with the primary audience stakeholders has been established and assures timely and high quality implementation of activities.

1. Introduction (KSA national policies on agriculture, SRAD program, review objective, approach, methodology and structure)

The Kingdom of Saudi Arabia is located on Arabian Peninsular and has the total population exceeding 35 million people. Agriculture is an important sector of economy in Saudi Arabia with annual production value of around US$18 billion in 2019 which has grown by 27% since 2010. Though the share of agriculture in total GDP was only 2.23% in 2019, the sector is important as the share of rural population in the country is around 16%. Agricultural production potential in the country is limited due to dry and hot climatic conditions and lack of water resources (Annex 1). All the policies and activities related to agricultural production and development are concentrated in the Ministry of Environment, Water and Agriculture.

Saudi Vision 2030 is a package of social and economic policies that are designed to free the kingdom from dependence on oil exports and to build a prosperous and sustainable economic future by focusing on country's strength and policies. The Vision Transformation Program Strategic Objective 5.4.1 "Ensure development and food security" specifically addresses the food situation in the country. Saudi Food Security Strategy and Implementation plan were adopted in 2018. The Strategy is based on five strategic objectives:

1. Achieve sustainable domestic food production system.
2. Diversify and stabilize external food supply sources.
3. Ensure access to safe and nutritious food to all KSA residents and promote healthy and balanced eating habits.
4. Build food resilience capabilities.
5. Institutionalize food security at the national level and ensure clear and accountable governance.

National Agriculture Strategy formulated five strategic objectives: 1) Enhance food security during normal circumstances and in emergencies across the Kingdom; 2) Protect and improve sustainable use of natural resources to contribute to water security and environmental conservation; 3) Contribute to rural development and provide adequate living conditions for agricultural producers and workers; 4) Enhance productivity and competitiveness of agricultural products and services and their contribution to the national economy and 5) Strengthen plant and animal health and ensure products safety.

The National Environment Strategy has four strategic objectives and six strategic pillars including Institutional robustness and private sector participation; vegetation cover conservation and combating desertification; wildlife conservation; environmental compliance; meteorology; and awareness, education and innovation. The bulk of natural resource conservation and management falls within pillar 2 that addresses vegetation cover conservation and combating desertification. This pillar includes six initiatives (i) Drought Preparedness and Mitigation; (ii) Revision and Implementation of the Rangeland Strategy; (iii) Implementation of the National Forest Strategy, (iv) Assessment and Remediation of Degraded Sites, (v) Development and implementation of national plan to combat desertification and reduce sand encroachment; and (vi) Establishment of a System for the Development and the Sustainable Management of National Parks.

National Water Strategy is composed of a vision, strategic objectives, programs and associated initiatives: The strategy vision is "A sustainable water sector, safeguarding the natural resources and the environment of the Kingdom and providing cost-effective supply and high-quality services". This vision statement is detailed into five strategic objectives: 1. Ensure continuous access to adequate quantities of safe water, under normal operations and during emergency situations.2. Enhance water demand management across all uses. 3. Deliver cost-effective and high-quality water and wastewater services, accounting for affordability. 4. Safeguard and optimize the use of water resources, while preserving the local environment for the highest benefit of the Saudi society in this generation and the future. 5. Ensure water sector competitiveness and positive contribution to the national economy through promoting effective governance, private sector participation, localization of capabilities and innovation. The strategy is structured into 10 programs.

To attain the objectives of the National Agriculture and Environment Strategies ten strategic programs were proposed including Sustainable Rural Agricultural Development (SRAD) Program (2019-2025). The MoEWA, in cooperation with the FAO, has developed this flagship program. The goal of the program is to achieve sustainable rural agricultural development and contribute to the sustainable conservation and management of natural resources in the Kingdom of Saudi Arabia. To accomplish its goal, the SRAD Program has the following six strategic objectives: 1) Diversify agricultural production base; 2) Improve income and living standard of smallholders; 3) Create job opportunities; 4) Contribute to food security; 5) Reduce migration and contribute to social stability and settlement in rural areas and 6) Preserve natural resources and environment. These four strategies and respective initiatives comprise the national framework for agricultural development, water and environment management. This framework is implemented through MoEWA. Its vision is to achieve sustainability of environment and natural resources, in such a manner that would ensure water security, contribute to achieving food security, and improve quality of life in KSA. The current project and activities on rainfed cereals contribute to the strategic initiatives related to food security and sustainable domestic food production.

The SRAD National Program was inaugurated by King Salman bin Abdulaziz in January, 2019[1]. Mr Abdulrahman Al-Fadli, Minister of Environment, Water and Agriculture, said that the program would help small producers across the Kingdom and greatly support the country's food security initiatives by fulfilling 43 percent of the total food required in target areas, as well as 19 percent of the total food needs of the Saudi Arabia. The program will ensure sustained access to healthy food, while increasing women's participation in the labour market according to Vision 2030. The minister said his ministry would implement the program through the application of the best global models in agricultural and rural development, in cooperation with more than nine governmental and private bodies, as well as the UN's Food and Agriculture Organization (FAO), which will serve as a consultant for the implementation and follow-up phases of the program. He pointed out that the program, since its adoption with an amount of SAR 8.750 billion in addition to SAR 3 billion from the Agricultural Development Fund, was celebrated by farmers and their families across the regions of the Kingdom due to its social and economic benefits.

The SRAD project adopted a three-phase methodology to identify and select target regions of the Kingdom for rural agricultural development:

1) Classification of the Kingdom's regions based on their agricultural natural resources endowment;

2) Classification of the Kingdom's regions based on their rural characteristics and socio-economic stability;

3) Identification and selection of promising agricultural sub-sectors in the targeted regions based on: Agricultural and natural resources; Rural characteristics and socio-economic stability; Promising agricultural sub-sectors.

Based on the above methodology, nine sub-sectoral components have been developed as a focus of the SRAD programme (2019-2025) containing selected categories of promising rural agricultural commodities in the eleven regions that have been identified as target regions as shown in Table 1.

Table 1. SRAD project components and respective administrative regions selected for implementation.

Project Component	Target regions
(1) Development of coffee Arabica production, processing and marketing	Jazan, Aseer and Al-Baha
(2) Development of beekeeping and honey production	Jazan, Aseer, Al-Baha, Makkah, Medina and Hail
(3) Development of rose production and trade	Jazan, Aseer, Al-Baha and Makkah
(4) Development of sub-tropical fruits production, processing and marketing	Jazan, Aseer, Al-Baha, Medina, Makkah and Hail
(5) Strengthening capacity of small-scale fishermen and fish farmers	Jazan, Aseer, Makkah, Medina and Eastern Region
(6) Strengthening capacity of small-scale livestock herders	Jazan, Aseer, Makkah, Northern Borders and Eastern Region
(7) Development of rain-fed cereals production	Jazan, Aseer, Al-Baha and Makkah

[1] https://cic.org.sa/2019/01/king-salman-unveils-major-sustainable-agricultural-rural-development-program/

(8) Enhancing value addition from smallholdings and rural activities	Jazan, Aseer, Al-Baha, Medina and Makkah
(9) Strengthening MoEWA's capacity in sustainable management of rangelands, forests and natural resources to support rural livelihoods.	Riyadh, Eastern Region, Tabouk, Najran, Makkah, Aseer and Al Baha

In formulation of SRADP, the inclusion of rainfed cereals as one of the seven commodity components of the project was justified on the following counts:

- Traditional rain-fed farming is of particular importance to small-scale producers in rural areas of the Kingdom contributing to family food and to their animal feed.
- Climate suitability, availability of appropriate land and rainwater harvesting support the cultivation cereals.
- Rain-fed cultivation contributes to domestic consumption and reducing import of these cereals.
- Rain-fed agriculture production stimulates rural development, improve local communities' income and therefore improving livelihoods.

Accordingly, the rainfed cereals production was selected as an important commodity with the focus on four target regions: Al-Baha, Aseer, Jazan and Makkah. The project document defines the challenges faced by the sector, interventions and activities leading to the project targets. The relevant sections below provide detailed information on these topics.

The current comprehensive review and situation analysis of rainfed cereal production in KSA is the first task in the project implementation to review the sector, evaluate the current status and develop approaches for conducting interventions and activities. The objective of this document is to summarize all secondary data available including relevant references as well as outcomes of field visit and communication with the stakeholders. In addition to technical production and value chain topics, the review also covers the themes related to research and extension, rural development and socio-economic issues as long as they are related to rainfed cereals production in the target areas. The comprehensive review is combined with the situation analysis, stakeholders analysis and SWOT matrix to arrive to proposed interventions and activities work plan. The ultimate objective is to review the sector, identify the development directions and fine-tune the interventions leading to achievement of the stated goals.

The review methodology was based on the literature search and included the following sources: a) FAO database and publications including FAOSA technical reports; b) publications from research journals found using Google Scholar and other engines; c) KSA documents including MoEWA reports both in English and in Arabic. All the literature was reviewed, filed in the database and included in the review only if relevant to the document objectives. The situation analysis included communication to FAOSA and MoEWA staff and wider group of stakeholders both in Riyadh and during the mission to Aseer and Jazan in March-April, 2021. The methodology for situation analysis included individual and group interviews and discussions as well as the survey tool. Overall more than 25 farmers cultivating cereals were surveyed and more than 100 individuals were communicated to. Agronomic evaluation of more than 40 fields of sorghum, sesame and wheat fields was conducted during the mission and visit to farmers.

The availability and quality of the data used in the review and situation analysis is of fundamental importance. Several sources of data were used in the current review: a) FAOSTAT data on national area, production and yield of selected crops, trade, import and export; b) 2015 KSA Agricultural Census data covering large number of production parameters to the level of regions within the country; c) 2018 KSA General Authority of Statistics data covering key production parameters to the level of regions within the country; d) Variable data from research papers, publications, web sites, etc. Frequently the same data from different sources would be different. One example is yield data for sorghum, millet and sesame which varies almost 2-fold depending on the source. In such cases the data was not used at all. While analyzing and presenting the data in this document the main approach was not to mix data from different sources. The source of the data is always mentioned in the document.

Collection and verification of statistical data is an important activity and will benefit all components of SRAD project.

The structure of the review covers socio-economic and agro-ecological characteristics of the target regions; current status of rainfed cereals production including cropping systems, genetic resources and varieties, production technology, crop protection. The review of institutional framework includes research and extension, varieties release, seed production and quarantine, value addition, marketing and cooperatives. Stakeholders analysis is followed by SWOT matrix. The document is concluded with description of interventions and implementation strategy.

2. Crops production and food security in KSA.

Most of Saudi Arabia is desert with variable soils and lack of moisture to grow crops. However, the total area under the crops and vegetables in the country is around 1 million ha with the majority of the land irrigated. According to the General Authority for Statistics, the main crops grown in 2018 were alfalfa (421,060 ha); barley (93,861 ha); wheat (89,756 ha); other cereals (84,714 ha), primarily rainfed sorghum and millet; winter vegetables (46,766 ha), mainly potato and watermelon; summer vegetables (36,239 ha), mainly watermelon and tomato. In addition, date palms occupy around 115,000 ha, fruit trees – 30,000 ha and greenhouses for vegetables and flowers – around 3,000 ha. There are more than 1 million olive trees in the country. Livestock is highly important sector in the country with the total number of sheep 17.5 million, goats 2.8 million, camels 1.4 million and cattle 0.4 million. Poultry production accounts for around 200 million chickens. The distribution of five main crops (barley, wheat, rainfed cereals, alfalfa and vegetables) across 13 country provinces is presented on the map on Figure 1.

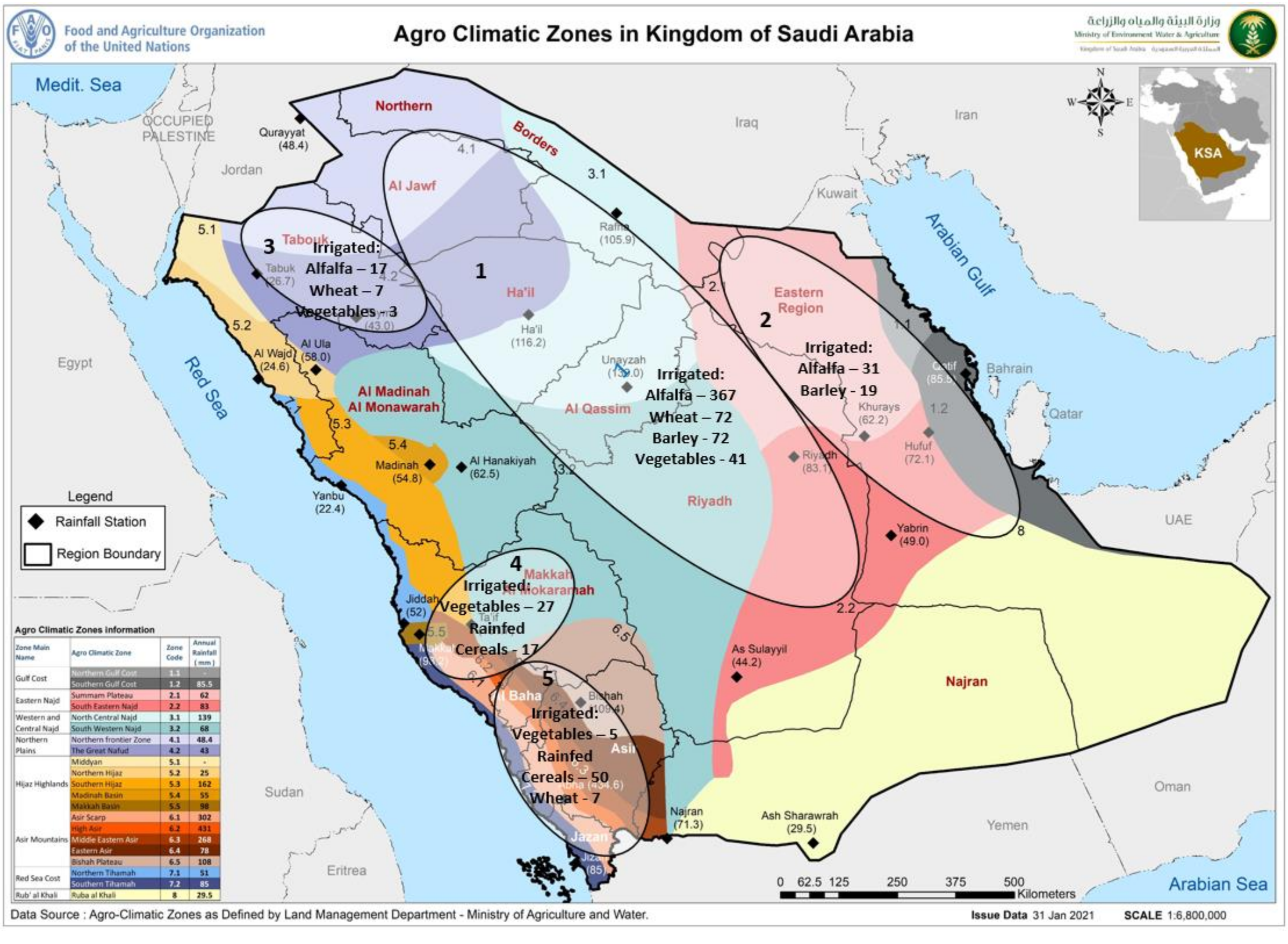


Figure 1. KSA agroclimatic zones and distribution of the major crops in 1000 ha based on 2018 GAS data.

There are five distinct crop productions areas:

1) Central irrigated region across provinces Al Jouf, Hail, Al Qassim and Riyadh. This is the largest production region with the total cultivated area exceeding 0.6 million ha or 60-65% of all cultivated area. Alfalfa was a dominant crop here, followed by barley, wheat and vegetables.
2) Eastern region grows alfalfa and barley under irrigation.
3) Tabouk region is characterized by cultivation of alfalfa, wheat and vegetables.
4) Makkah region is dominated by irrigated vegetables production with cereals (wheat, barley, sorghum) primarily under rainfed conditions.
5) South-Western corner of the country has mountains, higher rainfall and production is dominated by sorghum and millet, vegetables and fruits are grown under irrigation.

Overall, the crops area is very dynamic and responds to the government policies and regulations for different commodities.

The structure of agricultural production is driven by two major factors: food security and availability of land and water resources. Most of the irrigation water currently comes from non-renewable underground aquifers and there is an increasing concern not to utilize these sources for agricultural production. The restricted land and water resources and fast-growing population result in negative balance of the major food commodities (Table 2). For four staple cereals crops (barley, wheat, rice and maize) the country imported almost 14 million tons of grain in 2018 according to FAOSTAT database. This is ten times higher than domestic production. The situation is better for fruits and vegetables where on average 30-40% of the needs imported. The lamb and goat meat production meets around 75% of domestic demand while eggs and fresh milk production fully satisfy country needs and export exceeds import. Dates production has export potential with around 10% of the volume exported in 2018.

Table 2. Area, production, import and yearly per capita supply for major crop commodities in KSA in 2018 (Source: http://www.fao.org/faostat/en).

Crop	Area, ha	Production, 1000 MT	Import, 1000 MT	Import, % of production	Yearly per capita supply, kg
Wheat	94,786	518	1,366	264	100
Rice	0	0	1,828	All	55.6
Barley	90,336	505	7,658	1516	-
Maize	7,847	45	3,051	6780	28.1
Sorghum	50,165	124	8	6	3.4
Millet	4,492	9	14	156	0.45
Sesame	1,658	3	51	1700	n.a.
Alfalfa	421,060	4,431	n.a.	0	n.a.
Potato	18,058	425	265	62	16.1
Pulses	4,664	15	171	1140	4.8
Tomato	11,919	274	294	107	15.0
Onion	1,965	25	381	1524	11.4
Dates	116,125	1,428	1	0	37.1
Grapes	3,778	100	74	74	4.48
Beef	-	42	126	300	4.55
Lamb and goat	-	121	35	29	4.55
Poultry	-	554	640	116	35.0
Eggs	-	286	41	14	7.84
Milk	-	2,363	973	41	40.9

264

All

1516
6780
6
156
1700
0
62
1140
107
1524
0
74
300
29
116
14
41

Bedada (2020) report on cereals in KSA states that annual consumption of sorghum, sesame and millet was estimated at about 203,000, 36,000 and 15,000 tons, respectively, much higher than the amount actually produced (FAO, 2018). To meet this demand additional amount had to be imported. The KSA imported 3,423 metric tons (MT) of sesame seed valued at 5.34 million USD and 179 MT of sesame oil valued at 9.06 million USD. During the same time the country was net importer of sorghum and millet with quantity of 8,523 and 14,930 MT valued at 3.6 and 4.8 million USD, respectively (FAO, 2018). There is high demand locally and in foreign market for these crops which is motivating local production.

The FAO defines the food security in the following manner: "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (CFS, 2014). The four pillars of food security are availability, access, utilization and stability. From this perspective, the availability, safety and the price for food is of fundamental importance independently if the food is produced locally or imported from outside.

Woertz (2020) reviewed the Gulf Cooperation Council countries strategies on food security. The water scarcity at home increasingly compromises agricultural production. Farmland investments abroad have not matched announcements due to a complex mixture of commercial, socio-economic and political factors. The failure of such strategies has prompted a shift of focus towards value chain management to secure food availability. Rather than trying to fight food import dependence, the Gulf countries now accept and manage it. The Gulf countries find themselves in a relatively privileged position: their global supplies of agricultural products are unlikely to dry up in the foreseeable future, while their modern food value chains that are dominated by supermarkets and capital-intensive processing plants are less vulnerable to COVID-19-related disruptions. Securing food focusses now on the management of value chains. Food availability is not the primary issue – having proven to be manageable. The obesity epidemic highlights that food security is rarely an issue of lacking calories but appropriate diet, nutrition and lifestyle.

Based on 2020 Global Food Security Index (https://foodsecurityindex.eiu.com), KSA has been ranked 38 overall including rank 8 for availability, 40 for quality and safety, 42 for affordability and 112 for natural resources and resilience. The strengths are low proportion of population under global poverty line; presence and quality of food safety net programmes; access to financing for farmers; nutritional standards; food safety; change in average food costs; food loss; agricultural import tariffs. The weakness is public expenditure on agricultural R&D which is a way too small. KSA rank for Global Food Security Index was higher compared to countries with developed agriculture and production resources such as Brazil and Turkey.

3. Population, rural development and farm structure in the project target regions

The total population of the four target regions exceeds 13 million people and area exceeds 238 km^2 (Table 3). This is respectively 37.1% and 11.1% of the total country population and area. Makkah region and Jeddah mega city are the main contributors to population. The overall rural population in the Kingdom is around 16% and population of agricultural households is 6.4%. However, it is substantially higher in the target regions, especially Al-Baha, Aseer and Jazan where the population of agricultural holdings is 10.8-22%. This demonstrates the rural nature of the target regions.

Table 3. The total population, share of farming community and land area in four target regions (2015 Agric. Census data)

Parameter	Makkah	Aseer	Jazan	Al-Baha
Number of governorates	12	12	14	7
Population total	9,033,491	2,308,329	1,637,361	533,000
Number of agricultural households	60,663	69,373	20,985	11,665
Population of agricultural households	461,400	509,093	177,061	83,415
Population of agricultural households, % of total	5.1	22.0	10.8	15.6
Total area, km^2	140,100	76,693	11,671	9,921

Rural development is determined as set of developmental measures to reach the wellbeing of the rural population by implementing projects, where effective measures, such as investing into infrastructure, increasing the living standard, stimulating and supporting education and improving the living conditions complement each other (Kaposzta et al. 2018). The author case studied the rural development of a village in Aseer region of KSA. The conclusion was that the land use of a village (balance between agricultural use, rangelands and buildings) was very important for planning rural development.

There is clear disparity among KSA regions in access of houses to electricity, piped water and sewage services (Gazzeh and Abubakr, 2018). This study reported that southwestern regions had the least access to the essential services. The piped water on premises was available at 10% of housing units in Al-Baha, 21.3% in Aseer and 53.3% in Jazan compared to 87.7% in Riyadh or 57.1% national average. The access to public sewer system was respectively 3.6% (Al-Baha), 26.1% (Aseer), 10% (Jazan), 59.5% (Riyadh) and 34.8% (National). Overall FAO-SRAD project targets less developed and more rural regions of KSA.

The concept of farm structure has been an important tool to evaluate the production environment and possible interventions for enhancement (National Research Council, 2002). There are no publications on the farm structure as such in KSA and the information has been collected from available open sources on key characteristics:

- Size (measured in land area or farm sales) and size distribution. Average farm land in Al-Baha, Aseer and Jazan is almost ten time smaller compared to the national average. The number of agricultural holdings with land is 60,715 in Makkah; 69,465 in Aseer; 20,997 in Jazan and 11,667 in Al-Baha. The respective number of agricultural holdings without land which focus on livestock is 16,585 (21.5%); 6,938 (9.1%); 6,723 (24.3%) and 405 (3.4%) while national average is 17.8%. This demonstrates that the role of livestock is more pronounced in Makkah and Jazan regions putting additional pressure on land use to provide the forage. The data on distribution of the farms according to their size on regional level is not readily available. However, compared to the main irrigated agricultural production regions of Riyadh, Qassim and Hail, the share of medium and large farms is much smaller.
- Number of agricultural operations. This is defined by the farming system practiced in the target regions which depend on the agro-ecology and location of the farms in lowlands, mountain foothills or mountains. Generally, rainfed cereals production is less intensive compared to other crops and requires

less operations. However, due to environment the land is always occupied by crops and farmers are constantly engaged in production.

- Technology and production characteristics of agricultural operations. The rainfed cereals production system in the South-West of the country is characterized by the use of low input conventional technologies and old traditional varieties or landraces. The level of mechanization of the field operations is low as many activities are done manually. According to 2015 Agricultural Census, the total annual consumption of diesel fuel in the country was 1,826,288 tons, while 4 target regions consumed only 68,250 tons or 3.7% of the total diesel use. The annual diesel use per agricultural holding with land ranged from 0.14 t in Al-Baha to 0.44 t in Makkah while national average was 6.4 t reaching 24-25 tons per holding in irrigated areas of Riyadh and Qassim. So, the rainfed cereals production in the target region leaves very low carbon footprint.
- Extent and pattern of vertical and horizontal integration. The nature of the small cereals farmers implies limited integration either horizontal or vertical. However, horizontal integration is extremely useful for adoption of innovations as well as for marketing the products. In the flash flood crop production system several framers are united to manage the water in the valleys after the rainfall. Unless they agree on how to manage water in their farms together their crops would fail. So in Southern Tihamah region the level of horizontal integration is high.
- Characterization of the workforce, including age, gender, ethnicity, education, experience, skill level, and part-time versus full-time status of the operator. According to 2015 Agricultural Census, the total number of permanent labour in the farms with land exceeded 505,000 people including 37% of Saudi. The four project target regions housed more than 207,000 permanent labour including 46% Saudi. As mentioned earlier the South-western region has only 16% of agricultural land but employs more than 40% of total permanent agricultural labor. This is indicative of relatively labor-intensive farming system in the target regions and low level of mechanization. The number of permanent labour working on farm varies from around 1.2 in Makkah and Aseer to around 2 in Al-Baha and 3 in Jazan (Table 4). The contribution of family members to farm work is also highest in Al-Baha and Jazan – on average one individual is fully involved in farm operations. Considering the labour per unit area – Al-Baha is by far the highest (4.4 permanent and family labour) followed by Aseer (1.94). The educational level of the permanent farm labour is presented in Table 5. The share of labour without education and illiterate is in a range of 40-50% for Saudi nationals and 75-90% for non-Saudi. This indicates low level of education for labour which is probably used for field work with crops or animals. The low educational level is to be factored in extension and dissemination of technology as well as advancing methods of better farm management and market integration. Overall farm labour availability and cost represent a major challenge for farm operations.

Table 4. Involvement of labour for farmers in 2015 (Source: Agric. Census)

Region	Average family size	Type of labour per farm:						Average farm size, ha	Average labour/ha
		Permanent		Family members	Transit		Permanent and family		
		Saudi	Non-Saudi		Saudi	Non-Saudi			
Makkah	7.6	0.44	0.72	0.39	0.01	0.46	1.55	1.91	0.81
Aseer	7.3	0.50	0.56	0.45	0.03	0.45	1.51	0.78	1.94
Jazan	8.4	1.02	1.05	0.99	0.01	1.50	3.06	3.58	0.85
Al-Baha	7.2	1.09	0.60	1.08	0.01	0.77	2.77	0.63	4.40
KSA average	7.9	0.67	1.11	0.61	0.08	0.81	2.39	12	0.20

Table 5. Educational level of permanent labour for farmers in 2015 (Source: Agric. Census)

	Category	Total	Illiterate	Read and write	Elementary	Intermediate	Secondary	Diploma	University
Makkah	Saudi	26,652	30.4	15.1	10.6	13.2	18.7	3.5	0.1
	Non-Saudi	43,954	27.2	48.8	12.8	5.1	2.6	1.0	1.2
Aseer	Saudi	34,709	18.5	21.9	8.5	8.6	17.7	11.8	0.7
	Non-Saudi	38,709	39.1	45.5	9.2	3.0	1.6	0.5	0.7
Jazan	Saudi	21,483	31.9	22.2	10.8	10.4	12.6	4.1	0.1
	Non-Saudi	22,016	64.0	28.7	3.8	0.9	0.7	0.9	0.6
Al-Baha	Saudi	12,691	28.1	17.6	11.3	11.5	16.9	9.4	0.3
	Non-Saudi	6.968	37.6	45.8	8.6	5.2	1.8	0.6	0.2
KSA	Saudi	189,792	19.5	16.5	11.6	13.5	20.9	7.9	0.6
	Non-Saudi	315,306	33.3	44.7	11.2	4.5	3.1	1.3	0.8

4. Agro-ecological and soil characterization of the rainfed cereals target regions (Al-Baha, Aseer, Jazan, Makkah).

MoEWA agroecological division of the south-western region is presented on Figure 2. The respective maps of individual regions are presented in Annex 2. The key characteristic of the region is the mountains stretching from south-east to north-west. The air masses from the Red Sea bring the moisture with westerly wings which precipitates at the slopes and valleys providing suitable conditions for crop production. The air temperature in the mountains and foothills is also cooler compared to coastal plains. January and July mean air temperature and annual rainfall for 10 agro-ecological zones are presented in Table 6. The high Aseer zone has areas exceeding 2,000 masl with temperatures 8-10ºC lower compared with the coastal zones and with rainfall exceeding 400 mm. The western slopes of Aseer mountains receive slightly more rainfall compared to the eastern slopes but also slightly warmer throughout the year.

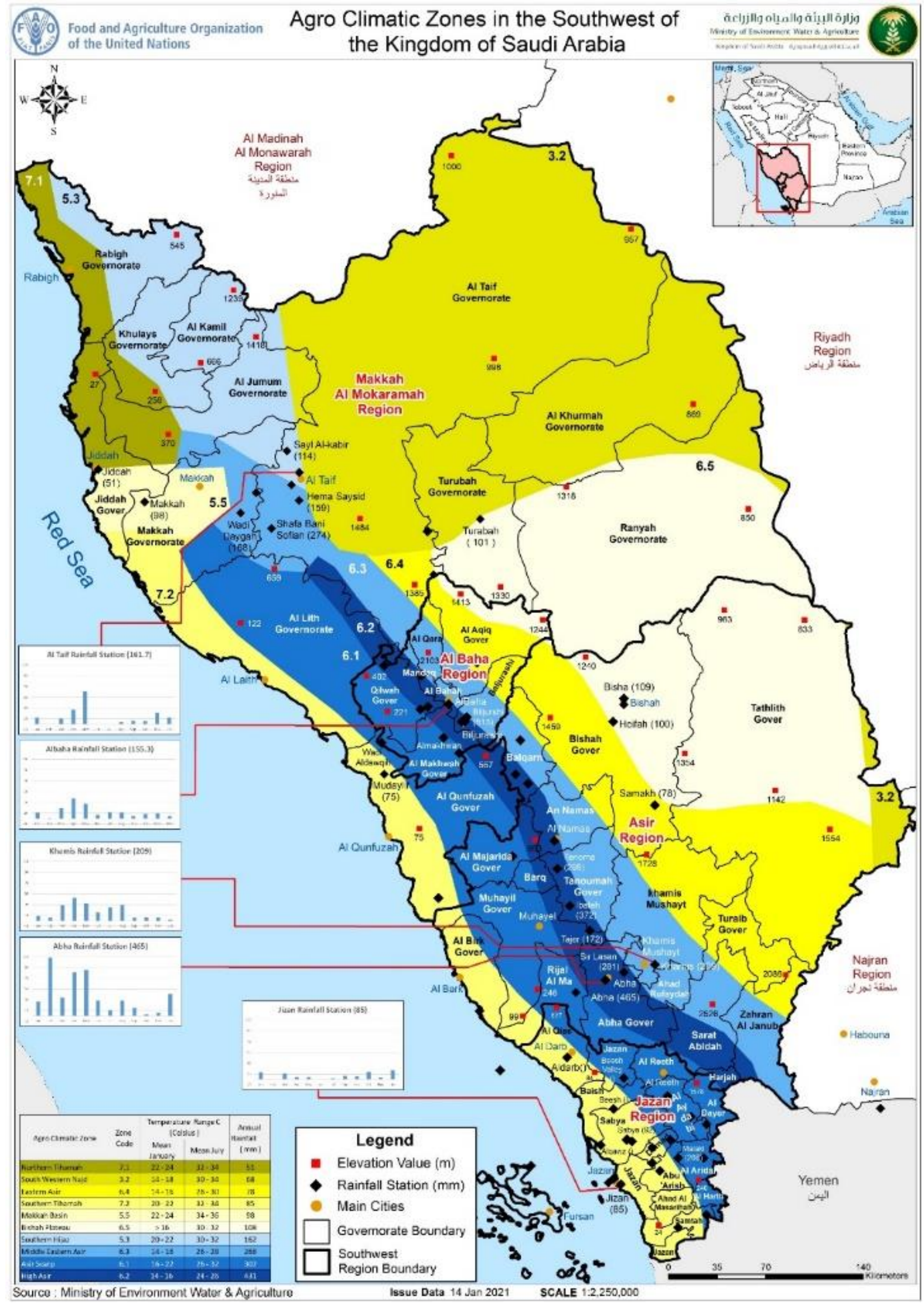


Figure 2. Agroecological division of the South-western part of KSA.

Table 6. Climatic parameters of agro-ecological zones from the target regions.

Agro Climatic Zone	Zone Code	Temperature Range, °C		Annual Rainfall, mm
		Mean January	Mean July	
Northern Tihamah	7.1	22 - 24	32 - 34	51
South Western Najd	3.2	14 - 18	30 - 34	68
Eastern Aseer	6.4	14 - 16	28 - 30	78
Southern Tihamah	7.2	20 - 22	32 - 34	85
Makkah Basin	5.5	22 - 24	34 - 36	98
Bishah Plateau	6.5	> 16	30 - 32	108
Southern Hijaz	5.3	20 - 22	30 - 32	162
Middle Eastern Aseer	6.3	14 - 16	26 - 28	268
Aseer Scarp	6.1	16 - 22	26 - 32	302
High Aseer	6.2	14 - 16	24 - 26	431

Rainfall pattern is important agro-ecological parameter, especially for component of rain fed cereals. Seasonality of rainfall determines the cropping pattern. From limited two years data on monthly rainfall for meteo stations given in Statistical Yearbook 2017 and 2018, the average monthly rainfall for KSA and for target regions derived and plotted (Figure 3). During the course of deliberations with colleagues in MoEWA, more detailed data analysis on rainfall can be done. The component team may develop suitable writeup on cropping of rainfed cereals taking into consideration the pattern of rainfall.

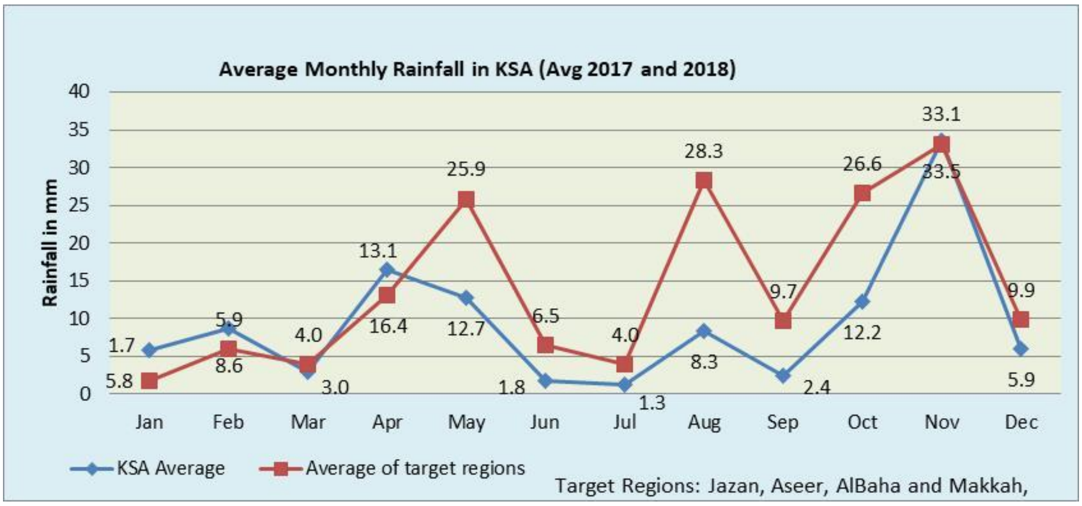


Figure 3. Average monthly rainfall distribution in the target regions KSA overall.

Detailed agro-ecological description of the south-western part of the country is presented in MoEWA publication "Field survey, remote sensing and GIS based evaluation of rangelands", volume IV. The publication provides regional maps for land use, rainfall, temperature, humidity, soils, geomorphology, slopes, vegetation communities and biomass. There is also rangeland vegetation species inventory. The soil map of the regions with four provinces is presented in Figure 4. There is great diversity of soils represented by 43 types and sub-types. However, leptosols and arenosols are two dominant types in four south-western regions. There are also alluvial fluvisols suitable for agriculture. These soils are along the valleys from Aseer mountains to the Red Sea.

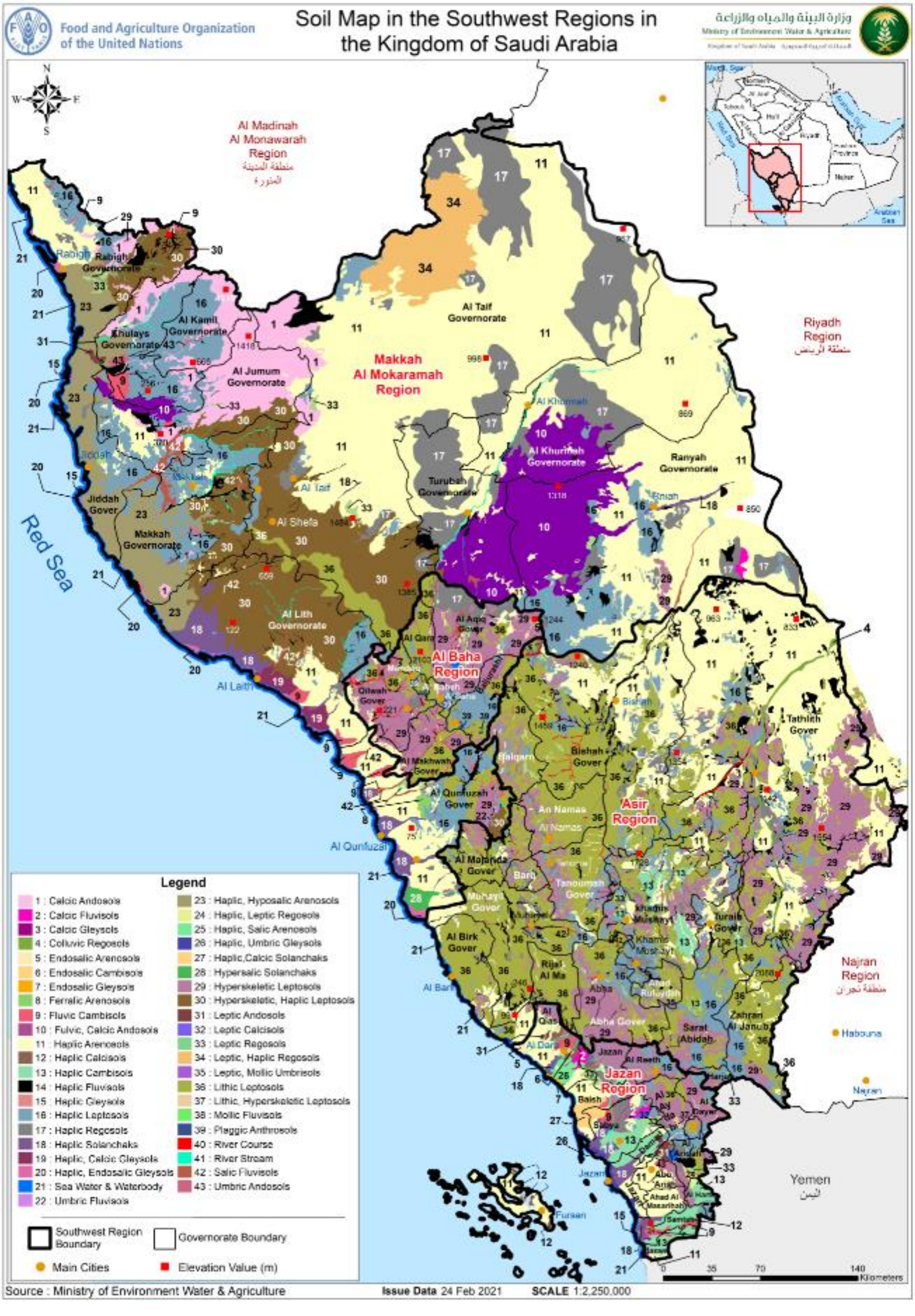


Figure 4. Soil map of the four target regions.

Shadfan et al. (1984) reviewed the mineral composition of soils in the country. It was affected by the rocks from which they were derived. Igneous and metamorphic rocks of the Arabian Shield affected the soils in the west, while sedimentary rocks had great influence on soils of the central and eastern regions. The mineralogy of Jazan region soils was studied by Al-Farraj (2008). The landforms of the region are mainly of alluvial nature formed by downward transportation of soil materials from the highland by valleys and channels that drain into the sea. The average sand content of five soil samples collected from different landscapes exceeded 55% while silt was around 30% and clay – 11%. Kaolinite was found to be a main mineral from the clay faction and it contributes to fertile soil characteristics. The study confirmed that the composition of the bedrock and old weathering are major factors contributing to soil evolution. However, air transmitted dust from surrounding arid regions also contributed to composition of clay minerals.

Aba-Husayn et al. (1980) studied mineralogical properties of soils along a 500-km north-south transect in the mountainous Aseer region. Soils developed on stable landscapes at higher elevation (> 2,000 m) have well-developed profiles and near neutral soil pH's. Soils developed on alluvial terraces near wadi banks at lower elevations (> 1,500 m) have deep but less developed profiles, and slightly greater than neutral pH's with carbonates present. Clay fractions of the soils are composed mainly of kaolinite, smectite, vermiculite, mica and chlorite minerals. Kaolinite is the most abundant clay mineral of the soils developed on well-drained highland areas. Smectite is the most abundant clay mineral in the alluvial soils developed on lower terrace areas.

De Pauw (2002) published detailed description of agroecology of Arabian peninsula addressing a range of factors contributing to suitability of land for agricultural production. Overall, the lowland areas and mountain foothills of Jazan and Aseer are suitable for production of sorghum, millet and sesame while the highlands are also suitable for production of wheat and barley. Moisture availability, yearly and seasonal patterns of rainfall and high temperature remain the major limitations for cereals production.

Bedada (2020) report provides following summary of agro-ecologies in the target regions. The climate here varies from hot and humid near the sea in the coastal plain with mean annual rainfall of only 150 mm to relatively cool and humid in the mountains with the rainfall of 400-600 mm year-1 (Masrahi, 2012). Aseer has an area of about 100,000 square km containing Red Sea coastal plains, high mountains, and the upper valleys of the wadis (seasonal watercourses) Bishah and Tathlith. It receives annual rainfall of up to 500 mm and is an important agricultural region. Makkah covers an area of 153,128 km^2 along the western part. Al-Baha has an area of 9,921 km^2 and Jazan covers an area of 11,671 km^2. The region has the highest population density in the Kingdom. The main agricultural land area of Jazan lies in the coastal plain where alluvial silts and fine sands from the highlands are deposited in the valleys, thus enhancing the fertility of the soil. Soils in these areas are generally blackish-brown or dark brown in colour, indicating the presence of high organic matter. Although the annual rainfall is low in the coastal plain of Jazan region, it falls typically as thunderstorms, filling the main channels and tributaries of wadis. The mean monthly rainfall reported for Jazan by Alfarhan et al., (2005) varies between 4 and 17 mm for February and December, respectively, while the daily mean temperature fluctuates between 30 and 39^{o}C for February and August, respectively. This erratic rainfall represents the main source of irrigation for seasonal agriculture. Some agricultural areas are located on mountain terraces.

5. Rainfed cereals production in KSA: history, statistics and current status.

Archeological history of South-West

The Arabian Peninsula, situated between Africa and Eurasia, is a key to narratives of global hominin dispersals. Traditional emphasis on the Nile-Levant corridor as the primary Paleolithic dispersal route between Africa and Eurasia has recently been challenged by evidence for dispersals across the Southern Red Sea during low sea stands. Paleolithic (from 2.6 million years ago to about 12,000 years ago) occupation of the South-West region of KSA (Jazan and Aseer) was documented by Inglis et al. (2014) in early-late Stone Age by collecting the artefacts from the sites in the region. Neolithic (10,000-2,000 years BC) settlement occurred within an environmental context of increased monsoonal moisture. Bronze Age (3,000-1,000 years BC) in the region exemplified by village- and town-scale settlements occupied by sedentary farmers relied upon terraced rain-fed and runoff agriculture (Edens, 1998). On the fringes of the Arabian desert, settlements were traced back to between 3600 and 2800 B.P., and even earlier. In contrast to the highlands, these societies relied upon food production from large-scale irrigation systems dependent upon wadi floods. The Bronze Age settlements, while showing some links with the southern Levant, now show equal or stronger linkages with the Horn of Africa across the Red Sea. So rainfed crops farming in South-Western region of KSA is millennial long tradition. Due to dry and hot climate sorghum and millet were the main crops cultivated by early farming communities. These crops originated in Africa and were brought across the Red Sea by human migrants. The system of their cultivation in using the terraces, rains, catchments and floods remained largely unchanged from ancient days till now.

The water supply in Saudi Arabia, and specifically the lack of water has always been the major constraint on agriculture and the determining factor on where cultivation occurred. The kingdom has no lakes or rivers. Rainfall is slight and irregular over most of the country. Only in the southwest, in the mountains of Aseer, accounting for three percent of the land area, the rainfall is sufficient to support regular crops. This region plus the southern Tihamah coastal plains sustained farming. Along the western coast and in the western highlands, groundwater from wells and springs provided adequate water for self-supporting farms and, to some extent, for commercial production.

Modern agriculture

Kim and van der Berg (2018) provided concise account of agriculture development in KSA. Since 1960s nomadic pastoralism declined as a result of several political and economic changes. New legal structures such as the 1968 Public Lands Distribution Ordinance created novel land relations and led to the dissolution of the Bedouin way of life. The establishment of a modern state provided incentives for large numbers of Saudi citizens to enter the regular, wage-based, or urban commercial employment. Until the 1970s, sedentary agriculture saw few changes and declined in the face of foreign imports, urban drift, and lack of investment. Introduction of mechanical water pumping in certain areas led to a modest level of commercial production, usually in locations close to urban centers. During the late 1970s and early 1980s, the government undertook a targeted program to modernize and commercialize agriculture. Indirect support involved substantial expenditures on infrastructure, which included electricity supply, irrigation, drainage, secondary road systems and other transportation facilities for distributing and marketing produce. Land distribution was also an integral part of the program.

The 1968 Public Lands Distribution Ordinance allocated 5 to 100 hectares of fallow land to individuals at no cost, up to 400 hectares to companies and organizations, and a limit of 4,000 hectares for special projects. The beneficiaries were required to develop a minimum of 25 percent of the land within a set period of time (usually two to five years) to obtain full ownership. In 1989, the total area distributed was more than 1.5 million hectares. Of this total area, 7,273 special agricultural projects accounted for just under 860,000 hectares, or 56.5 percent; 67,686 individuals received just under 400,000 hectares or 26.3 percent; 17 agricultural companies received slightly over 260,000 hectares, or 17.2 percent. The average fallow land plot given to individuals was 5.9 hectares, 118 hectares to projects, and 15,375 hectares to companies. The government also mobilized substantial financial resources to support the raising of crops and livestock during the 1970s and 1980s: interest-free loans to farmers for well drilling and casing; purchase of farm machinery, pumps, and irrigation equipment. There was official procurement program, purchasing locally produced wheat and barley at guaranteed prices for domestic sales and exports. The procurement price was steadily reduced because of massive overproduction and for budgetary reasons, but it was substantially higher than international prices. The government also granted import monopolies for some agricultural products to the SAGO, while procurement and import subsidies on certain crops have been shifted to encourage a more diversified production program. Agricultural and water authorities provided massive subsidies in the form of low-cost desalinated water, and electric companies were required to supply power at reduced charges.

The program prompted a huge response from the private sector with rapid increase in land brought under cultivation and agricultural production. Private investments went mainly into expanding the area planted for wheat. Between 1983 and 1990, the average annual increase of new land brought under wheat cultivation rose by 14 percent. A 35 percent increase in yields during this period further boosted wheat output; total production rose from 1.4 million tons per year in 1983 to 3.5 million tons in 1989. Saudi Arabia was the sixth largest wheat exporter in the early 1990s.

The 2000s witnessed gradual decrease in grain production and expansion of alfalfa. The government regulates the irrigated crops production through commodity prices and quota for land allocated to irrigated crops. MOEWA identifies the priority commodities for the country "stable state" to ensure safe and nutritious food for all in a stable and sustainable manner: fish, red meat, chicken, fruits and vegetables, edible oils, sugar, dates, milk, rice, wheat and four compound feed ingredients (barley, corn, clover and soybean). The "emergency state" targets quick and reliable provision of affordable, safe and vital commodities: chicken, edible oils, sugar, dates, milk, rice, wheat and four compound feed ingredients (barley, corn, clover and soybean). However, the inclusion of the commodity into priority list does not mean that it has to be produced locally but can be imported. Rice is a good example as it is not produced in the country at all due to its high water demand but imported and its diversity abundantly available in the stores.

USDA FAS (2021) report suggests that wheat production area decreased from 71,000 to 67,000 hectares in 2020-21 season, with an average yield of approximately 6 MT per HA, as many farmers found it more profitable to produce alfalfa than wheat. Saudi's decision to reduce domestic forage cultivation by 42.5 percent dissuaded large producers from domestic forage production, although smaller sized farmers were exempt from this regulation. In the 2020/21 crop year, SAGO increased the maximum local wheat production cap to 1.5 MMT per year until MY 2022/23. However, it has been difficult for SAGO to convince local farmers to produce wheat at the maximum set production level since farmers make more money by planting alfalfa in place of wheat. Alfalfa produces for up to three years and yields between 6 - 9 cuts a year depending on the Kingdom's region and weather conditions. While, MOEWA licenses local wheat production, SAGO is the monopsony buyer of licensed production. Traditionally, Saudi Arabia grows a hard-winter variety known as "Yecoro Rojo" that was developed by the International Maize & Wheat Improvement Center in cooperation with the Mexican Ministry of Agriculture in Mexico. Saudi wheat is preferred by SAGO due to its hard kernel and a lower moisture content than imported wheat. These two attributes allow for extended storage times.

<u>Suitability of sorghum, pearl millet and sesame for dry and hot environments</u>

Bedada (2020) reports summarizes comparative advantage of rainfed cereals crops in southwest of the country. Sorghum is known for its drought tolerance among cereal crops because of dense and deep root system, an ability to reduce transpiration through leaf rolling and stomatal closure, and its capability to reduce metabolic processes to near dormancy under extreme drought. Because of these, sorghum can survive dry periods and resume growth once soil moisture becomes available (Wagaw, 2019). Millets are also among the major cereal crops that are mainly cultivated in marginal environments. The unique character of millets is that they are all grown under extreme environments having inadequate moisture and poor soil fertility which are poorly suited to the major crops of the world (Baker 2003). Similar to maize and sorghum, millets possess a C4 photosynthesis system (Brutnell, et al. 2010 and Warner and Edwards, 1988) hence, they prevent photorespiration, and efficient in utilizing the scarce moisture present in the semi-arid regions. Since C4 plants are able to close their stomata for long periods, they can significantly reduce moisture loss through the leaves.

Pearl millet is the only millet being grown in Jazan region of Saudi Arabia which has hot, dry and sandy soil based production environment. Research reports indicate that pearl millet inherited the ability of its wild progenitors to aggressively colonize disturbed habitats and adaptation to difficult crop production regions tolerating heat and drought (Jukanti et al., 2016). Pearl millet has also inherited behaviors of dormancy which provided the ability to tide over unfavorable climatic conditions and also to germinate under favorable climatic conditions. Profuse tillering coupled with the ability to produce new tillers under favorable conditions also contributes to enhanced development and reproduction. Abundant seed germination, survival and viability, rapid growth and development, and relatively good seed set under moisture and heat stress conditions are observed in pearl millet and make it a crop of choice in these regions. A deep root system coupled with a short life cycle enables pearl millet to be grown in areas with low rainfall (Panaud 2006), unfavorable for other cereals such as maize or sorghum.

Sesame is an herbaceous annual plant requiring 80-130 days to attain physiological maturity and can fit well in agro-ecologies having short growing period. Sesame has high agronomic importance as it adapts to harsh environments that other food crops cannot tolerate. It is a low-input crop. It does not need as much water as corn and wheat. Even under conditions that reduce sorghum yields, sesame performs well due, in part, to an extensive root system but it requires adequate moisture for germination and early growth.

Rainfed cereals production statistics

The conversion of crop production into modern irrigated systems did not affect rainfed areas in the south-west of the country where sorghum is a predominant crop followed by pearl millet, sesame and wheat. This rainfed system largely remains unchanged based on traditional varieties and cultivation practices. The general agricultural statistics for the project four target regions is presented in Table 7. The country total number of farms with land exceeded 285,000 according to 2015 Agricultural Census. The four target regions housed more than 162,000 farms or 57.1% On the other hand, the four regions area under these farms was only around 252,000 or 7.4% of the total land registered under farms in the country. Indeed, the land size per farm is below 1 ha in Aseer and Al-Baha. The arable land is even less that that since cultivated land is below 50% of total area. The artesian wells reach fossil non-renewable water and it was available to 90% of total cultivated land in the country while rainfall source of water is accountable for only 3%. In the four target regions, crops grown under rainfall account for 40%. Other renewable sources of water in this region include flood water, manual wells and various water reservoirs. Overall, very limited non-renewable water is used for cereals production in the target region making them environmentally friendly and sustainable.

Table 7. Total agricultural area, number of farms and irrigation sources in four target regions in 2015 (Source: Agric. Census)

Region	**Number of farms with land**	**Average farm area, ha**	**Total area, ha**	**Including irrigated by:**	
				Artesian wells, %	**Rainfall, %**
Makkah	60,715	1.91	116,051	28.4	41.8
Aseer	69,465	0.78	53,920	33.7	30.9
Jazan	20,997	3.58	75,066	48.7	44.8
Al-Baha	11,667	0.63	7,394	34.7	39.3
Target regions	162,844	1.73	252,431	36.3	39.2
KSA total	285,166	12.0	3,421,854	90.5	3.0
Target regions % of total	*57.1*	*14.4*	*7.4*	-	-

The official statistical information for cereals provides only overall country data and break down for wheat and barley. There is no official statistics for sorghum, millet or sesame or rainfed cereals at the level of regions as such and efforts are needed to collect relevant information. However, the values for "other cereals" can be calculated based on the available data. The "other cereals" almost entirely include sorghum and millet with very little area of corn, probably 5,000 ha in the whole country. The data for all main crops in the target regions is presented in Table 8 and Figure 5. South-West of the country has negligible contribution to production of barley and forage crops including alfalfa. For wheat – the region contributes almost 10% to overall production area growing this crop mainly under rainfed conditions or irrigation using rainfall catchments. Sorghum and millet main production zone is in the South-West with area exceeding 60,000 ha contributing almost 80% of total production. Among the regions – Jazan is the main producer followed by Makkah and Aseer. Open field vegetables are important in Makkah region and to lesser extent in Jazan. Otherwise rainfed cereals dominate the production system.

Table 8. Area under major crops in four target regions in 2018, ha (Source: General Authority for Statistics)

Region	All cereals	Including (ha)			Forage crops including alfalfa	Summer and winter vegetables	Fruits*
		Barley	Wheat	Others (sorghum, millet, etc.)			
Makkah	18,951	400	1,166	17,385	1,126	27,591	2,396
Aseer	12,556	697	4,491	7,368	285	896	1,105
Jazan	43,276	131	2,817	40,327	1,539	2,793	4,258
Al-Baha	2,282	55	58	2,168	253	1,536	1,054
Target regions	77,066	1,285	8,532	67,248	3,204	32,636	8,813
KSA total	268,331	93,861	89,756	84,714	486,613	83,016	29,130
Target regions % of total	28.7	1.4	9.5	79.4	0.6	39,3	30.2

* - calculated based on the number of trees and 25 m^2 per tree.

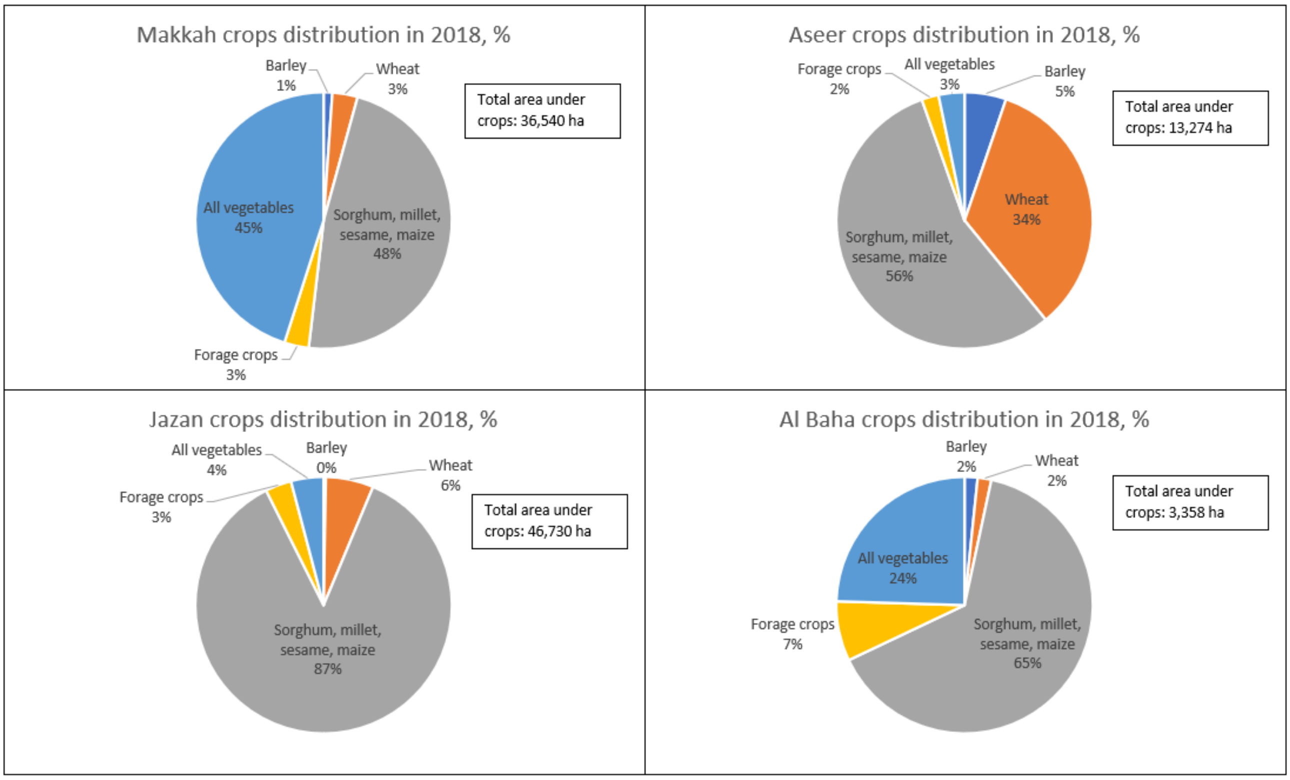


Figure 5. Crops area distribution in four target provinces (Source: General Authority for Statistics, 2018)

<u>National rainfed cereals area and production trends</u>

The FAO data for three target crops area and production from 2001 till 2019 is presented in Figure 6. There is an obvious tendency for reduction in area of sorghum by almost three times. The production respectively declined. This area decline is probably driven by reduced demand and lower prices for forage and grain, competition from fruits and vegetables, increased labor costs, consumption transition from traditional to modern diet. There was a market for sorghum grain to be used as seeds for forage sorghum in irrigated areas of Riyadh and Qassim. However, the overall reduction of irrigated crop production in Central part of the country negatively affected the demand for sorghum seeds. Sesame area was below 2,000 ha in early 2000s and then increased to beyond 3,000 ha in 2005-07 to drop again recently to around 1,800 ha. This area variation cannot be clearly explained as sesame seeds and oil are highly demanded to the industry. Millet area and production went through gradual decrease in 2001-2005 and bottomed up in 2006-2015 demonstrating the upward trend recently. The productivity showed a slight upward trend though the yield data precision is challenging to establish. There are a number of factors affecting the production trends: demographic (migration from rural areas and aging of farming communities), technological (utilization of traditional varieties and cropping practices), financial (cost of production versus the product size, subsidies), access to labor, rural and agricultural services, shifting consumption patterns and possibly others. The study on this subject is well justified. Overall, there is great potential for all rainfed cereals crops expansion both in area and in productivity. The target is to reduce the need for import for all three crops and for sorghum and millet possibly reach self-sufficiency in the long-term.

In the past ten years the total feed and fodder import to KSA has increased by more than double (from 0.88 Million tons in 2010 to 2.74 million tons in 2019) hence the demand is increasing rapidly (Figure 7). On the other hand, the unit import value is coming down from 410 USD per ton to 356 USD per ton. Thus, domestic forage production is losing its competitiveness and profitability of farmers would be reducing. This is important in the context of sorghum that has significant use as forage. Thus, improving cost efficiency of production on rainfed cereals and other such products is important for domestic production system to remain viable and sustainable.

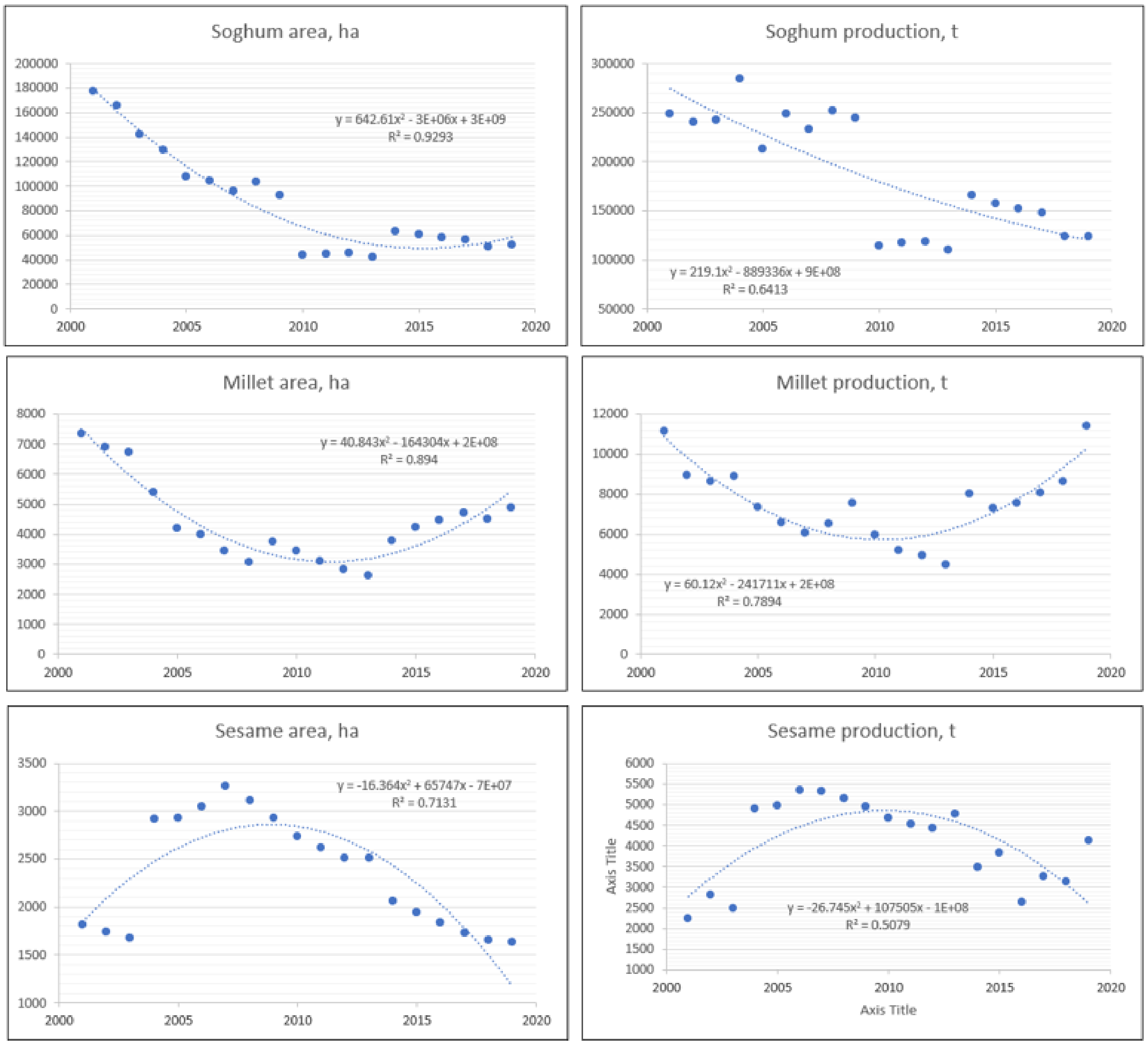


Figure 6. The rainfed cereals area and production trends in KSA in 2001-2019 (FAOSTAT data).

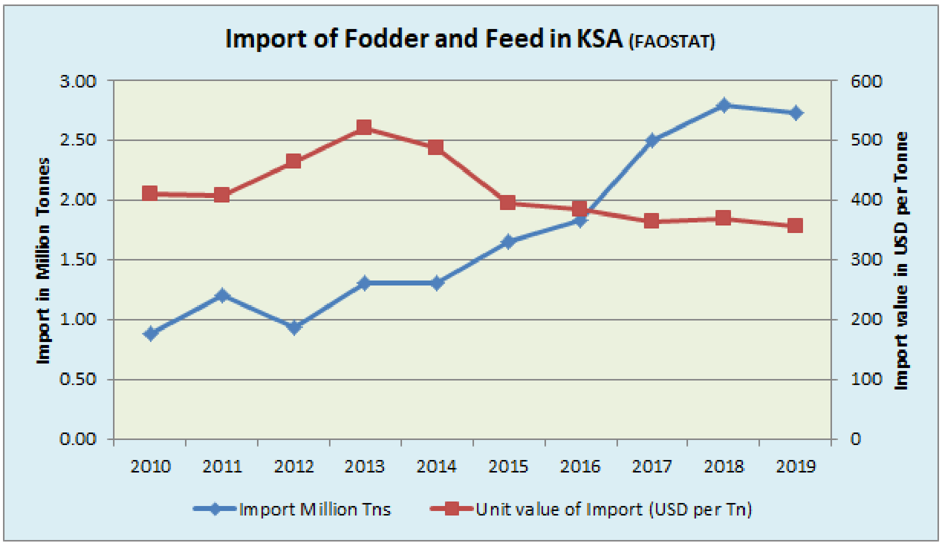


Figure 7. Volume and value of feed and fodder to KSA.

6. Farming/Cropping systems.

Analysis of the farming systems within which the rural population live and work can provide powerful insights into strategic priorities for rural development. A Farming Systems Approach recognizes the diversity of the livelihoods of farmers and provides a framework to explore various pathways that may offer an improvement in a changing world (Dixon, 2001). Rural development ultimately depends on the outcome of the daily decisions of millions of individual men and women. The challenge for governments, civil society organizations and the private sector is to provide the institutional environment and incentives that will enable farm households themselves to achieve agricultural growth and poverty reduction. A cropping system refers to the type and sequence of crops grown and practices used. It encompasses all cropping sequences practiced over space and time based on the available production technologies. Cropping systems have been traditionally structured to maximize crop yields. Study by Alzahrani et al. (2012) focused on potential of proper cropping pattern as a water demand management tool to enhance water and food security in Saudi Arabia. The objective was to optimize water demand management policy that will result in reduction of water usage and/or water demand. The analyses revealed that existing cropping pattern did not benefit from the relative advantage of different regions in producing different crops. Thus, there is a great potential for enhancing food and water security in Saudi Arabia through altering existing cropping pattern by encouraging production of different crops in the regions that have clear relative advantage. For example, production of cereals could be concentrated in Jouf and Tabuk areas, while vegetables production in the Eastern region and Aseer area.

The study and analysis by FAO-SA (Mekki Omer, 2018) identified four main farming systems in the South-West of the country:

A. Rainfed farming system:

Traditional rain-fed farming system is found in dry coastal zone of the southern Tihama plains, which receive an annual rainfall between 70 and less than 200 mm with high variability. Favorable climatic conditions are summer temperature and good water retention of sandy and sandy loam soils. The system zone in southern Tihamah extends on parts of Makkah, Asser and Jazan Regions covering 8690, 2782 and 6355 km^2, respectively totaling 17,844 km^2 (1,784,475 ha) and represents 7.4 % of the total area in the southwest region. It is dominated by growing millet, sorghum and sesame in the poor sandy and sandy loam soils and overlapped with raising of livestock (sheep, goats and camels). There are local cereal varietal crops, drought tolerant deep rooted capable of extracting moisture from lower depths and well adapted to this environment. The risk of drought is high with crop failure 3 years out of 5 years. The average farm plot is 1.5 ha divided at 1ha sorghum, 0.3 ha millet and 0.2

ha sesame. Cropping sequence is normally sorghum or millet followed by sesame. The livestock, including great number of small ruminants (sheep and goats) and camels interact strongly with this system by grazing on natural fallow land as well as the crop residues. In good years, rain-fed cereals are grown for grain, but when there is insufficient rainfall, it is commonly fed as forage to livestock. Manual labor with limited mechanization of tillage for land preparation and planting are normal cultivation operations. Estimate of total crop production cost from Quonfudah Governorate, Makkah Region reported 1000 SAR per dunam (10,000 SAR/ha), whereas the net income for grain sorghum, millet and sesame plus crop residues is 1300 SAR, 1200 SAR and 1500 SAR, respectively. Sorghum is most favorable crop to the farmers, probably due to its higher resistance to drought.

The sample crop calendar for the rainfed farming system

Crop	1	2	3	4	5	6	7	8	9	10	11	12
Sorghum	X	X						X	X	X	X	X
Millet	X	X	X	X	X							
Sesame	X	X	X	X	X							

B. Flood irrigation-based farming system:

This includes wadi spate flows generated by opening of dam gates to discharge irrigation water to downstream farmers as well as natural wadi flow. The flood irrigation system has led to the evolution of relatively large farm size investment, intensification and diversification of cropping pattern including high value cash and market crops like tropical fruit trees (mango, banana, citrus, Ziziphus spina-christi, fig) and vegetables (tomatoes, okra, watermelon and sweet melon, cucurbit and beans) as well as the traditional growing of millet, sorghum, sesame and fodder. Cropping pattern is sorghum/fodder/sesame followed by one of the vegetables with permanent fruit trees at 0.9 ha, 0.1 ha, 0.2 ha and 0.3 ha for sorghum, sesame, vegetables and mango, respectively. The cereals occupy 65% and other crops (vegetables and mango) 35 %. Except for the permanent fruit trees, variation exists in the adoption of these crops mix according to the size of land holding, market, return and financial resources of the farmers. Mango was the most favored fruit tree in the region of Southern Makkah and Jazan. Cereals and fodder are grown strictly under spate irrigation, whereas high value fruit trees and vegetables are supported by supplementary irrigation pumped from the recharged shallow wells drilled in the wadi plains. In case of low wadi flood, two supplementary irrigations are provided to sorghum, sesame and vegetables. Irrigation practices adopted is flood and modern system at 35 % and 15 %, respectively. Significant water table rises in irrigation wells is common impact with increases to 20 – 25 m compared to 50 – 60 m depth before spate flow. This system is associated with construction of large earth embankments to enable cascading the spate flow smoothly between farms from up to downstream and governed by traditional arrangements. Due to the nature of this flood irrigation system the soils are annually renewed by silt accumulation providing deep soil profile of excellent sedimentary alluvial quality. It has a high water holding capacity which is sufficient to support cereal crop production without subsequent irrigation. This farming system is found on the western slope of the Aseer escarpment where it flattens into low gradient uplands and plains towards the Tihamah and the Red sea coast. The second area of this system is to the east of the escarpment, which is characterized by large catchments with a milder slope and extensively covered by terraces.

The sample crop calendar for the flood irrigation-based farming system

Crop	1	2	3	4	5	6	7	8	9	10	11	12
Sorghum	X	X	X	X				X	X	X	X	X
Millet	X	X	X	X							X	X
Sesame	X	X	X	X							X	X

C. Highland mixed farming system:

The highland mixed rain-fed farming system is the most important system in the region considering the number of farmers engaged in agriculture and association with terrace farming and cultivated areas. It is located at an altitude of about 1000 – 2400 meter asl in the semi-arid climate with annual rainfall between 250 – 300 mm, sand clay loam to sandy loam soils on valley plains, but shallow gravelly loamy sand soils on upland terraces; suitable temperature during the major cropping seasons (spring and winter) and availability of multiple valleys in the region, the most important of which is the Baesh and Damad valley in Jazan, Wadi Alganebein in Baha and Wadi Bawa in Taif. It covers two sub-systems in Aseer Mountains. The first is dominated by rain-fed cereals and vegetables cropping, with fruit trees on terraces and common in Aseer, Al-Baha and Jazan and part of Makkah. This sub-system includes wheat, barley, sorghum, and maize, variety of vegetables, pomegranate, peaches, almonds and olive. Coffee is traditionally the most important tree crop in Jazan mountain region. The second sub-system is based primarily on Apiculture (bee-keeping) on communal forest lands between terraces. The hilltops and foothill are cover with forests of significant importance to bee-keeping. Selection of the crop is based on farmer's choice as well as market potentials. Monoculture of cereals is grown during a season, or a mixed cereals with fruit trees and/or vegetables, or permanent fruit trees. Growing two crops in a year is possible when sustainable source of irrigation water is available. About 80 % of the terrace land is privately owned. The most important problems facing farming system are the small agricultural terrace holdings. Due to unpredictable water supply bench terraces are the most important technique of water harvesting on steep lands and it is often used in association with supplementary irrigation during dry periods from shallow wells with motorized pump sunk in wadi bed and construction of water tanks positioned at upper height and connected with regular polyethylene pipe for storing runoff. For overcoming the problems of the limited water storage capacity of water tanks and poor yield of wells; some farmers use more than one well and water tanks and modern irrigation systems for water savings. This system runs by small farmers and characterized by high labor demand and initial capital investment, account for the major portion of agricultural production in southwest regions. Previous survey by the MoEWA showed that about 30 % of landowners own farm machinery, whereas the rest rent from the neighboring farmers.

The sample crop calendar for highland mixed farming system

Crop	1	2	3	4	5	6	7	8	9	10	11	12
Wheat/barley	X	X	X	X	X	X			X	X	X	X
Sorghum/maize				X	X	X	X	X	X			

D. Irrigated farming system:

This is either small-scale or relatively large irrigated farming systems occuring widely across the region. The small-scale system draws water from shallow aquifers recharged by flood water and permanently irrigated. The major crops grown within small-scale irrigation schemes in open and closed green house systems, are high value horticulture and industrial crops. The cropping pattern of this farming systems and its level of crop production is influenced by capital, marketing, labor, transport, economic capacity of farmer, technological and institution and policy induced factors, and hence farmers earning. The specialized crop production and market-oriented farming has been increasingly adopted to transform agriculture activity from a traditional and household subsistence level to modern, sustainable and profitable high-value cash agri-business level. Farm holding is relatively large with 2 – 10 ha and intensive technology use has enabled the small holding to provide remarkable economic return. The large, irrigated farming schemes are based on comparative advantage to access to permanent irrigation water resources such as dams and groundwater sources. In the southwest region there are around 66 dams of these types. The most stated challenge to this large-scale farming system is the variability of irrigable area annually which very much related to amount of rainfall in the catchment of the dam and hence water storage volume. The major crops grown within this system are mixed cereals, fruit trees, fodder and intensive vegetable cropping. Intensive technological packages of crop production are used with the irrigation-based farming system.

The sample crop calendar for irrigated farming system

Crop	1	2	3	4	5	6	7	8	9	10	11	12
Sorghum	X	X	X	X	X	X	X	X	X	X	X	X
Sesame	X	X	X	X							X	X

The summary of the four farming systems and related cropping patterns is presented in Table 9.

Table 9: Farming systems and cropping patterns practiced in southwest regions (modified from Mekki Omer, 2018)

Farming system	Cropping pattern			
	Aseer	Jazan	Al-Baha	Makkah
Rain-fed farming system (mainly coastal zone)	Sorghum, millet, sesame, animal production (goats, sheep, camel)	Millet, sorghum, sesame, animal production (goats, sheep, camel)	Animal production (small ruminants)	Millet, sorghum, sesame, animal production (goats, sheep, camel)
Highland mixed farming system	Wheat, barley, sorghum, maize, lentils, fruit, vegetables, bee-keeping	Wheat, barley, maize, fruit, sorghum, vegetables, coffee, spices, bee-keeping	Wheat, barley, fruit, vegetables, bee-keeping	Wheat, green house, bee-keeping,
Flood irrigation-based farming system (wadi system)	Sorghum, millet	Sorghum, millet, sesame, mango, banana, papaya, citruses, dairy production	Wheat, almond, pomegranate, peaches	Fruit trees (mango, banana, fig, citrus), vegetables (tomatoes, okra, watermelon and sweet melon), sorghum fodder, sesame, dairy production
Permanent irrigated farming system	Sorghum, sesame, vegetables, fruits	Sorghum, sesame, vegetables, alfalfa	Olive, grapes, citruses, vegetables (tomatoes, cucumber, pepper) open & in green houses	Pomegranate, almond, peaches, grapes, roses, flowers, mango vegetables open & green houses

7. Genetic resources and varieties

Sorghum and millet have been cultivated in South-Western part of Saudi Arabia for centuries if not millenia. Due to farmer's selection the local varieties evolved into well adapted, drought and heat tolerant genotypes with forage and grain quality highly suitable for local use. International scientific survey and collections of local varieties in the South-West were conducted in the 1980s by International Board for Plant Genetic Resources (1992). The collection expedition recognized six agro-ecological zones of sorghum and millet cultivation on the Arabian Peninsula.

1. Tihamah coastal plain and mid-altitude western foothills. Tropical semi-arid to arid regions with temperature exceeding 30ºC and annual rainfall under 220 mm mainly confided to summer. Three quarters of the area was under flood irrigation and one quarter was under regular irrigation. Rainfall increases to 400 mm at 1000 masl altitude in the mountain foothills. Sorghum is the main crop grown in summer and winter with estimated 250,000 ha (including Yemen). It is cut up to four times for fodder and then left to set the grain. Pearl millet area is around 20,000 ha.
2. The mountains of the southwest. This high-altitude region stretches for 1,000 km from Yemen to Aseer mountains and Taif. Mean annual temperature is around 18ºC at 2,200 masl and annual rainfall 300-1000 mm. Sorghum is grown in summer in wadis and rainfed terraces at estimated 700,000 ha, not less

than half of the cultivated land. It is a multipurpose crop being used for food and drink, fodder, building and as energy material. The pearl millet was grown at the altitudes up to 2,000 masl on area under 100,000 ha.

3. The mid-altitude inland region of the southwest. Within 600-2,200 masl to the east of the crest of the southwestern mountains, the main sorghum-growing areas are Lodar plateau, belt of oases stretching north Beihan and wadi Hidramawa region but on much less extensive basis. Mean temperature is 21-23^{o}C and rainfall is generally <200 mm. Sorghum is grown in summer and wheat in winter.
4. The Arabian Sea coastal plain. South of the high ground of the southwestern corner of the peninsula, sorghum and millet are grown in Kahej, Abyan and Ahwar deltas under 10,000 and 5,000 ha mainly using spate irrigation. Sorghum and millet are often grown in mixtures with cowpea or mung bean. Annual temperature is 29^{o}C.
5. Dhofar mountains of southern Oman. Very small area affected by monsoon. The crop used to be grown under rainfed conditions in the mountains behind the coastal strip.
6. Batinah coastal plain and foothills of Hajar mountains. Sorghum and millet were grown under irrigated conditions in Northern Oman on area under 1,000 ha millet being more common.

Collection of sorghum and millet in Saudi Arabia took place in 1989 and resulted in 21 sorghum and 3 millet samples which are currently maintained at ICRISAT Gene Bank. Five sorghum varieties were generally recognized: Azeida (or Maribi) and Zaar grown in Tihamah; Beida, Hajiri and Shoha were grown in the mountains. Zaar is similar to Beini which is commonly grown on the coasts of Red and Arabian seas. Considering south-western corner of the Arabian peninsula, at least three different types of sorghum are grown on Tihamah and other coastal areas. At higher altitudes, there were probably more than 20 main types, concentrated in the southern part of the mountains. Sorghum was identified as extremely important crop in Yemen with farmers generally attached to their traditional varieties. The modern varieties were tested but did not satisfy dual purpose requirements. Short statue variety Acsad was to be released at the time of collection. The collection mission in 1980s raised concern that agricultural development in south-western Saudi Arabia, introduction and spread of modern varieties would contribute to genetic erosion. However, this has not happened as the development did not take place and the same varieties are still grown in the region as of 2021.

In 1989 cereals collection was conducted by IBPGR in Aseer, Al-Baha and Taif regions (Guariono and Al-Juwaeid, 1991). The main crops in Aseer were wheat, barley, sorghum and alfalfa though millet, lentil, cowpea and sesame were also grown. The wheat area in 1982/83 was 14,500 ha but declined to 5,500 in 1986/87. The harvest was in June-July depending on the altitude. Crops are either only rainfed or irrigated from small wells. Improved varieties were gown by traditional farmers on very limited scale. Local wheat varieties were preferred though the state mills would accept only grain from the modern varieties. The number of samples collected during the mission is summarized in Table 10. At least one sample of the following wheat varieties or landraces was collected: Najran – Misani, Arbi, Zrai, Samra; Aseer – Humta, Ghiad, Seeb, Samra; Al-Baha – Humta, Kolani, Kobbari, Seeb, Asseria, Samra; Taif – Hanis, Makhlea. Most of these are durum wheats though Humta is bread wheat. Humta, Ghiad, Seeb and Samra are the main varieties in the mountains, the last being particularly widely grown. Each is recognized as having distinct agronomic features. The seeds were preserved in NAWRC.

Table 10. Crops collected in the regions of Saudi Arabia in 1989 (Guariono and Al-Juwaeid, 1991).

Crop	Number of samples collected:				
	Najran	Aseer	Al-Baha	Taif	Total
Bread wheat	0	3	6	1	10
Durum wheat	4	6	5	1	16
Barley	1	2	5	5	13
Sorghum	2	6	12	1	21
Millet (*Pennisetum* spp)	0	1	1	0	2
Maize	1	1	3	3	8
Finger millet	0	0	1	0	1
Setaria millet	0	0	0	1	1
Cowpea	0	2	4	1	7

Fenugreek	0	1	0	0	1
Alfalfa	1	2	1	0	4
Sesame	0	1	1	0	2
Total	9	27	40	13	89

The seeds from these collections which took place in the late 1980s are probably maintained in the Seed Center in Riyadh as well as outside of the country in ICRISAT and other institutions. The literature search did not identify collections of cereals between 1980s and very recent time. In 2010s, King Saud University collected 11 wheat (Qassim, Najran, Wadi e DawAseer), 4 barley (Jazan), 15 sorghum (Jazan) and 6 maize (Jazan) genotypes from farmer's fields of Saudi Arabia and evaluated for their morphological and genetic diversity (Alghamdi et al. 2017). Significant differences were observed in the morphological characters of tested wheat, barley, sorghum and maize genotypes under field conditions. Sequence-related amplified polymorphism showed substantial genetic diversity in the tested genotypes of all the cereal crops. All the genotypes of wheat and barley significantly differed for the plant height, productive tillers, 1000 grain weight, and days to 50% flowering and maturity. Similarly, sorghum and maize genotypes differed significantly for the leaf area and plant height. Existence of genetic diversity of collected wheat, barley, sorghum and maize genotypes offers opportunities to exploit favorable alleles for use in the breeding program aimed at yield improvement.

Al-Turki et al. (2019) collected five traditional crops from the Jazan region of southwestern Saudi Arabia: Sorghum: (*Sorghum bicolor* (L.) Moench); Barley (*Hordeum vulgare* L.) Millet (*Pennisetum glaucum* (L.) R. Br.); Sesame (*Sesamum indicum* L.) and Guar (*Cyamopsis tetragonoloba* (L.) Taub). Forty-one seed accessions of these five crops were collected and tested to determine seed moisture content (MC%) and quality as indicators of their potential to survive during long-term dry storage at -18 °C (i.e. ex-situ conservation of genetic resources). Seeds of the five crops had very low MC% and high viability (fully developed embryos and germination >91%), indicating that they were of good quality and had high potential for long-term survival in gene banks. The genetic resources of these crops (seeds) have now been preserved at the gene-bank of King Abdulaziz City for Science and Technology (KACST-BGB), Riyadh, Saudi Arabia. The collections sites were documented in the paper, however, there is no agronomic or morphological description of this collection.

Al-Turki et al (2020) described wheat genetic resources recently collected across the country. Farmers in the Kingdom have traditionally planted locally selected landraces of *Triticum aestivum* which have been inherited by many generations of farmers and their seeds represent genetic assets. The importance of these local wheat varieties lies in their capacity for adaptation to the extreme climatic conditions of heat and drought in the Kingdom. Sixty-one accessions of bread wheat (*Triticum aestivum* L.) were collected from eight different regions of Saudi Arabia: 28 accessions were collected from Al- Qassim region, 18 from Aseer region, five from Najran, four from Al-Taif, two from Al-Madina, two from Jazan, and one each from Al-Baha and Wadi Al-DawAseer. The study also showed that the geographical distribution of wheat crops is clearly concentrated in the Al-Qassim, Al- Taif and Aseer regions, which have relatively low temperatures and high rainfall. Al-Qassim region is famous for its agriculture with five landraces of wheat: Al-Juraba, Al-Ma'a-, Halba, Al-Ma'a- Samma, Hanttah-Najed (Hanttah-Al-Qassim), and Al-Qaimi. The Aseer area is also famous for the presence of some varieties of local wheat, including: Al-Mabia, Al- Qayyad, Smyran. In Al-Taif region, three different varieties of wheat were distinguished: Al-Nakhla, Al-Naqra and Hamis. In Al- Madinah region, the wheat farmers refer to the existence of another variety of wheat (Sindhi). It was clear from visiting different farms that > 126 varieties of wheat can be found in Saudi Arabia. For example, Al-Qassim region alone is famous for its cultivation of five landraces of wheat. Some varieties of wheat are concentrated in high mountains in Jazan region, such as in the Jabal-Fayfa and Jabal Al-Hashr mountains, which are also characterized by low temperatures and high rainfall. More collecting and preservation of wheat genetic diversity is urgently needed before these varieties disappear.

The farmers survey in 2021 identified the following rainfed cereals varieties grown by farmers:

- Sorghum: Zeir (red grain) normally used in summer; Beza (white grain) normally used in winter; Hamra (red grain, 2 months for maturity); Zeydi (Yemeni white grain, 4 months for maturity); Maflich (white grain, 4 months for maturity); Dura beysheti (red grain). All sorghum varieties are local type or landraces with tall stature up to 2.5-3.5 m. There is substantial diversity within the population.

- Millet: Romay, Misrahi.
- Wheat: Sip (longest vegetation, soft); Gyatz (long vegetation); Alhalba (drought tolerant, short maturity); Nabiya (short stature); Australian (susceptible to stripe rust); Llyabi. Most of the varieties seem to be modern semi-dwarf types.

Improvement of varieties grown through introduction, testing, evaluation and selection is one of priority activities for the rainfed cereals activities. There is also a possibility for improving local varieties through targeted selection.

King Abdulaziz City for Science and Technology (KACST) has established the botanical Gene-bank (KACST-BGB) along with the KACST-MUZ-Herbarium, and these are important accomplishments in terms of securing food security and preservation of wheat genetic diversity (Al-Turki et al 2020). The authors suggest that these achievements must be followed by large national research projects that contribute to the collection and preservation of plant genetic resources for all local and developing agricultural crops in all the Arabian Gulf countries. The paper concludes with three recommendations: 1) Establishment of several national centres for plant gene banks in various important environmental regions of Saudi Arabia; 2) Establishment of a regional centre for plant genetic banks to preserve plant genetic resources with the aim of collecting plant germplasm in the Arabian Peninsula and the Arabian Gulf region; 3) Establishment of botanical gardens in a strategic environmental region would contribute positively to the work of gene banks by identifying plant biological properties, by cultivating and maintaining many local plants and tracking their life cycle and stages of development.

Strategies for global *Ex Situ* conservation of genetic diversity for sorghum, pearl millet and wheat have been developed and available (https://www.genebanks.org/publications). These strategies can be used for development of comprehensive plan for PGR work on cereals in KSA. At present, there are 602 Saudi accessions stored outside of the country including 182 wheat, 43 sorghum and 2 millet (www.genesys-pgr.org). This outside collection comprises 209 traditional cultivars or landraces. The main holders are United Kingdom (182 accessions), USA (143 accessions) and Australia (78 accessions). One potential priority for KSA PGR program is to repatriate these accessions back to the country for characterization, evaluation and potential use.

Limited studies were recently conducted in Saudi Arabia on characterization and evaluation of cereals varieties. AL-Shoaibi, A. A. (2020) at Taibah University (Medina) studied combined effects of salinity and temperature on germination, growth and gas exchange in two cultivars of sorghum. The treatments contained 3 temperatures (20°C, 30°C, 40°C) and 4 NaCl concentrations (0, 50, 100, 200 mM). The results presented that as NaCl increased, germination, growth and gas exchange declined with greatest effects at 40°C than at the other temperatures. Proline was higher in the Hindi and Jazan cultivars at 20°C and 30°C under different salinity conditions. On the other hand, the chlorophyll content was increased at 20°C under increased salinity in both cultivars. The interactions between salinity and temperature significantly affected most measurements; however, Hindi cultivar showed more tolerance toward stress.

The current status of sorghum research and breeding has been summarized in a recent book "Sorghum in the 21st Century: Food – Fodder – Feed – Fuel for a Rapidly Changing World" (Tonapi et al, eds. 2020). Tremendous progress has been made in development of high yielding varieties with resistance to diseases and pests and satisfying the diverse uses of this crop. Hybrids are common across all major sorghum producing countries. Similar situation is for millet with hybrids competing well and providing high and stable yield with good quality (Serba et al. 2017). Improvements in plant stature, maturity, photoperiod insensitivity, discovery of cytoplasmic male sterility (CMS), and transfer of apomixis from wild relatives have led to increased grain and forage yields, nutritional quality, and enhanced disease resistance. Hybrids developed using CMS reportedly have an average of 50% higher grain yield than open- pollinated cultivars.

Tripathy et al (2019) reviewed sesame (*Sesamum indicum* L.) breeding and identified that narrow genetic base, less attention to genetic improvement and cultivation in marginal lands with poor management practices are the major constraints for increased yield potential. Sesame has ample scope to breed cultivars with greater yield, as the gap between the potential and realized yields in this crop is enormous. Capsule shattering leads to heavy loss of seed yield and the crop is sensitive to a wide array of biotic and abiotic stresses. Innovative breeding approaches such as mutagenesis, somaclonal variation, interspecific hybridization, somatic hybridization and genetic transformation can be used to restructure the plant's ideotype. In addition, identification of candidate genes/quantitative trait loci (QTL) and their monitoring in succeeding breeding cycles using molecular markers can pave the way for genetic improvement in sesame.

Genetic progress has been made in breeding all three major rainfed crops: sorghum, millet and sesame. However, this progress exemplified in new varieties and hybrids yet to reach the farmers on the southwest of Saudi Arabia.

8. Production technology

Bedada (2020) report provides description of current agronomic practices in rainfed cereals production with three scenarios in Jazan region.

- ❖ Scenario 1: Sorghum production in wetlands in which water level is receding as a result of the current change in climate. In this scenario sorghum is being grown on residual moisture remaining from the drying of wet lands. Farmers are trying to maximize crop production utilizing even pockets of wet lands with the remaining residual moisture.
- ❖ Scenario 2: Sorghum, millet and sesame are grown in flat lands without any external water application; only one day rain fall is utilized to grow the crops to maturity.
- ❖ Scenario 3: A scenario under which the crops are grown in terraces at the bottom of mountains with rain water harvested from the gullies and streams coming down from the mountains. In this condition farmers wait for the rain and use the harvested water to grow crops by just one time cultivation to make rows for planting sorghum after 15 days when the soil is dry enough to make rows for planting the crop. In this scenario farmers grow crops three times a year, for example, sesame-millet-sorghum. The first rain fed cultivation is summer cultivation in which crops are planted beginning in March until Mid-April and the second rain fed winter cultivation begins from mid-September to-end of November. The third planting is done in September using residual moisture. In the other two previous scenarios only one time production is possible. Under the third scenario rotation cropping is also practiced where the first crop is planted with one time rain and subsequent rotation crops are harvested two times. Farmers wait for the crop to come up with minimal intervention without any crop management practices.

These three scenarios correspond to the farming systems described above. In general, farmers in Jazan region grow sorghum, millet and sesame in rotation in any one of the scenarios indicated above. On average a farmer owns up to 2 hectares of land. They plant the first crop in August and then follow with the second one after harvesting the first crop in December. The rotation is usually Sesame-Millet and then sorghum. The report author saw green sorghum ready for harvesting in February, 2020. The crop was planted in December following the harvest of sesame which was planted in August as the first crop. The few farmers met during the mission reported average grain yield of up to 1.25 t/ha for sorghum and 0.65 t/ha for Millet and Sesame. These figures are low when compared to the average national productivity of 2.6, 1.69 and 1.86 t/ha respectively reported for sorghum, millet and sesame by FAOSTAT (2018).

Land preparation is usually done following the flooding of bottom lands with rain water harvested from rains received in the upper hilly areas. The rainwater usually comes with soils from the hills and farmers start preparing the soil for planting by simply making rows fifteen days after the flooding when the soil is dry but moist enough for land preparation and for planting seeds. They use tractor or animal drawn machine which make rows for planting sorghum. Crops are first planted in August to September except the second and third crops which are planted, respectively, in December and mid-March-April after harvesting the first crop to utilize residual moisture left over from the first crop. Both row and broadcast plantings are practiced depending on the crop. In most cases sorghum is planted in rows because of its relatively bigger seed size which is easy to plant. However, sesame and pearl millet are broadcasted. It is also possible to plant pearl millet in rows. Row planting was introduced through farmers own innovation rather than being brought in through research and extension as it has been commonly practiced in other countries. Under the current situation farmers are not applying fertilizer to their crops as the soil is fertile enough to supply plants with the necessary nutrients. No pesticides are also used to control weeds or insects. Based on this ground farmers justify their crops are organic as no chemicals, neither fertilizers nor pesticides, are applied. Data available on land use pattern indicate that organic agriculture covers 17,100 ha of land of which 12,500 ha are certified organic in Saudi Arabia (FAOSTAT, 2018).

In Aseer region sorghum is grown under two scenarios. In the first scenario it is grown on terraces which were constructed across slopes on mountain sides to harvest rainwater coming from the upper parts of the mountain. It is a practice that combines soil and water conservation with crop production. In the absence of rain, supplementary irrigations are given from rain water harvested in concrete tanks located up the hill so that water comes down to the crop field through gravity. The second scenario is growing sorghum in lowland areas harvesting rain coming from the mountains. In the valleys lying along the high-way heading from Abha to Muhayil farmers prepare plots of land tied by bunds on all sides so that whatever rain water comes down from the mountains would be captured and utilized for crop production. Sometimes dry planting is practiced so that seeds stay in the soil waiting for the first rain for germination and subsequent growth. In dry land agriculture this type of planting is practiced commonly to effectively utilize the first rain. The soil in this area is sandy since it originates from the rocky mountains hanging around the valley. A farmer growing sorghum on mountain Hadas (Mr. Shaye Al Asmeer) explained that whatever practices they are applying in crop production have been inherited from generation and nothing is from extension services.

Farmers plant sorghum through broadcasting in density much higher than the optimum as a result of which plants die because of competition for resources, such as soil moisture, which is critical problem in the region. Planting usually takes place in September in hilly areas with the onset of rainfall and the crops are harvested in December. Farmers store grains of their crop outside in sacks. They justify themselves saying this avoids storage insect pests which otherwise damage the grains if stored in the house. They have modernized the storage structure by putting certain heights above the ground so that termites and rodents will not get in contact with grains. They cover the grain with plastics and no damage can happen even if it rains.

The important source of information for rainfed crops production in the southwestern region is MOEWA report on farm survey prepared by M. Ahmed bin Saleh Al-Khamsi (2019). The report summarizes the production practices in Jazan, Aseer, Al-Baha, and Makkah (Taif Governorate) including 738 farms with total area of 283 ha (Table 11). The forage yield is as important as grain in all regions except Taif. Production costs vary 3-fold between the regions. There are numerous tables and graphs giving detailed explanation of the climate, distribution of crops, productivity and production costs. The report is in Arabic, but some tables and graphs have been translated into English and available from the authors of this report.

Table 11. Rainfed cereals area, production and its cost and water use in surveyed farms across four regions.

Region	Cultivated area, ha	Area per farmer, ha	Number of farmers	Production cost pe ha, SAR	Total production, t		Grain yield, t/ha	Production price, SAR	Irrigation Water, m3/ha
					Feed	Grain			
Jazan	80	0.84	90	3,693	741	103	1.3	1,035,000	102,300
Aseer	80	0.25	230	6,044	358	138	1.6	1,396,000	128,000
Al-Baha	62	0.44	142	3,892	151	40	0.7	485,000	45,000
Taif	61	0.34	181	2,800	0	58	1.0	573,300	58,100
Total	283		738			333			

Note: According to the average price prevailing in the market at the time of harvest, the selling price of a kilogram of sorghum, corn and wheat was 10 riyals, and therefore the price per ton = 10,000 riyals (10 riyals x 1000 kg).

The survey arrives to the following conclusions:

• There is a large production of several rainfed crops which contributes to 70% of self-sufficiency.

• Rainfed agriculture contributes greatly to the diversity of the sources of income, it is practiced by a large number of farmers with substantial contribution to job creation.

• Rainfed areas are characterized by a great variety of cereals crops that are used as food alongside the production of feed, and this in turn contributes to the nutrition of dairy and meat producing animals, and this production contributes to food security for the Kingdom.

• Each region was characterized by a specific type of crops, as the main crops in the Aseer region was wheat. While Al-Baha region was characterized by the production of sorghum and wheat crops. Sorghum, millet and sesame were grown in Jazan region. Sorghum crop is produced in all regions except Taif Governorate which has wheat as the main crop.

• Planting and harvesting dates varied in the regions. The date of planting in Jazan begins in early September and harvesting in the month of February, and this loop is called the autumn harvest. The second round starts in November and early December and extends through the months of January and February, while the third loop starts in the month of March and extends to the date of harvest in April and it is called the tab of the summer.

• Production costs were represented by the value of plowing the land and seeds and the cost of harvesting, which was the highest value, reaching 2760 riyals, per hectare on average, which represents 67% of the total cost per hectare and amounted to 4107 riyals.

The report provides the following recommendations which are important for the SRAD project: 1) Work to enhance farmers' knowledge of the services provided by agricultural associations for seasonal labor. 2) Providing agricultural machinery and equipment through associations or the agricultural fund for each governorate, provided that these machines are returned to them after the end of the harvest. 3) Facilitate marketing of rainfed crops through associations or relevant government agencies or holding exhibitions agricultural products during the harvest season to encourage the sale of products. 4) Facilitate access to and support of improved seeds that suit the climate of each region, which in turn increases productivity. 5) Encourage use of organic fertilizers to conserve soil from chemical fertilizer residues. 6) Apply discretionary prices, in order to improve the selling prices of production during the harvest period. 7) Improve the work of agricultural product markets in production areas and assist in developing methods of storing agricultural products. 8) Improve the ability to obtain financial services and adequate financing, especially during agricultural activities and harvest. 9) Encourage and motivate producers through cooperative agricultural societies and sending informational messages to farmers. 10) Improve agricultural sustainability of rain crops and making them one of the tributaries of sustainable development, as agriculture in rural areas encourage stability and development in these areas, thus reducing migration to cities. 11) Follow-up on extension fields during the growing seasons to provide information that helps in improving production and solving problems facing farmers. 12) Development of annually updated database of rainfed agriculture to know the areas suitable for rainfed cultivation and suitable crops for each region, by evaluating the annual productivity of each crop.

The literature search identified only one publication devoted to agronomic practices of growing rainfed cereals in KSA. Tounekti et al. (2020) from Jazan University studied seed priming of sorghum on germination and seed reserve utilization under drought stress. Seeds of three sorghum (*Sorghum bicolor* (L.) Moench.) varieties from southwest Saudi Arabia were used to investigate the potential of osmopriming with polyethylene glycol (PEG 8000) to improve germination performance, seed reserve utilization and early seedling growth and drought stress tolerance. The primed (PS) and unprimed (UPS) seeds of the three sorghum varieties were germinated for 8 days under increasing PEG- induced osmotic stress. The treatments were arranged in a completely randomized design, in a factorial arrangement, with three sorghum cultivars ('Zaydia', 'Shahbi' and 'Ahmar') and four osmotic potentials (0.0; - 0.4; -0.8 and -1.2 MPa) with four replicates of 50 seeds each. The results showed that drought stress affected seed germination and seedling emergence and establishment but increased the activity of the antioxidant enzyme catalase. Under increasing drought stress conditions, variety 'Ahmar' showed the highest yield stability index in comparison to the other two varieties during the seedling establishment stage. Therefore, the former variety can tolerate better a rigorous water stress condition. ‘Zaydia’ appears to be the most vulnerable to drought stress.

Relevant research on weeds management in sorghum fields was conducted in Arkansas, USA to evaluate various herbicide treatments, including sequential and tank-mix applications for weed control in grain sorghum (Bararpour et al (2019). The herbicide treatments used were quinclorac, atrazine + dimethenamid-p, S-metolachlor followed by (fb) atrazine + dicamba, dimethenamid-p fb atrazine, S-metolachlor + atrazine fb atrazine, S-metolachlor + mesotrione, and S-metolachlor fb prosulfuron. All herbicide treatments provided excellent (90% to 100%) control of *Ipomoea lacunosa, Ipomoea hederacea var. integriuscula*, and *Sida spinosa* by 12 weeks after emergence. Quinclorac and S-metolachlor fb prosulfuron provided the lowest control of *Ipomoea lacunosa*, *Urochloa platyphylla*, *Amaranthus palmeri*, and *Ipomoea hederacea var. integriuscula*. Weed interference in the non-treated control reduced grain sorghum yield by 50% as compared to the weed-free control. S-metolachlor + mesotrione and S-metolachlor fb prosulfuron reduced sorghum yields by 1009 to 1121 kg ha^{-1} compared to other herbicide treatments. The five best herbicide treatments in terms of weed control and grain sorghum yield were quinclorac, atrazine + dimethenamid-p, S-metolachlor fb atrazine + dicamba, dimethenamid-p fb atrazine, and the standard treatment of S-metolachlor + atrazine fb atrazine. The project will test no-till/reduced till production system with ground cover/cover crops to maximize the soil water retention and reduce use of herbicides (Sims, B.; Corsi, S.; Gbehounou, G.; Kienzle, J.; Taguchi, M.; Friedrich, T. Sustainable Weed Management for Conservation Agriculture: Options for Smallholder Farmers. Agriculture 2018, 8, 118. https://doi.org/10.3390/agriculture8080118

There is a range of publications on application of modern production technologies for all three rainfed crops. Sorghum: Lubadde et al (2019) - Sorghum production handbook for Uganda; Prasad & Staggenborg (2011) - Growth and production of sorghum and millets published by Kansas SU; Stichler et al. - Grain Sorghum production South and Southwest Texas; Myers (2002) - How to grow sesame, Jefferson Institute.

Two recent publications address successful practices of sesame production. Dossa et al (2017) summarized sesame production in West Africa’s Sahel. The region is characterized by a dry and hot climate with limited rainfall that impairs the production of crops. Sesame is a resilient crop that is well suited to this environment. Investigations were made in four major sesame-growing areas of Senegal and Mali, into the status of the crop’s production, its agronomic practices, the challenges farmers face and their preferences concerning the traits that should be improved. A total of 256 sesame producers in 47 villages were interviewed using a semi-structured questionnaire. The results showed that sesame is a multi-ethnic crop and only 20% of the total fields owned by farmers were allocated to its cultivation. The yield and the seasonal production of sesame per farmer was quite weak showing that this crop is still a commodity grown on a small scale. Various cultivars were grown, and the most widely grown ones have considerable levels of oil (53–60.34%) and protein (18–21.89%) contents. In both countries, seed marketing was the main impediment the producers faced on account of a lack of reliable markets and of a considerable fluctuation in prices. Overall, the sesame sector is still traditional but is progressively developing and sesame could become an important cash crop for smallholders in West Africa’s Sahel. Research programs should target the release of the varieties with higher yield, a stronger resistance to drought, heat, diseases and pests, a good seed quality and improved plant architecture.

Myint et al (2020) described sustainable sesame (*Sesamum indicum* L.) production through improved technology in Myanmar. The global sesame market demand is rising with increasing health awareness. There is high competition in the market among producing countries for an international trade. Smallholder farmers in developing countries cultivate sesame as a cash crop on marginal soils. For sustainable production of sesame, an integrated approach is needed to overcome the challenges and the critical limiting factors should be identified. In recent years, sesame genomic resources, including molecular markers, genetic maps, genome sequences, and online functional databases, are available for sesame genetic improvement programs.

9. Crop protection

KSA is a member of International Plant Protection Convention and General Manager of Plant Health Department, MoEWA is a Focal point. However, the country profile at IPPC web site lacks the information on the status of crop protection, pests, quarantine and other issues.

There is a lack of studies and publications on occurrence, distribution and losses from insects and pests of sorghum, millet and sesame in southwest of the country. Ai Nazmi (Nematology in Saudi Arabia - http://www.fao.org/3/v9978e/v9978e0k.htm) mentions that sorghum is affected by four major nematode species: Longidorus africanus, Meloidogyne javanica Pratilenchus spp and Tylenchorhynchus spp, however, again the spread and severity of infection is not clear. Moustafa et al (2015) from King Saud University in Riyadh evaluated spring bread wheat genotypes for resistance to cereal cyst nematode (Heterodera avenae Woll.) using field trials and molecular markers. The performance of 17 genetically diverse wheat genotypes (local and international material) were evaluated for two years (2009 and 2010) in a *H. avenae*-naturally-infested field at the Hail region, north Saudi Arabia. Results show that the tested wheat genotypes were significantly different in field performance and resistance to CCN. The grain yield ranged from 4.58 tons/ha for cv. Yecora Rojo (the susceptible) to 8.2 tons/ha for the genotype 15- SAWYT-31. Ten local genotypes were designated as resistant. The local cv. KSU 119 was the most resistant genotype (no. cysts/plant = 0.7) among all the genotypes tested. Ten out of 17 wheat genotypes (LNM-72, LNM-99, LNM-126, LNM-136, KSU118, L11-8, L11-17, L11-21, KSU 119, and AUS-30851) had both *Cre1* and *Cre3* genes and were found in the same sub-cluster. The spread of cereal cyst nematode needs to be clarified and evaluated in the target regions in the southwest of the country.

The seed-born fungi were identified on three sorghum varieties by Kassim (1985). The following species were identified: *Aspergillus glaucus, A. terreus, Alternaria alternata, Aureobasidium pullulans, Penicillum sp* and *Rizopus stolonifera*. Variety Shahla was most contaminated (50 colonies) followed by Red variety and white variety. The fungicides were applied and their effectiveness was the following: Ceresan, Benlate, Bavistin, Dethane and Vitavax. In a similar study, Mahmoud (2013) evaluated Aspergillus flavus and aflatoxin contamination of wheat grains from Saudi Arabia. Twelve species belonging to six fungal genera were found to be associated with wheat (*Triticum aestivum* L.) grain samples collected from three main regions in Saudi Arabia. The most common genera (average frequency) were *Aspergillus* (14.3%), *Fusarium* (29.1%), *Penicillium* (9.3%), and *Alternaria* (8.2%). Obviously seed born fungi diseases represent a challenge for both sorghum and wheat and need to be addressed for productivity enhancement through IPM approach.

Fusarium oxysporum is one of the main diseases of sesame and was observed in the fields in Jazan region. The work by Hassan et al (in press) aimed to evaluate the impact of the cultivation of some preceding crops and seed inoculation with antagonistic rhizospheric bacteria and actinomycetes on the incidence and development of Fusarium damping-off and wilt disease. Results showed that the lowest pre and/or post-emergence damping-off and wilt of sesame were recorded after onion and garlic, followed by wheat compared to clover in both the 2019 and 2020 seasons. In vitro, soil extracts from plots where onion and garlic have been cultivated slightly decreased the conidia germination and mycelium radial growth of *F. oxysporum*. Among all isolated bacteria and actinomycetes associated with sesame roots cultivated after preceding plants, the *Tricoderma viride* and Bacillus subtilis (isolate No.3) profoundly reduced F. *oxysporum* mycelial growth in vitro. When sesame seeds were inoculated with *Tricoderma viride, Bacillus subtilis, Streptomyces rochei and Pseudomonas fluorescens*, the disease incidence of damping-off and wilt significantly decreased in the greenhouse and field trials conducted in both tested growing seasons. The current study suggested that using the preceding onion and garlic plants could be used for eco-friendly reduction of damping-off and wilt disease of sesame.

10. Cereals research and extension

The National Agricultural Research System (NARS) of the MoEWA was established fifty years ago. Throughout these years it went through several restructuring processes with an objective to make it effective in the planning and executing of agricultural research in general and applied research in particular to overcome the production constraints of major cultivated crops in the country. This includes all crops cultivated under irrigated agriculture and those cultivated as rainfed cereals crops produced in the south western part of Saudi Arabia. Currently, NARS has six research centers (Table 12) preforming research activities to the best of their scientific infrastructure and human as well as financial resources.

Table 12. Agricultural Research Centers Operated by Ministry of Environment, Water and Agriculture

No	Title
1	National Agriculture and Animal Resources Research Center in Riyadh
2	Camel and Range Research Center in Al-Jouf
3	Date Palms Research Center in Alhasa
4	Horticulture Research Center in Najran
5	Organic Farming Research Center in Qassim
6	Agricultural Research Center in Jazan

It is worth mentioning that although NARS has long history, it has very serious limitations to do the research job in an effective and successful way. The main limitations include the following:

- Lack of well qualified, well trained and well experienced fulltime permanent researchers
- Small number of good technical supporting staff that can carry out accurately all kind of chemical and physical analysis and pathogenetic tests, etc. which are needed for successful research work
- Inefficient administrative and financial systems regulating the NARS daily activities
- Some of the research centers have no or insufficient (area wise) experimental fields
- The monthly income of local researchers and the promotion system of NARS is not attractive to convince bright and well experienced local researchers to join NARS.
- The policy makers of NARS have no systematic effort on the ground to develop the capacity building of its few researchers through on job training or through higher education at Master and Doctorate level.

The attempts to comprehensively improve the ability of NARS to effectively contribute to the flourishing of local agricultural sector were not successful because of their inability to address the challenges and have a tangible solutions for the above mentioned limitations. Relevant actions are to be taken to improve the current situation of NARS to contribute to the success of local agricultural sector. The possible may include establishment of an independent agricultural research authority with a mandate to activate agricultural research to be able to compete with international standards. At the beginning, this authority has to introduce a new framework that can overcome all obstacles and shortcomings which are hindering the execution of successful agricultural research.

Jazan Agricultural Research Center

Jazan Agricultural Research Center (JARC) is located in Abu Arish governorate in Jazan region at altitude of 150 meters above sea level. It was established in 1971 as a small research station to conduct agricultural applied research in a small scale. Several years later it was promoted to be a Research Center to carry out agricultural research in and around Jazan region. During its first few years especially in the late seventies and the beginning of eighties, some research on agronomic practices of cereals crops especially sorghum, millet and sesame was conducted. However, in 1982 the mandate of research of the Center was shifted to conduct its research on sub-tropical fruits such as Mango, Guava and Papaya. Mango varieties, introduced from India, America and Australia, have been planted in a field of 45 hectares at the center and are under evaluation for adaptation to the hot and dry environment. Currently the trials on these fruit crops are in advanced stage. Though there is no well-established linkage with farmers, seedlings are being disseminated to small scale farmers in Jazan region.

A recent visit to JARC by the cereals component revealed some important facts about the current situation of the Center. These facts can be summarized as follows:

- A strategic research plan for the year 2021 was received from the Agricultural Research Department of the MoEWA to conduct research on 6 to 7 activities that include sub-tropical fruit and cereals crops.
- A sesame research observation conducted on a 200 m^2 field to compare drip irrigation to that of flood irrigation. The sesame crop was harvested and the results analysis is going on.
- At the moment the JARC has only 6 research staff 2 of them have Bachelor degree indicating clearly very limited capacity of doing research work which requires supervision by well experienced researchers. The number of non-research staff is over 70 out of them 17 agricultural technicians working in mango plantation of the center field which has about 2700 mango trees of good imported varieties.
- The interaction with local farmers is limited to doing some soil analysis and visiting certain farms if they complain about plant diseases.
- There were some cereals activities from 1972 till 1982 on sorghum, millet, barley, wheat and sesame but unfortunately no publications and/or reports are available.

Seed Center

The Seed Center (established in 2012) and the Gene Bank are housed in the same facility in Riyadh. Overall, the Gene Bank houses 1400 species. The herbarium established in 1970s comprises 20,000 specimens from 129 families. The documentation is maintained using NCBI database from USA. The Seed Center prepares 840 samples to be sent to Svalbard Global Seed Vault in Norway. The Center has access to 9 stations across the country. The Center has several projects including one with ICARDA on seed multiplication and promotion of traditional varieties with progressive farmers in the South-West. This includes sorghum, millet, sesame, wheat and barley. Other projects are focused on development of facilities for the Center including field and greenhouse. There is also a project with SASC to establish genomic facility. The Seed Center is tasked to establish seed production and breeding programs for priority crops including cereals and vegetables. The potential areas for the Seed Center cooperation with FAO: 1)Assistance in assignment of accessions ID to their germplasm; 2) Seed systems development; 3) Establishment of breeding programs; 4) Repatriation of KSA genetic resources back to the country; 5) Identification of wheat genetic resources using genomic tools; 6) Collection of traditional varieties. The Seed Center is an important stakeholder and the will develop a cooperation framework.

Role of local universities in conducting agricultural research

There are five major universities with agricultural colleges as well as King Abdul Aziz City for Science and Technology (Table 13) conducting agricultural research

Table 13. Universities with Agricultural Colleges in Saudi Arabia

No.	Universities	Colleges
1	King Saud University	College of food & Agricultural Sciences, Agricultural Research Center 7 Research Chairs
2	King Abdul Aziz University	Faculty of Meteorology, Environment and Arid Land Agriculture, Water Research Center, Central Arid Zone Research Institute
3	King Faisal University	College of Agriculture & Food Sciences, College of Veterinary Medicine, 5 research centers
4	Qassim University	College of Agriculture & Veterinary Medicine Agriculture & Veterinary Sciences Research Center
5	King Abdullah University of Science and Technology (KAUST)	Desert Agriculture, Core Agricultural Laboratories Water desalination and Reuse Center, Desert Research Institute
6	King Abdul Aziz City for Science & Technology (KACST)	Life Science and Environment Research Institute Finding`s Agency

Although these universities and KACST have published huge number of papers on agricultural research, the bulk of that research is descriptive by nature and just on a few occasions these important bodies have conducted an applied agricultural research. In the south west of the country the production of rainfed cereals crops which includes sorghum, millet, sesame, wheat and barley is practiced for centuries. The available literature shows very little applied research that cover agronomic practices, supplementary irrigation, fertilization and plant protection of these crops was conducted by these bodies.

It is quite clear that the time has come to involve the agricultural research carried out by both NARS and Universities with agricultural colleges to maximize the production of rainfed cereals crops. That must include genetic improvement of major crops including sorghum, millet and sesame and develop through breeding with modern varieties, new varieties and release them for commercial production in south western regions of the country.

Extension

The extension system in the country is under MoEWA with central department in Riyadh and assigned staff across the country working in regional and governorate branches on MoEWA. The cereal component staff visit to Aseer and Jazan regions demonstrated their limited number and capacity in working with the farmers and contributing to their training and actual extension work. There is Agricultural Economics and Extension Department at King Saud University which is quite active in the work related to extension and publications. Baig et al. (2012) described extension difficult present and demanding future. The state has been making concerted efforts through its five-year development plans to develop its agriculture to ensure food security. However, in order to produce more food for the increasing population, the country realized its agricultural potential but at the cost of over-exploitation of its natural resources. The government has launched a new plan on the cultivation of crops that require less quantities of water. The government, academia and the researchers are convinced that the use of over-exploitation of water is not a sustainable practice. A balance between agricultural production and the use of its resources, particularly water, without harming the environment needs to be maintained. In this task, the role of Agricultural Extension has become more challenging and demanding. The extension work in the state is quite difficult and presents unique problems as the farms are being managed by the overseas workers who are unable to understand extension messages being delivered in Arabic or English languages. King Saud University (KSU) has developed an Extension Centre to promote sustainable agriculture in the kingdom.

11. Varieties release, seed production and quarantine

The International Union for the Protection of New Varieties of Plants (UPOV) was established in 1961 with the mission to provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants for the benefit of society. UPOV unites 77 members countries and organization (as of February, 2021) which adhere to rules and regulations on plants varieties testing, release and protection. KSA is not a member of UPOV and referred to category ii. “States and intergovernmental organizations which have been in contact with the Office of the Union for assistance in the development of laws based on the UPOV Convention”. There is no harmonized system of development or introduction of plant varieties, there evaluation for agronomic suitability, distinction and uniformity (as required by UPOV) subsequent release or registration and protection of varieties authors rights.

For the seed system two approaches are generally defined as formal and informal (https://www.agrilinks.org/post/seed-system-definitions). The formal seed system is a deliberately constructed system and involves a chain of activities leading to genetically improved products: certified seed of verified varieties. The chain starts with plant breeding or a variety development program that includes a formal release and maintenance system. Guiding principles in the formal system are to maintain varietal identity and purity and to produce seed of optimal physical, physiological and sanitary quality. Certified seed marketing and distribution take place through a limited number of officially recognized seed outlets, usually for sale. The central premise of the formal system is that there is a clear distinction between "seed" and "grain." To the knowledge of the authors, the formal system does not exist in KSA for rainfed cereals. There is no formal breeding program, variety release or registration system and seed certification following common steps.

The informal system, also referred to as a local seed system, is based on farmer-saved seed. These systems are dominated by farmer-saved seed where farmers themselves produce, disseminate, and access seed directly from their own harvest that otherwise would be sold as grain; through exchange and barter among friends, neighbors, and relatives; or sale in rural grain markets. Varieties in the informal system may be variants of improved varieties originally sourced from the formal system or they may be landrace varieties developed over time through farmer selection. There is no emphasis on variety identity, genetic purity, or quality seed. The same general steps or processes take place in the local system as in the formal sector (variety choice, variety testing, introduction, seed multiplication, selection, dissemination and storage) but they take place as integral parts of farmers' production systems rather than as discrete activities. While some farmers treat "seed" as special, there may be no distinction made between "seed" and "grain." The steps do not flow in a linear sequence and are not monitored or controlled by government policies, regulations or inspections. Rather, they are guided by local technical knowledge and standards and by local social structures and norms. The production of rainfed cereals in southwestern regions of KSA so far follows informal seed system. The farmers grow their own varieties using the seeds they obtain without special efforts to improve them.

Quarantine service is highly important to limit invasion of diseases, pests and weeds from outside of the country through seeds or planting material. MoEWA established a procedure for obtaining the import permit and evaluation of imported seeds. The current project plans to review to evaluate the quarantine system framework, capacity and efficiency through dedicated expert.

12. Value addition, marketing, sales

FAO technical report "Value Chain of Cereals (Sesame, Millet and Sorghum)" prepared by Mr Sanjay Kumar Gupta (2018) is the main source of information on the subject. The report presents detailed account of global and KSA area, production, productivity and trade from 2001 till 2016 using FAOSTAT data. The general value chain scheme is presented in Figure 8. The current marketing mechanisms are selling the grain to traders or directly to consumers. The forage is taken to market customers and sold on the spot. The recent visits and survey found that this scheme has been evolving towards direct sales of cereals products to consumers including through social media tools. The prices have also changed substantially since the study was conducted.

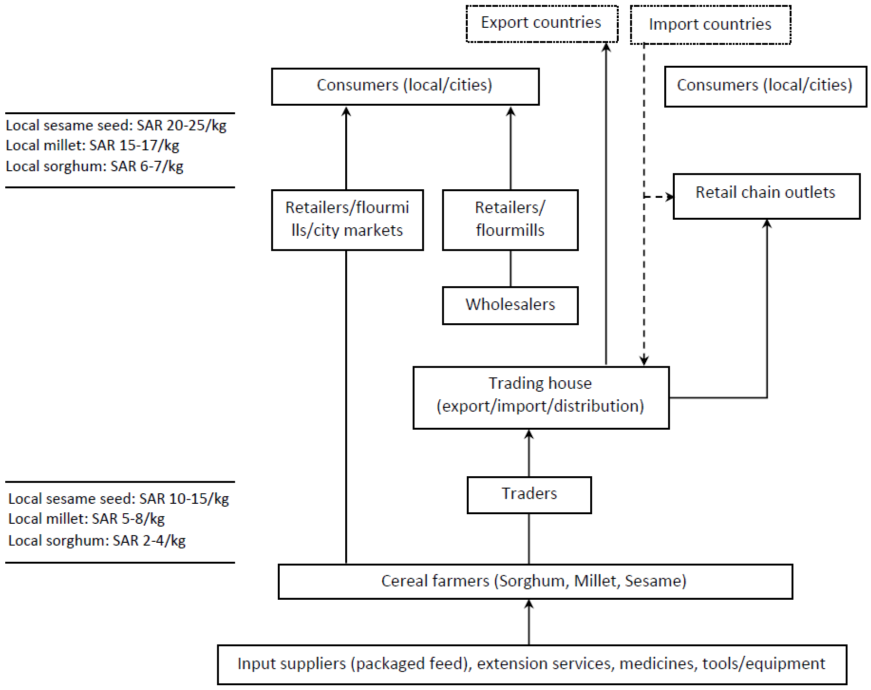


Figure 8. Value chain organogram of rainfed cereals in KSA, Gupta (2018).

Small farmers produce a number of rainfed cereals, but are unable to optimize the possible full economic benefits. This is due in part to inadequate knowledge of appropriate value-adding technologies coupled with lack of entrepreneurship and business skills and the absence of coherent policies to support such an undertaking in rural areas. Currently, little value addition is taking place at the small producers' end. There exist value addition opportunities in the form of organic cereals production, sesame oil unit, cereals flour units and food-based enterprises. However, most small producers find it challenging to make a transition as skill sets required for value added food business products is far more complex than just cereals production and selling. The report proposes three strategies to enhance market integration of farmers and value addition: 1) Direct linkages with the markets; 2) Cereals producers and cooperatives become retailers, wholesalers and exporters; 3) Promote cereals based microenterprises.

There are several relevant reports and research papers on value chain of sesame in West Africa (Dossa et al. 2017) and Ethiopia (Gebremedhn et al., 2019), millet in India (Dayakar et al, 2014), sorghum in Zimbabwe (Musara et al. 2019). They provide different options which can be applicable for production environment in Saudi Arabia.

One of the options for sorghum and millet value addition is improvement of the health benefits of their products through biofortification – increase of essential microelements like Iron and Zinc. Alswailem et al (2018) studied the prevalence of iron deficient anemia (IDA) within Saudi Arabian females to examine the risk factors leading to the IDA. A cross-sectional study on 683 healthy females aged between 18 and 40 years was performed within April 2016. Data on the participants' socio-demographics, diet, health, anthropometry, and hematological and biochemical iron status indices were gathered. The prevalence of IDA was 41.6%. In the multivariate regression analysis; inadequate iron and vitamin C intakes, infrequent (≤2 times per week) consumption of red meat and fish, menstruation disorder, blood disorder and previous blood transfusion, past personal history of IDA and familial history of IDA were significantly associated with increased odds of IDA. The country needs a multifaceted approach that incorporates iron supplementation, food fortification, rich dietary iron sources and by raising awareness of the food and drinks which facilitate or hinder bioavailability of iron.

Zinc is an important trace mineral for our body, the deficiency of which can cause many complications like inadequate or stunted growth, immune deficiency with increased morbidity, etc. In more severe cases, zinc deficiency causes hair loss, diarrhea, delayed sexual maturation, impotence, hypogonadism in males, and eye and skin lesions (Ahmed, 2017). Weight loss, delayed healing of wounds, taste abnormalities, and mental lethargy can also occur. Zinc absorption is inhibited by phytates (seen in cereals, rice, corn, etc) and cadmium (from environment). The aim of the study was to determine the prevalence of Zinc deficiency by testing about 1000 patients of regular out-patient clinic both genders between the ages of 15 -90 over a period of 6 months (in 2013) irrespective of any signs or symptoms. Out of 1000 patients about 440 (44%) patients were low in Zinc levels and treated for Zinc deficiency. There is probably Zinc deficiency in greater numbers in the general population which should be addressed before it becomes an epidemic if there is not one already. Most of the women with Zinc deficiency complained of hair loss.

These two studies demonstrating high occurrence of Iron and Zink deficiency in KSA have implications for sorghum and millet production. For both crops, there are successful biofortification programs to increase the concentration of these two elements in grain. These varieties with high Fe and Zn content shall be introduced and utilized in the country for the benefit of human population.

13. Cooperatives

FAO technical report "Value Chain of Cereals (Sesame, Millet and Sorghum)" prepared by Mr Sanjay Kumar Gupta (2018) provides short summary on cereals cooperatives in the country. Farmers, generally, work individually to source inputs (seeds, fertilizers, pesticides, equipment/tools) and sell the agriculture produce to markets/markets players. There are over 200 agriculture cooperatives societies in the country, which can be commodity specific to general ones engaged in multiple crops. These societies provide inputs such as seeds for feed crops and packaged feed for small ruminants. The agriculture cooperative society in Hawat Wani Tammim, for instance, was registered in 1982 but has been active for the last 5 years only after changing some members and the management team. Currently, there are 350 registered members who can get pesticides, feed crop seeds (sorghum and alfalfa) and packaged feeds at %10 discounted price. Members who devote time in the day-to-day operations and management expect monthly payment in return. However, they have been informed by the government agency to work voluntarily which they find strange. There is limited conceptual clarity among small farmers on the cooperative principles and capacity building support is required. Government established the Cooperative Societies Council on 17th March 2008 and got it formally affiliated to International Cooperative Alliance on 28th January 2016. Most of its members are national level co-operative organizations that serve all types of co-operatives operating in all sectors of national economies including those engaged in agricultural production and marketing, wholesale and retail, small and medium scale industries, financial services, insurance, housing, transport, health and other services.

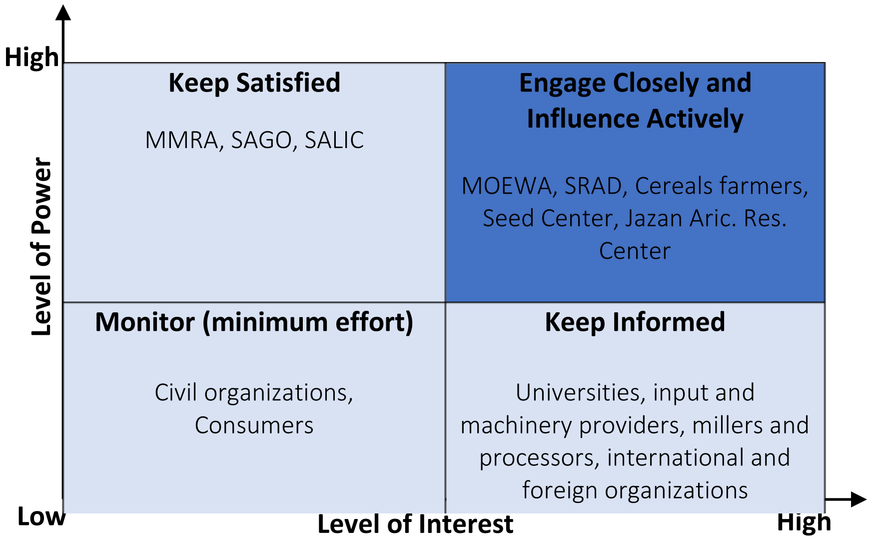
14. Stakeholders analysis

The stakeholders analysis was based on Stakeholders Management Guide developed by FAOSA and followed the following steps.
Stakeholder identification.
a) Assess the domain of the project activities and possible actors. This has been done both at FAO office in discussion with the management and colleagues as well as with MoEWA and during the field visit.
b) Brainstorming of all possible stakeholders was conducted within Cereals Component group.
c) Discussions with various stakeholders was conducted to see who the potential stakeholders for the Cereals Component.
d) Prepare stakeholders list and describe the stake or mandate of each stakeholder.
f) Describe potential role of each stakeholder in the project/component.
As a result of this process the list of stakeholders was developed and provided below:

- *Policy makers, government agencies*. These include primarily MoEWA and SRADP/REEF project. Agricultural production enhancement including rainfed cereals is the mandate and responsibility of MoEWA. SRAD/REEF project is directly responsible for the implementation of the project in the south-west of the country in cooperation with FAOSA. Communication of the Cereals Component staff with MoEWA and SRAD focal points demonstrated high interest in enhancing productivity and profitability of rainfed cereals. MoEWA departments are involved in activities like crop production and protection, water management, research and extension which are also part of the FAO project. These two agencies play key role in project implementation and certainly can be classified as primary audience. Special importance shall be given to regional and governorate branches of MOEWA who already demonstrated their interest and commitment during the field mission. The other government agencies with interest in rainfed cereals production are Ministry of Municipal and Rural Affairs (MMRA), Saudi Grain Organization (SAGO) and Saudi Agriculture and Livestock Investment Company (SALIC). Improvement of local grain production and rural development is part of their mandate. However, their interest and influence are of secondary nature and though the project will benefit from their involvement, they can be classified as secondary audience.
- *Cereals farmers* are amongst the main stakeholders in rainfed cereals development. This is diverse group and their social and farm characteristics vary depending on the region. One important factor is the role rainfed cereals play in their livelihood. This is variable depending on the outside job or income, role of other crops or fruits and livestock. However, forage and grain from rainfed cereals contribute to their income and livelihood. They are directly involved in production and the seed, technology applied affect the outcome. The farmers are also target of agricultural research and extension to benefit from innovations. Rainfed cereals producers are, therefore, the primary audience of this project.
- *MoEWA Seed Center in Riyadh and Jazan Agricultural Research Center* are directly involved in rainfed cereals research which is part of their mandate. Though limited adaptive research is conducted at these centers, their anticipated role in the project is very high. On one hand they will benefit from capacity building being part of the project activities, on the other hand they will contribute to the project success by carrying out some activities. These can be classified as primary audience.

- *Universities in Saudi Arabia* dealing with rainfed cereals are limited and include King Saud University and King Abdulaziz City for Science and Technology in Riyadh. Some relevant activities have been conducted by Jazan University which is located in the center of sorghum production. KAUST has cereals research group though its activities on rainfed cereals are not clear. The relevant research groups at these universities are interested in the rainfed cereals project activities and can contribute through their knowledge and experience in cooperative manner. They can be classified as secondary audience.
- *Input and services providers* both public and private have an important function of supplying the producers and processing industry with the needed materials, inputs and provision of numerous services to achieve efficient production. However, the situation analysis demonstrated that in low input extensive production this framework is underdeveloped. While visiting the region, it was clearly observed that some farmers provide services to other farmers, for instance, through renting the tractors and land preparation equipment. Transportation of forage and grain to the markets or consumers is an important expense in the overall production. The input providers and transportation stakeholders influence the productivity and also profitability of rainfed cereals. On the other hand they benefit from dynamic and profitable production. They are interested in innovations as this will lead to higher inputs and increased turnaround. This group can be classified as secondary audience.
- *Machinery and equipment manufacturers*. Due to low level of rainfed cereals mechanization, and lack of small-scale processing equipment, for sesame oil for instance, this is an important secondary audience who will contribute and benefit from the increased demand for equipment and machinery.
- *Traders* buying the grain from farmers and supplying the processing industry, wholesale and retail sector. The interest of this group is in sourcing the forage and grain and selling it to mills and processors or to grain retail shops. They benefit from higher production and lower productions costs. Therefore, they are interested in enhancement of rainfed cereals production. However, their direct influence on the project is low and they can be classified as secondary audience.
- *Milling and processing industry* producing the flour or oil from the grain and seeds and supplying the wholesale and retail markets. This group of stakeholders was visited during the field mission. They expressed their interest in increasing local production as the customers ask and like to purchase locally produced grain. There is even customer's preference for certain varieties or production regions. However, frequently imported sorghum or millet is cheaper compared to locally produced. Maintaining good grain quality and lower prices will benefit this group which can be classified as secondary audience.
- *Retailers* are interested in good quality locally produced grain with competitive price. Small retailers may have different approach compared to big retailers or supermarket chains which are able to influence production through contract farming. However, retailing network is an important secondary audience stakeholder.
- *Consumers* are the final users of the product benefitting from its functions and quality and paying the price for the whole chain of production and processing. Eventually, they are the ultimate beneficiaries and important stakeholders. This group includes both individuals and associations. Being secondary audience, they need to be reached with awareness of the health benefits of rainfed cereals.
- *A range of civil societies* including youth, women, healthy diet and environmental associations are interested in sustainable rural development and availability of good quality, safe locally produced grain. This group cannot be ignored despite its low influence but shall be properly communicated on the project activities and outcomes.
- *International and foreign research and development organizations*. International Crop Research Institute for Semi-Arid Tropics (ICRISAT) with headquarters in India and regional/country offices in Africa has global mandate for sorghum and millet improvement. This mandate covers KSA. The institute is interested in establishing partnership with FAO and MoEWA for sustainable development of rainfed cereals production. At present it is secondary audience but may be upgraded to the primary audience if a partnership agreement is reached. Similarly, International Maize and Wheat Improvement Center (CIMMYT) is interested in enhancement of wheat production in rainfed areas of KSA. National and private research organizations working with sorghum, millet and sesame in India, Sudan, Ethiopia, Myanmar, Australia and USA may also be interested in establishing bilateral links to relevant research and extension activities of the project.

The summary of the stakeholders interest and power matrix is presented below and summary in Table 14.



Power measures their degree of ability to help or have an impact on your project.
Interest measures their degree of support or opposition to your project's goals and objectives.

A combination of various techniques will be used to engage stakeholders at various stages of the project interventions as presented below:

1. *Multi-Stakeholder Focus Groups*: applicable to MoEWA/SRAD in Riyadh and in the target regions, Seed Center. Some discussion were conducted already during field mission.
2. *One-On-One Meetings*: have been conducted already with MoEWA/SRAD focal points and with key farmers.
3. *Questionnaires/Survey*: During the field mission this was the main approach in talking to farmers, and governorate MoEWA branches.
4. *Stakeholder Interviews*: these were conducted during field mission with the small millers and processing industry, universities.
5. *Consultation Workshops or Forums*: planned for stakeholders in the target region for the next field mission as well as in Riyadh with focus on extension.
6. *Formal and Informal Reviews*: will be organized as needed.

Table 14. Summary of rainfed cereals stakeholders' analysis and engagement methodology.

Stakeholders		Key interest	Level of		Engagement method
Group	Category		Interest	Influence	
Policy makers, government agencies	MoEWA	Rural development, food security	High	High	Regular communication, updates, meetings, focus groups, joint visits.
	SRADP	Project implementation	High	High	
	MMRA	Rural development	Medium	Low	Communication through project updates, invitations to project events, workshops.
	SAGO	Food security	Medium	Low	
	SALIC	Food security	Medium	Low	
Cereals producers	Smallholders	Farm productivity and profitability enhancement	High	High	Continuous communication/ discussions through individual and groups meeting, updates, workshops, field days, training events, publications. Surveys.
	Medium farms		High	High	
	Cooperatives		High	High	
Research and extension	MoEWA branches	Promotion of new technologies, practices	High	High	Regular communication, updates, meetings and discussions, joint visits, field days.
	MoEWA research centers	Development, adoption and promotion of new technologies	High	High	
	Universities	Academic research, new technologies, extension	Medium	Medium	Engagement through involvement in project activities, updates, workshops.
Input and services providers	Domestic	Supply the producers and get profit	Medium	Medium	Sharing project updates, field days, workshops.
	Multinational	Supply and promote brand products	Medium	Medium	
Traders	Domestic	Purchase quality grain at good price	Medium	Low	Communication through project updates, groups discussions and attendance of events.
	Export-Import	Develop competitive local production	Medium	Low	
Processing industry	Small local mills	Good quality grain at good price	Medium	Low	
	Medium/large mills	Large volumes of grain at good price	Medium	Low	
Retailers	Small shops	Small packages of product at low price	Low	Low	Distribution of knowledge materials, web sites information.
	Supermarkets	Product volume with consistent quality	Low	Low	
Customers	Individuals	Product safety, availability, quality and price	Medium	Low	Information through web sites. Social media.
	Associations		Medium	Low	Engagement through distribution of regular project updates, information though web sites and invitation to project events. Social media.
Civil societies	Youth associations	Rural employment	High	Low	
	Women associations	Rural employment, gender	High	Low	
	Healthy diet groups	Consumers health	High	Low	
	Environmental groups	Saving water, healthy soil, clean air	High	Low	

International and foreign organizations	CGIAR centers	Productivity enhancement, research and development projects	Medium	Low	Targeted communication on the issues of common interest, bilateral visits, discussions and formulation of common activities.
	Academic centers/universities	Research opportunity	Medium	Low	

15. Challenges and SWOT analysis

The review of the cereals sector outlined in the project document defines the following main challenges faced by the sector:

- Farming of cereal crops is characterized by use of traditional and inappropriate technologies and practices especially with respect to water harvesting, farming and crop harvesting practices and post-harvest operations.
- Small producers either lack or have limited access to extension services and technical support.
- Weak scientific and applied research programmes related to the development of rain-fed farming.
- Small producers lack or have limited access to institutional funding.
- Absence of effective producer's cooperatives capable of providing services including advisory and marketing services.

The current comprehensive review and the situation analysis conducted by the Cereals Component expanded and detailed these challenges from technical perspective of project implementation.

I. Water remains the key limiting factor and challenge. Despite the location of southwestern region in relatively high rainfall zone, the amount and distribution of rain do not guarantee stable and sufficient amount for rainfed cereals. The farmers adapted to the rainfall scarcity and erratic distribution through adapting their crops and growing seasons to coincide with the likely rainfall. Specific challenges are the following:
    a. Lack of water harvesting and storage facilities or their deteriorated structure not allowing to capture the water especially during spade rainfall.
    b. Farmers having access to stored water or manual wells are not able to take full advantage of supplementary irrigation due to lack of irrigation systems and deteriorated wells.
    c. Current production system leaves bare soil exposed to sun and winds for long time making it very dry. Introduction of conservation agriculture practices is needed.
    d. Flood irrigation used by some farmers does not follow ridges and results in losses of valuable moisture.

II. Crop production and protection systems are of extensive type with little if any input.
    a. Land preparation and harvesting are two main activities which require mechanization and present the main cost for farmers. Lack of mechanization results in hiring equipment for extra cost, un-timely operations and losses.
    b. Planting by seed broadcasting not in rows and without planters results in poor establishment.
    c. Fertilization of cultivated cereals crops is not practiced by local farmers; however, some farmers are adding little amount of organic fertilizer to their fields at the beginning of cultivation.
    d. Most of the farmers do not believe plant protection form plant diseases, pests and weeds is needed throughout the season of cultivation. Very good IPM programme must be introduced to improve the productivity of their fields.
    e. In the highland governorates around Abha city another kind of challenge represented by animals such as monkeys and donkeys invading the plantation fields of cereals crops and destroying the cultivated crop is happening throughout the season of cultivation.

III. Varieties and seeds. There is neither formal nor informal seed system in place for rainfed cereals.
    a. The seed used for rainfed cereals crops cultivation during planting is taken from previously cultivated crops and without any treatment recycled for next season plantation.
    b. There is no access to new varieties or seeds despite high interest from the farmers to try new seeds/varieties.
    c. Some sorghum and sesame varieties represent populations which can be easily improved through mass selection. However, the farmers need to be trained on this.

IV. Agricultural research and extension services.

   a. The National Agricultural Research System (NARS) is not well developed to carry out applied research to improve the productivity of cereals crops. There is no research activities on rainfed cereals neither in the southwestern region nor in Riyadh.
   b. The extension services and the number of good technical and knowledgeable staff to provide good technical advices and information to farmers to overcome agricultural obstacles they normally face is currently unavailable.

V. Rural development and cooperatives.
   a. Lack of rainfed cereals crops cooperatives that can address and find solutions for common technical problems which face farmers.
   b. Immigration especially of youth to big city to search for better life is affecting the cycle of cultivation between generations and resulting in many agricultural fields suitable for cultivation being abandoned.
   c. The difficulties of hiring labour to carry out the duties of cultivation practices throughout the season.
   d. In certain governorates in the target regions a real shift from cultivating cereals crops to other agricultural activities such as plantation of coffee and establishing honey bee activity is underway.

VI. High production cost versus commodity prices.
   a. Because of so many challenges and other obstacles the production of rainfed cereals crops per unit area is low.
   b. The total cost of production of almost all cereals crops per unit area is generally high and farmers indicate that in certain cases the desire to continue cultivation is diminishing.

VII. On-farm or cooperatives grain processing and marketing is underdeveloped and as a results farmers price for their grain is low.

The list of challenges could continue but the list presented above demonstrates the complexity of improving the system while engaging all the stakeholders. At the same time there are several positive features in rainfed cereals production:

- ✓ Farmers commitment to their land and crops. The farming communities involved in rainfed cereals production are not subsistence farmers whose livelihood depends on the crops they grow. Most of the farmers main income comes from jobs, businesses, livestock, etc. However, there is high degree of commitment to use the land and resources to grow rainfed cereals. This commitment derives from cultural and religious values ingrained in the rural society. The farmers are also open to innovations and will be ready to test them and adopt if suitable.
- ✓ The government commitment to agricultural and rural development in the southwestern part of the country. This is exemplified in subsidies for rainfed crops as well as SRAD project.
- ✓ Availability of innovations. The scientific and production progress in rainfed cereals is very profound both in developed and in developing countries. Modern varieties, hybrids, IPM and conservation agriculture practices are progressing and available for introduction to the target regions.

The summary of strengths, weaknesses, opportunities and threats is presented in Table 15.

Table 15. Analysis of strengths, weaknesses, opportunities and threats for rainfed cereals production in southwestern part of KSA.

Strengths	Weaknesses
- Long history and tradition of rainfed cereals cultivation in the South-West of the country - Farmers experience and commitment to cultivating rainfed cereal crops - Availability of land for crops cultivation and expansion - Low water consumption making these crops a strategic alternative under limited irrigation production system - Drought and heat tolerance of rainfed cereals making them a natural cultivation choice in the face of climate change - Consumption of sorghum, millet and sesame products contribute to human health and considered healthy functional food - Research work at universities targeting different aspects of rainfed cereals production and consumption - Recent collection of rainfed cereals traditional varieties - Seed Center possesses germplasm for rainfed cereals and interested in collaboration - Established value chain system	- Inadequate applied research support - Lack of adopted improved varieties and technologies - Absence of specialized seed production for rainfed crops - Low level of mechanization for land preparation and harvesting - Poor extension and technical support services to cereals producers - Limited water availability and inadequate use of rainfall catchments and water harvesting - Poor post-production services - Poor finance services for small-scale cereals growers - Inadequate storage and marketing infrastructure - Limited cereals grain and products market promotion - Limited numbers of effective agricultural cooperatives for rainfed cereals - Absence of effective market integration and sales platform for grain - Higher production cost compared to imported grain and products - high prevalence of illiteracy in farmers and constraints in adoption of technology.
Opportunities	**Threats**
- MoEWA interest and support to develop rainfed cereals sector - Grain has high domestic demand as healthy food - Strong research and development of rainfed cereals in neighboring countries - CGIAR International Center (ICRISAT) working on semi-arid sub-tropical crops including sorghum and millet - Consumer driven demand for healthy ancient grains - New SRAD subsidy scheme supporting rainfed cereals production - Presence of capable research groups in Universities (King Saud, Jazan, KAUST) able to work on rainfed cereals.	- Uncertain labor availability during harvesting seasons - Lack of market information to farmers - Arbitrary setting of the prices - Small farm sizes limit application of modern technologies, income and livelihood for farmer families - Faster climate change pace resulting in drier and hotter weather, weather extremes - Low prices for these commodities undermining local production - Slow transformation of research and extension service limiting provision of products and services to producers. - Import dependence and domestic price competitiveness to imported substitutes.

16. Interventions and implementation strategy.

The key project targets for the rainfed cereals component are: increase in Sorghum production from 170,000 to 195,000 tns; in Millet from 4,800 to 7,200 tns and Sesame from 4,000 to 6,000 tns. These key targets are to be achieved through a number of interventions and activities to be undertaken throughout the project duration.

Comprehensive review and situation analysis clearly defined the status of rainfed cereals in southwestern region of KSA. There are substantial challenges and weaknesses but also advantages and opportunities. The project has been designed to enhance the whole sector of rainfed cereals in a holistic manner with clearly defined activities, outputs and milestones. The key project interventions are the following:

- Promote appropriate crop management technologies and practices among smallholders (22 deliverables)
  - Promote conservation agriculture;
  - Evaluate, select, pilot test and promote modern adopted cereals varieties;
  - Develop and implement an IPM programme to control cereals pests and diseases;
  - Develop a catalogue of major diseases, pests and weed;
  - Establish and operate community seed system;
  - Design, pilot test and promote climate-resilient rain-water harvesting packages;
  - Identify and promote modern efficient irrigation technologies and groundwater recharge structures;
  - Promote farm power and appropriate technology, sustainable mechanization and business models http://www.fao.org/sustainable-agricultural-mechanization/hire-services-as-a-business/hire-services/en/;
  - Establish agricultural research and extension center.
- Strengthen capacity of smallholders and rural institutions (45 deliverables)
  - Promote and support NARS adoption of new varieties, smart technology and practices;
  - Strengthen pests and diseases control services;
  - Strengthen capacity of the of rural knowledge and advisory institutions;
  - Train and develop smallholder related farmers skills to access technologies and services through Farmers Field Schools;
  - Establish a network of demonstration farms for introduction and adoption of innovative practices and technologies;
  - Identify and document the technologies and good practices, baseline information on rain-fed cereals production platform;
  - Establish the knowledge and information sharing mechanism;
- Integrate rain-fed cereal producers into markets, agribusiness and value chain (27 deliverables)
  - Develop pilot business model for rain-fed cereal growers' cooperatives;
  - Support establishment of local rain-fed crop marketing centres;
  - Develop appropriate contract farming models, smallholder-adapted e-market information systems;
  - Strengthen business and marketing skills of smallholders through incorporation of relevant subjects in the Farmers Field Schools;
  - Develop sustainable and responsible value chain and commodity/enterprise specific viable business plans;

- Develop agripreneurs models to demonstrate and promote rural youth and women involvement in small agribusinesses;

These project interventions and activities have been aligned with 20 MoEWA Rainfed Cereals Initiatives developed to guide implementation of SRAD project (Annex 3). Through the consultation process of FAOSA Cereals Component staff and MoEWA/SRAD focal points the project activities/deliverables were aligned and prioritized for implementation. The first priority initiatives to start in 2021 are the following:

2. Developing solutions for rain water harvesting and supplementary irrigation.

5. Establish pilot/demonstration farms to disseminate and develop modern agricultural practices.

13. Establish research centre to test latest agric. technologies.

17. Establishment of special program to select high quality cultivars and high productivity plants.

6, 9, 19. Introduction of modern equipment for land preparation and seeding including zero and minimal till, harvesting.

For each of these initiatives FAOSA Rainfed Cereals Group developed Activity Profiles detailing their implementation, including implementation steps with timeframe and expertise needed. The profiles have been translated into Arabic and currently under review to be submitted to MoEWA/SRAD for discussion and implementation. Each profile is concise document to guide implementation of specific initiative through the synergy of expertise and resources.

The second priority initiatives to start in 2022 are the following:

1. Fertilization Program.

3. Enhancing crop rotation and using safe insecticides to control insects.

4. Providing training courses and awareness programs that aiming at raising and developing Farmers' Skills.

8. Empowering cooperative societies to sell members farmers products under joint trademark.

10. Seeds treatment and sterilization.

11. Developing database to enhance manpower rotation across farms.

14. Setting national standards to classify sorghum, sesame and millet quality.

15. Establishing national online platform to sell and deliver grains.

16. Enhancing domestic product distinction by labelling "made in KSA".

18.Enhancing using fixed price supply agreements.

Towards the end of 2021 activity profiles for each of these initiatives will be developed.

One of the keys for implementation strategy is focus on pilot governorates where demonstration farms will be established to test, adopt and promote innovations and sustainable practices. The process of four regions prioritization and identification of pilot governorates has been completed and presented in a separate report. The main consideration for the regions prioritisation was the area under rainfed cereals, diversity of the farming/cropping system, complementarity between the target regions and convenience for the project implementation considering geographical location. As a result, the project proposes the following priorities for the regions to start implementing the project activities:

1. **Jazan**: largest area of rainfed cereals among all regions, typical sorghum flash flood cropping system, irrigated system and terraces cropping system, presence of all crops – sorghum, millet, sesame and wheat. Project activities to start in 2021.
2. **Aseer**: neighbouring region to Jazan with similar cropping systems based on flash floods and terraces, largest rainfall wheat area among all target regions. Most populous region (except Makkah) with small holders. Project activities to start in 2021.
3. **Makkah**: this the largest and most diverse region, however, there are few governorates producing rainfed cereals located in the south-western part of the region. Being geographically isolated from south Tihamah plain this area requires focused efforts. Project activities to start in 2022.
4. **Al-Baha**: this is by far the smallest region with the least area under rainfed cereals. The region is quite diverse having highland farming systems. Though cropping is important for the local farming community, this region is of less priority compared to the other target regions. Project activities to start in 2022.

Selection of the pilot governorates followed similar criteria as prioritization of the regions. The pilot governorates are shown on the regional map (Figure 9) and in Table 16. The summary of the selections are below:

- Total 23 governorates have been selected following the established criteria including 11 governorates in Jazan region, 7 in Aseer, 2 in Makkah and 3 in Al Baha.
- Selected governorates include 84,944 ha of total cultivated land in the four regions (77.2%) including 50,119 ha of rainfed cereals (93.1%) and 79,344 farmers.
- Selected governorates belong to two major agro-ecological zones: Southern Tihamah (69,699 ha of planted land including 39,933 ha of rainfed cereals) practicing mainly flash floods farming system with domination of sorghum, millet and sesame; Aseer Scarp and High Aseer (14,755 ha of planted land including 10,186 ha of rainfed cereals) practicing mainly terraces system with domination of sorghum and wheat.
- The total population living in selected target governorates exceeds 2.5 M people.
- Selected regions and pilot governorates to start project activities in 2021:
  - Jazan: Sabya, Abu Arish, Baish, Damad, Samtah, Al Dayer, Ahad al Masarihah
  - Aseer: Al Birk, Abha, Muhayil, Namas, Rijal Alma
- Selected regions and pilot governorates to start project activities in 2022:
  - Jazan: Al Twal, Al Aridhah, Al Edabi, Al Reeth,
  - Aseer: Balqarn, Tanouma
  - Makkah: Al Lith, Al Qunfudhah
  - Al-Baha: Qilwah, Al Makhwah, Al Mandaq

Once the pilot governorates identified, the next logical step is to select the demo farms in each pilot governorates. The component strategy is that the demo farms will be the key entry points for study, identification, testing and promotion of the project interventions. It is anticipated to start with establishing two demo farms in each pilot governorate. This work has been started and will be completed by the end of August, 2021. The process of demo farms identification involves analysis of the cropping system and production challenges and development of demo package for each farm.

The important implementation strategy component is partnership with national and international research entities. Due to lack of the seeds of new varieties the project anticipates cooperation with ICRISAT which will also involve Seed Center and Jazan Agricultural Research Center. This partnership has high priority and time sensitive to manage to obtain new seeds of sorghum and millet prior to planting of the new season in fall.

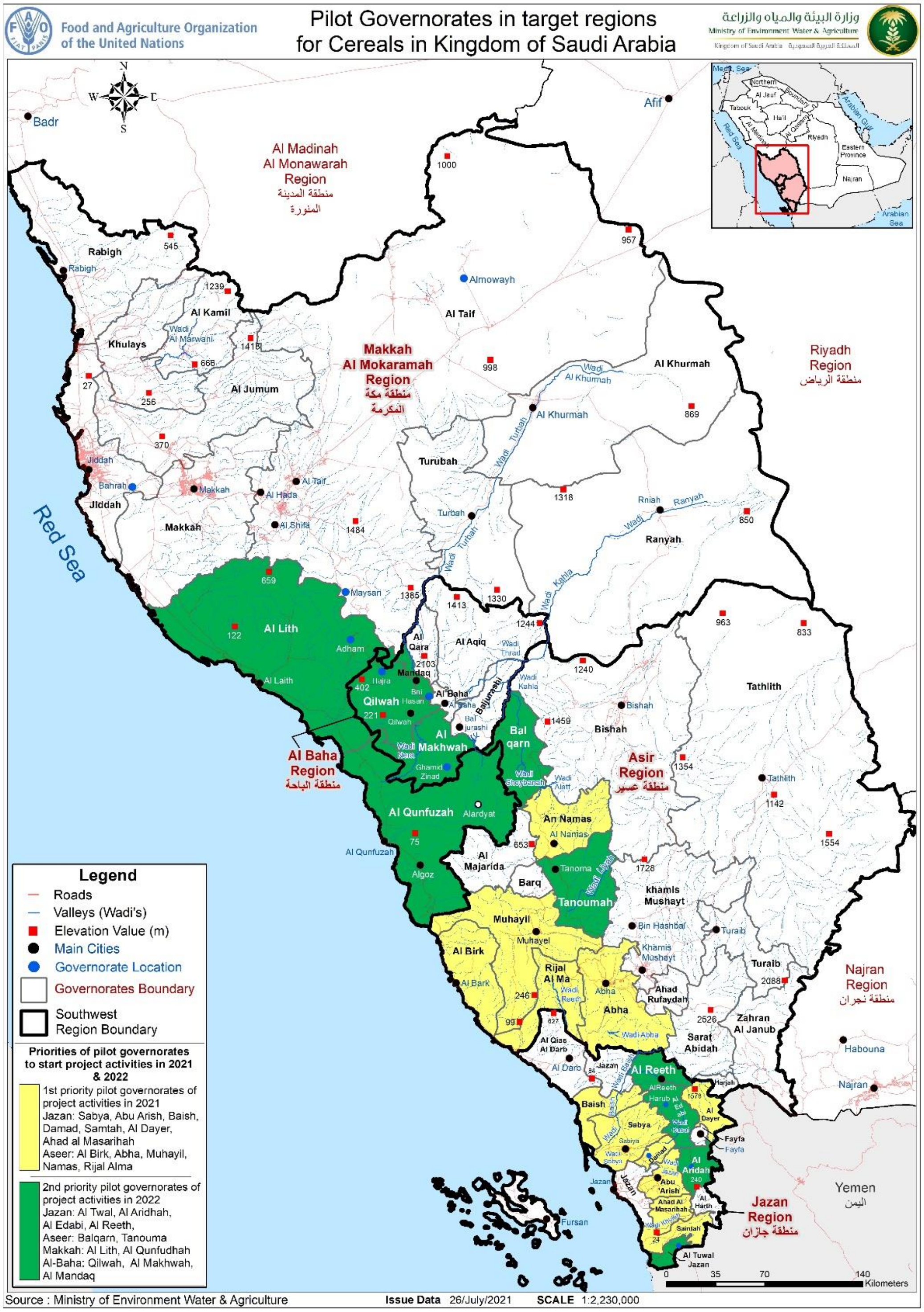


Figure 9. Location of pilot governorates in four target regions (red – 1st priority; white – 2nd priority).

Table 16. Summary of pilot governorates selection in four target regions.

Region	Agro-ecological zone	Priority	Governorates	Planted area	Cereals	Number of farms*
Jazan	S. Tihamah	1	Sabya, Abu Arish, Baish, Damad, Samtah, Ahad al Masarihah	42,001	31,362	15,163
	Aseer Scarp**	1	Al Dayer	1,028	152	371
	S. Tihamah	2	Al Twal	1,790	1,510	646
	Aseer Scarp	2	Al Aridhah, Al Edabi, Al Reeth,	5,880	4,965	2,123
	Total		*11 governorates*	*50,699*	*37,989*	*18,303*
Aseer	S. Tihamah	1	Al Birk, Muhayil	4,421	3,257	13,397
	Aseer Scarp	1	Abha, Namas, Rijal Alma	3,050	2,092	9,242
	Aseer Scarp	2	Balqarn, Tanouma	1,059	780	3,209
	Total		*7 governorates*	*9,000*	*6,129*	*27,273*
Makkah	S. Tihamah	1	Al Lith, Al Qunfudhah	21,487	3,804	23,612
Al-Baha	Aseer Scarp	1	Qilwah, Al Makhwah, Al Mandaq	3,758	2,197	10,157
Grand total			***23 governorates***	***84,944***	***50,119***	***79,344***
% of all farms in 4 regions				***77.2***	***93.1***	***-***
Including Southern Tihamah			***11 governorates***	***69,699***	***39,933***	***52,818***
Including Aseer Scarp, High Aseer and Middle-Eastern Aseer			***12 governorates***	***14,755***	***10,186***	***25,102***

* - Estimated based on average cultivated area for respective region (Table 4).

** - Includes also High and Middle-Eastern Aseer agro-ecological zones.

17. Conclusions.

Agriculture is important for the Kingdom of Saudi Arabia not only due to food security consideration but also for rural development to attend the needs of 16% of population residing in the countryside. In the agrarian regions of Al Baha, Aseer and Jazan, rural population is almost 50%. However, the rate of urbanization is not evenly spread, for example, some regions like Aseer, Al Baha and Jazan have high rural population rate of 50% or more. In 2017 the total labor force participation rate was 56.1% and the employment rate in agriculture was 6.3%. According to the most recent data available during the period 2012-2017 the unemployment rate among youth was 16.1%. The crops production areas in the country are well defined and based on irrigated production of wheat and forage crops, primarily alfalfa. Vegetables and fruits are important commodities produced locally. However, the irrigated crop production relies on non-renewable water aquifers. Southwestern part of the country is the only region practicing rainfed production of sorghum, millet, sesame and wheat. This region is the focus of the current project with the key objective of sustainable production enhancement to satisfy the local needs and reduce exports.

Agriculture and crops production in KSA are constrained by lack of moisture. However, crops production both irrigated and rainfed are dynamic responding to the government policies and market forces. The overall food security situation in the country is stable and ranked one of the highest in the world due to combination of local production and effective import value chains. Saudi Vision 2030, National Strategies on Agriculture, Water and Environment and respective initiatives provide legal and operational framework for the sector development based on sustainability, food security, rural development and environmental considerations. SRAD is one of strategic programs to achieve sustainable rural agricultural development and contribute to conservation and management of natural resources in the Kingdom of Saudi Arabia. Development of rainfed cereals production was selected as one of the project components with focus on four target regions: Al-Baha, Aseer, Jazan and Makkah.

Southwestern part of KSA is densely populated region with relatively high share of rural population and less developed compared to the rest of the county. Short analysis of the farm structure demonstrated several important challenges like small farm area, low mechanization level, dependence on labor, lack of horizonal and vertical integration, lack of support including financing. However, the opportunities are also there for improvement as the farmers are attached to their land and continue production of crops in the challenging and dynamic environment. Agroecological conditions of southwestern region are highly diverse due to landscape, mountains and soils. The main feature of the region is variable and erratic rainfall frequently in large quantity. The agroecological diversity defines the diversity of the farming and cropping systems. For this reason the technological interventions to improve the production system have to be targeted considering this agroecological diversity as well as farming and cropping systems.

Crop production has millennial history in the southwestern region of Saudi Arabia. Sorghum and millet are well adapted to the dry and hot local conditions and provide food and forage to local communities. Sorghum and sesame faced some area and production decline recently while millet is on the rise. The three crops along with wheat represent highly important commodities for agricultural and rural development in the southwestern region. The main farming and cropping systems represent the basis for improvement considering the role of rainfed cereals and their interaction with other crops, trees and livestock. The main consideration for enhancement of the farming system is sustainability and profitability of the farmers involved in rainfed cereals cropping.

Two systematic collections of rainfed cereals genetic resources were conducted in southwestern part of the country in the late 1980s and in 2010s. There is reasonable documentation of what was collected where but much less information on agronomic characterizations of collected genetic resources. There is clear recommendation to continue systematic inventory and collection of rainfed cereals genetic resources which is important project intervention. There is limited information and description of cereals varieties currently grown which requires consideration in the project implementation. Substantial progress has been made in the development of new varieties and hybrids elsewhere using conventional and genomic tools and this new material shall be utilized in KSA.

The current production technologies for all rainfed crops vary depending on the environment and the cropping system and generally well understood. This is extensive production system using old varieties, very little if any inputs, mechanized only at a stage of soil preparation and versatile to respond to available moisture. The system has great potential for improvement both through sustainable intensification and by enhancement of individual production components. Rainwater harvesting and supplementary irrigation are of fundamental importance for rainfed cereals in the southwestern region. Substantial knowledge has been generated leading to technical directions and identification of the target interventions. The further work need to focus on specific selected pilot governorates for detailed implementation plan.

The agricultural education, research and extension system in KSA has been well established and includes both MOEWA and universities framework. Situation analysis demonstrated its limited efficiency in conducting relevant research, delivering public research products and extending it to the farming communities. The whole system requires optimization taking into account the needs-based objectives. The seed production of rainfed cereals in the country follows informal system. There is great potential for improvement of informal system and establishment of the formal system. Both options need to be considered taking into account medium and long-term objectives.

Value chain improvement represents an important opportunity for enhancement of rainfed cereals production. However, it is not sufficiently studied to develop targeted interventions especially from the perspective of sorghum forage use for livestock which is as important as grain. Biofortification of cereals represents an opportunity to enhance the value and improve the nutritional value of the grain. The cooperatives of farmers involved in rainfed cereals production are clearly underdeveloped and require targeted and focused efforts to make their role visible and contributing to productivity enhancement, value chain and rural development.

The project strategy on rainfed cereals is to build on the current strengths and utilize the opportunities to overcome the weaknesses and avoid the threats. Old technologies and lack of mechanization will be overcome by establishment of the demonstration farms to start test and adoption of new varieties and technologies or their components. Lack of research support will be addressed by establishing rainfed cereals department at Jazan Agricultural Research Center including the selection program for rainfed cereals. The extension system will be strengthened as well. Partnership with ICRISAT will address the issue of new varieties and seeds. A number of activities will be undertaken to enhance the value-chain, marketing and agribusiness. Collectively, these actions will correct the weaknesses and assist in avoiding the threats. Overall, interventions, activities and outputs have been well defined and coordinated with respective MOEWA initiatives. Four regions have been prioritized for the activities and pilot governorates have been identified. Selection of demo farms as key entry points for the project interventions is underway. The scale of cereals project activities covers 90% of all area planted by rainfed cereals in the four target regions. Emphasis on youth and women is an important priority for the project implementation to contribute to the goals rural development clearly defined in Saudi Vision 2030.

18. References

Aba-Husayn M. M., J. B. Dixon S. Y. Lee (1980) Mineralogy of Saudi Arabian Soils: Southwestern Region. Soil Science Society of America Journal, 44(3): 643-649.

Ahmed, Z. Is zinc deficiency a worldwide problem and is there a silent epidemic in Saudi Arabia?. [IGD abstract 036]. Int J Growth Dev. 2017;1(suppl):S36, doi: 10.25081/ijgd.2017.v1i1.37.

Al-Farraj A.S. (2008) The mineralogy of clay fractions in the soils of the southern region of Jazan, Saudi Arabia.Journal of Agronomy, 7(2): 115-126.

Alghamdi, S. S., Alfifi, S. A., Migdadi, H. M., Al-Rowaily, S. L., El-Harty, E. H., & Farooq, M. (2017). Morphological and genetic diversity of cereal genotypes in kingdom of Saudi Arabia. International Journal of Agriculture and Biology, 19(4), 601–609. https://doi.org/10.17957/IJAB/15.0307.

Al-Shoaibi, A. A. (2020) Combined effects of salinity and temperature on germination, growth and gas exchange in two cultivars of Sorghum bicolor . Journal of Taibah University for Science, 14(1), 812–822. https://doi.org/10.1080/16583655.2020.1777800

Alswailem Abdullah Mansour, Sulaiman Mohammed Alahmad, Muath Ali Alshehri The Prevalence of Iron Deficiency Anemia and its Associated Risk Factors among a Sample of Females in Riyadh, Saudi Arabia. The Egyptian Journal of Hospital Medicine (July 2018) Vol. 72 (6), Page 4625-4629.

Al-Turki, T. A., Al-Namazi, A. A., & Masrahi, Y. S. (2019). Conservation of genetic resources for five traditional crops from Jazan, SW Saudi Arabia, at the KACST Gene-Bank. Saudi Journal of Biological Sciences, 26(7), 1626–1632. https://doi.org/10.1016/j.sjbs.2018.09.007.

Al-Turki, T. A., Al-namazi, A. A., Al-ammari, B. S., Al-mosallam, M. S., & Basahi, M. A. (2020). Saudi Journal of Biological Sciences Ex-situ conservation of wheat genetic resources from Saudi Arabia. Saudi Journal of Biological Sciences, xxxx. https://doi.org/10.1016/j.sjbs.2020.04.015.

Alzahrani, K. H., Muneer, S. E., Taha, A. S., & Baig, M. B. (2012). Appropriate cropping pattern as an approach to enhancing irrigation water efficiency in the Kingdom of Saudi Arabia. Journal of Animal and Plant Sciences, 22(1), 224–232.

Bararpour, T., Hale, R. R., Kaur, G., Singh, B., Tseng, T. M. P., Wilkerson, T. H., & Willett, C. D. (2019). Weed management programs in grain Sorghum (Sorghum bicolor). Agriculture (Switzerland), 9(8), 1–13. https://doi.org/10.3390/agriculture9080182.

Bedada A. (2020) FAO reports on cereals breeding, research and development and benchmarking. FAO, Riyadh, Saudi Arabia.

Committee on World Food Security (CFS) Global Strategic Framework For Food Security & Nutrition (GSF). Third Version – 2014. 65 p.

Dalton Timothy J. and M. Hodjo (2020) Trends in Global Production, Consumption, and Utilization of Sorghum. "Sorghum in the 21st Century: Food – Fodder – Feed – Fuel for a Rapidly Changing World" (Springer, 2020).

Dayakar Rao B, Patil JV, Hymavathi TV, Nirmal Reddy K and Rajendraprasad MP. 2014. Terminal report of NAIP sub-project on „Creation of Demand for Millet Foods through PCS Value Chain". Directorate of Sorghum Research, Rajendranagar, Hyderabad, AP- 500 030.

De Pauw E. (2002) An agroecological exploration of the Arabian Peninsular. ICARDA, Aleppo, Syria, 77p.

Dixon John. Farming Systems and Poverty. IMPROVING FARMERS' LIVELIHOODS IN A CHANGING WORLD. and Aidan Gulliver with David Gibbon. Malcolm Hall. FAO and World Bank. Rome and Washington DC, 2001

Dossa, K., Konteye, M., Niang, M., Doumbia, Y., & Cissé, N. (2017). Enhancing sesame production in West Africa's Sahel: A comprehensive insight into the cultivation of this untapped crop in Senegal and Mali. Agriculture and Food Security, 6(1), 1–15. https://doi.org/10.1186/s40066-017-0143-3.

Edens, C., Wilkinson, T.J. Southwest Arabia During the Holocene: Recent Archaeological Developments. Journal of World Prehistory 12, 55–119 (1998). https://doi.org/10.1023/A:1022449224342.

Gazzeh, K., & Abubakar, I. R. (2018). Regional disparity in access to basic public services in Saudi Arabia: A sustainability challenge. Utilities Policy, 52(April), 70–80. https://doi.org/10.1016/j.jup.2018.04.008.

Gebremedhn Mengstu Berhe, Worku Tessema, Girma Gezimu Gebre, Kahsay Tadesse Mawcha & MoEWAel Kiros Assefa | (2019) Value chain analysis of sesame (Sesamum indicum L.) in Humera district, Tigray, Ethiopia, Cogent Food & Agriculture, 5:1, 1705741, DOI: 10.1080/23311932.2019.1705741.

General Authority for Statistics (2019) Agricultural Production Survey Bulletin, KSA, 90 pp.

Inglis, Robyn Helen orcid.org/0000-0001-6533-6646, Sinclair, Anthony, Shuttleworth, Andrew et al. (5 more authors) (2014) Investigating the Palaeolithic Landscapes and Archaeology of the Jazan and Aseer Regions, Southwestern Saudi Arabia. Proceedings of the Seminar for Arabian Studies. pp. 193-212.

Kaposzta Jozsef, Henrietta Nagy, Samir Zaien, Gabriella Horvath-Csikos, Hanna Andrea Solyomfi (2019) rural development according to regional planning strategies case study (Egypt and Saudi Arabia). Engineering for rural development. Jelgava, 22.-24.05.2019. 1811.

Kassim M.Y. (1985) Seed born fungi on sorghum in Saudi Arabia. Pak. J of Botany, 17: 263-265.

Kim and van der Berg, 2018 A Holistic Assessment of the Water-for-Agriculture Dilemma in the Kingdom of Saudi Arabia. Center for International and Regional Studies Georgetown University in Qatar. Occasional Paper No. 19. ISSN 2072-5957. 44 p.

Kumar Gupta Sanjay FAO technical report "Value Chain Report Cereals (Sesame, Millet and Sorghum) (2018)

Lubadde, G., J. Ebiyau, J.C. Aru, C. Andiku, J.A. Wandulu, M.A. Ugen. 2019. Sorghum production handbook for uganda. pp 37. National Semi Arid Resources Research Institute of the National Agricultural Research Organisation (NaSARRI-NARO), Uganda.

Mahmoud, M. A. (2013). Molecular characterization of Aspergillus flavus and aflatoxin contamination of wheat grains from Saudi Arabia. 12(3), 3335–3352.

Mekki A. Omer (2018) Identify and Define Suitable Crop Mix and Farming Systems in Four Selected Regions in Kingdom of Saudi Arabia. FAO-SA,

Moustafa, K. A., Al-Doss, A. A., Motawei, M. I., Al-Otayk, S., Dawabah, A. A. M., Abdel-Mawgood, A. L., Al-Rehiayani, S. M., & Al-Hazmi, A. S. (2015). Selection of spring bread wheat genotypes for resistance to cereal cyst nematode (Heterodera avenae Woll.) based on field performance and molecular markers. Plant OMICS, 8(5), 392–397.

Musara, Musemwa, Mushunje, Mutenje & Pfukwa Sorghum value chain analysis in semi-arid Zimbabwe. S. Afr. J. Agric. Ext. Vol. 47 No. 1, 2019: 164 - 178 http://dx.doi.org/10.17159/2413-3221/2019/v47n1a497.

Myers (2002) - How to grow sesame, Jefferson Institute, 4–7. Short production guide.

Myint, D., Gilani, S. A., Kawase, M., & Watanabe, K. N. (2020). Sustainable sesame (Sesamum indicum L.) production through improved technology: An overview of production, challenges, and opportunities in Myanmar. Sustainability (Switzerland), 12(9), 1–21. https://doi.org/10.3390/SU12093515.

National Research Council. 2002. Publicly Funded Agricultural Research and the Changing Structure of U.S. Agriculture. Washington, DC: The National Academies Press. doi: 10.17226/10211

Prasad, P. V. V., & Staggenborg, S. A. (2011). Growth and Production of Sorghum and Millets. Soils, Plant Growth and Crop Production, 2(March), 1–27. Kansas SU.

Serba, D. D., Muleta, K. T., St. Amand, P., Bernardo, A., Bai, G., Perumal, R., & Bashir, E. (2019). Genetic Diversity, Population Structure, and Linkage Disequilibrium of Pearl Millet. The Plant Genome, 12(3), 180091. https://doi.org/10.3835/plantgenome2018.11.0091.

Shadfan H., A. Mashhady, A. Eter, A. A. Hussen (1984) Mineral Composition of Selected Soils in Saudi Arabia. Journal of Plant Nutrition and Soil Science. 147(6): 657-668.

Sims, B.; Corsi, S.; Gbehounou, G.; Kienzle, J.; Taguchi, M.; Friedrich, T. Sustainable Weed Management for Conservation Agriculture: Options for Smallholder Farmers. Agriculture 2018, 8, 118. https://doi.org/10.3390/agriculture8080118.

Stichler, C., Mcfarland, M., & Coffman, C. (n.d.). Grain Sorghum Production South and Southwest Texas. Reproduction.

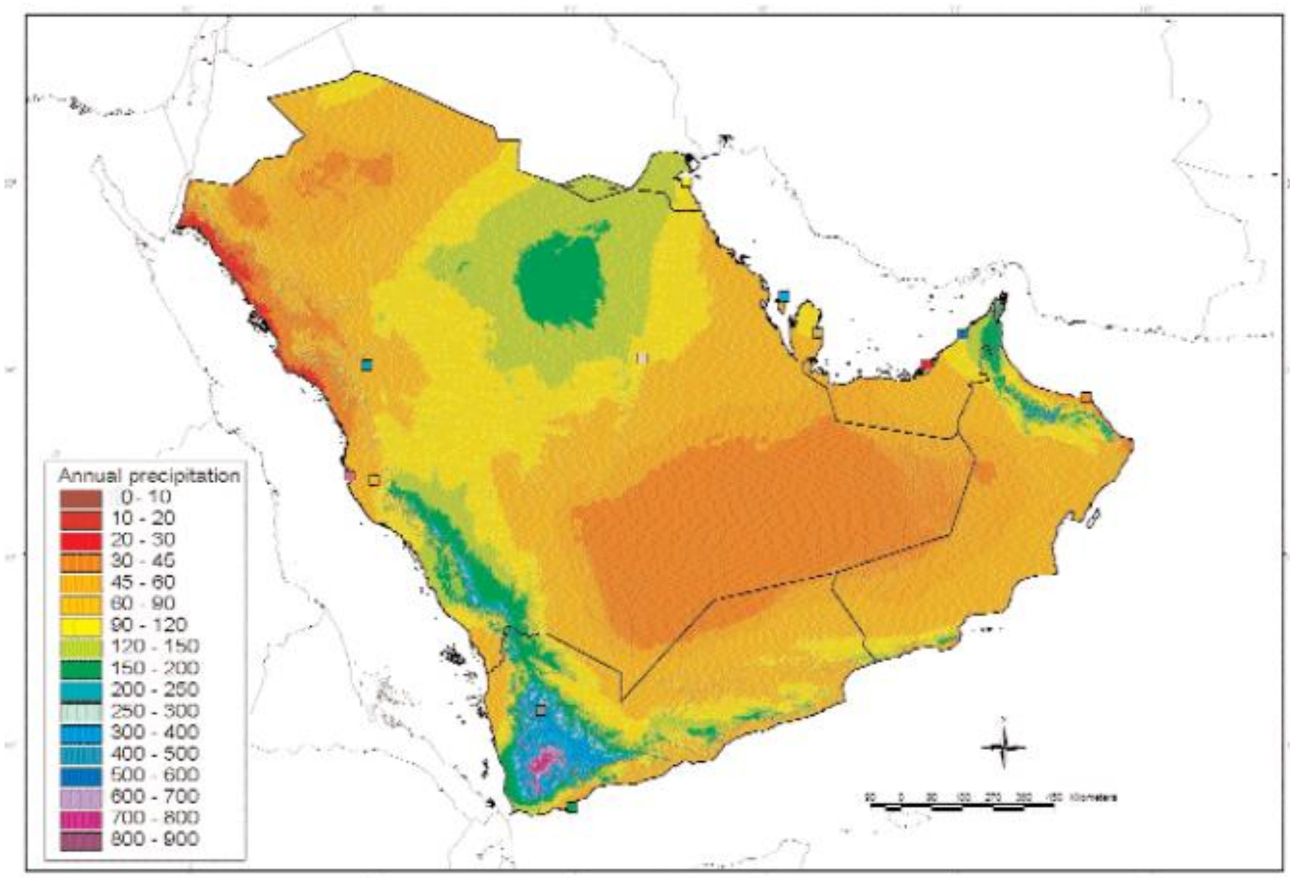
Tonapi et al, (eds) 2020 Sorghum in the 21st Century: Food – Fodder – Feed – Fuel for ¬a Rapidly Changing World. Springer, 2020.

Tripathy S.K., Kar J., Sahu D. (2019) Advances in Sesame (Sesamum indicum L.) Breeding. In: Al-Khayri J., Jain S., Johnson D. (eds) Advances in Plant Breeding Strategies: Industrial and Food Crops. Springer, Cham. https://doi.org/10.1007/978-3-030-23265-8_15.

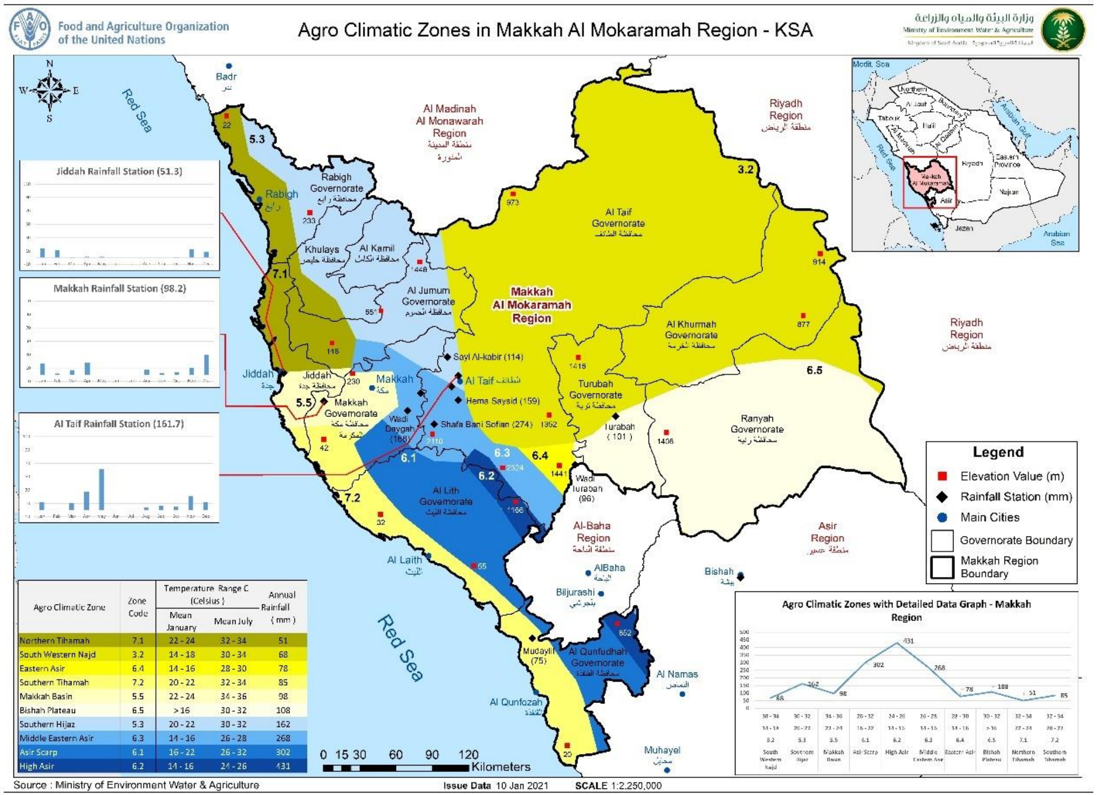
Tounekti , T., Mahdhi, M., Al-Faifi, Z., & Khemira, H. (2020). Priming improves germination and seed reserve utilization, growth, antioxidant responses and membrane stability at early seedling stage of Saudi sorghum varieties under drought stress. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 48(2), 938–953. https://doi.org/10.15835/nbha48211841.

Woertz Eckart (2020) Wither the self-sufficiency illusion? Food security in Arab Gulf States and the impact of COVID-19. Food Security 12:757–760.

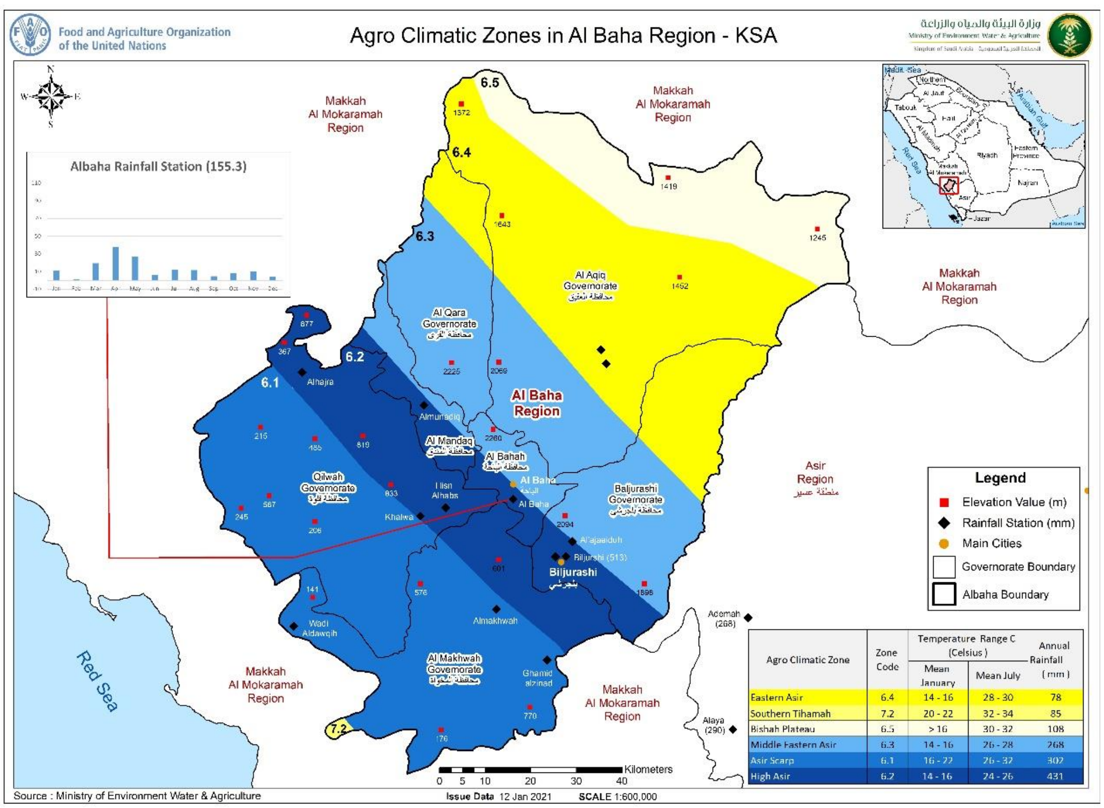
Annex 1. Arabian peninsular annual precipitation map (De Pauw, 2002).



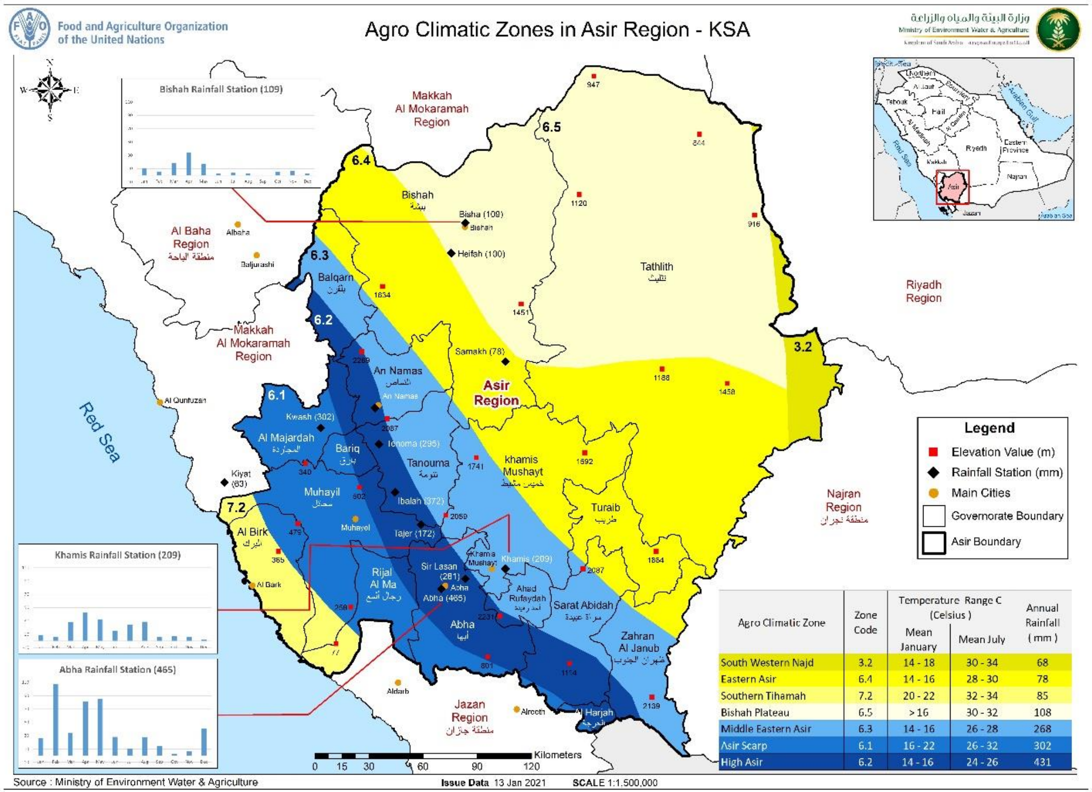
Annex 2. Agroecological zones of the target regions.



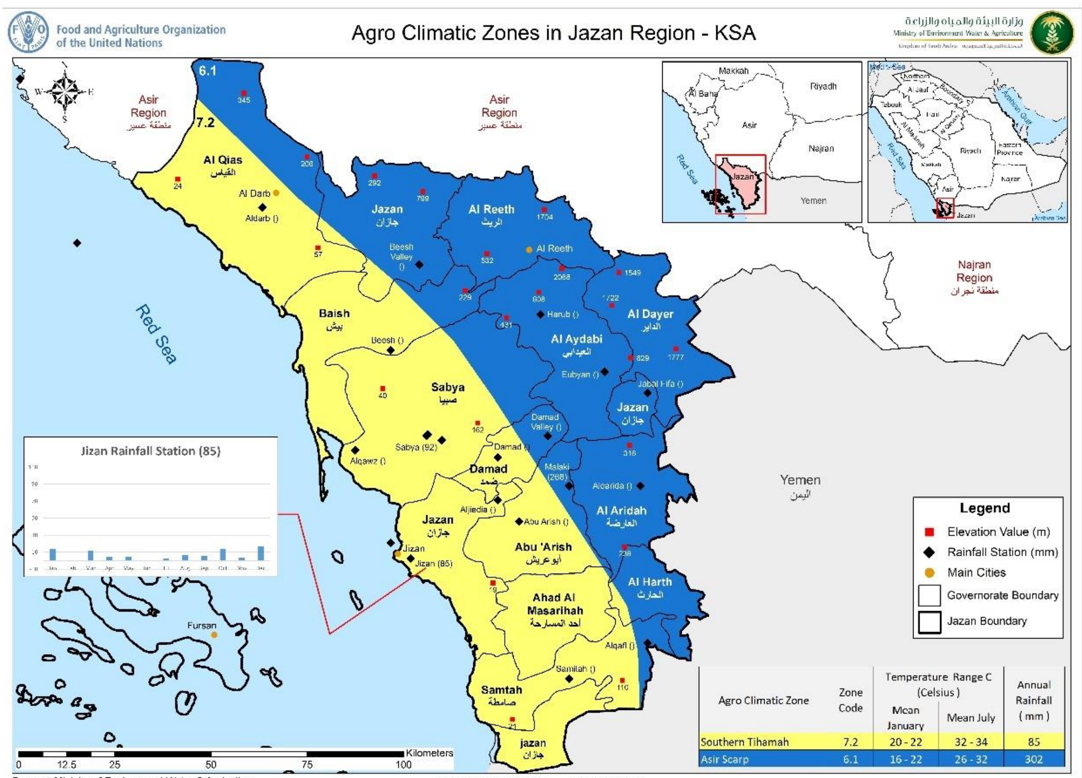
Agro Climatic Zone	Zone Code	Temperature Range C (Celsius) Mean January	Mean July	Annual Rainfall (mm)
Northern Tihamah	7.1	22 - 24	32 - 34	51
South Western Najd	3.2	14 - 18	30 - 34	68
Eastern Asir	6.4	14 - 16	28 - 30	78
Southern Tihamah	7.2	20 - 22	32 - 34	85
Makkah Basin	5.5	22 - 24	34 - 36	98
Bishah Plateau	6.5	> 16	30 - 32	108
Southern Hijaz	5.3	20 - 22	30 - 32	162
Middle Eastern Asir	6.3	14 - 16	26 - 28	268
Asir Scarp	6.1	16 - 22	26 - 32	302
High Asir	6.2	14 - 16	24 - 26	431



Agro Climatic Zone	Zone Code	Temperature Range C (Celsius) Mean January	Mean July	Annual Rainfall (mm)
Eastern Asir	6.4	14 - 16	28 - 30	78
Southern Tihamah	7.2	20 - 22	32 - 34	85
Bishah Plateau	6.5	> 16	30 - 32	108
Middle Eastern Asir	6.3	14 - 16	26 - 28	268
Asir Scarp	6.1	16 - 22	26 - 32	302
High Asir	6.2	14 - 16	24 - 26	431



Agro Climatic Zone	Zone Code	Temperature Range C (Celsius) Mean January	Mean July	Annual Rainfall (mm)
South Western Najd	3.2	14 - 18	30 - 34	68
Eastern Asir	6.4	14 - 16	28 - 30	78
Southern Tihamah	7.2	20 - 22	32 - 34	85
Bishah Plateau	6.5	> 16	30 - 32	108
Middle Eastern Asir	6.3	14 - 16	26 - 28	268
Asir Scarp	6.1	16 - 22	26 - 32	302
High Asir	6.2	14 - 16	24 - 26	431



Agro Climatic Zone	Zone Code	Temperature Range C (Celsius) Mean January	Mean July	Annual Rainfall (mm)
Southern Tihamah	7.2	20 - 22	32 - 34	85
Asir Scarp	6.1	16 - 22	26 - 32	302

Annex 3. Summary of MoEWA initiatives and FAO project activities for the 1st Phase to be undertaken in 2021

MOEWA initiative	FAO activity	Implementation steps	Years	Experts needed in 2021
5. Establish pilot/demonstration farms to disseminate and develop modern agricultural practices.	1.6.9. Design and implement programme of promoting adoption of advance farming technology and management practices through the network of progressive farmers.	1. Data collection and identification of the pilot governorates, villages and farmers, assignment of MoEWA focal points in the pilot governorates.	2021	1. Conservation agriculture expert (2 months) 2. IPM expert/s (3 months) 3. Mechanization expert (1 month) 4.. Irrigation expert (1 month)
		2. Assessment of the current status of production constraints, identification of gaps and development of need-based recommendations for technology demonstrations for each pilot village and demo farm including demonstration package.	2021	
		3. Training of MoEWA focal points and pilot farmers. Preparation and distribution of knowledge products.	2021-22	
		4. Provision of demonstration package to the pilot farms and establishment of demonstration fields.	2021-22	
		5. Conducting technology promotion and extension activities.	2022-25	
13: Establish research centre to test latest agric. technologies.	3.2.5. Establish smallholders' extension and applied research centres for cereals in the target regions.	1. Detailed capacity assessment of Jazan Agricultural Research Center.	2021	Agricultural technology Expert (3 months)
		2. Research and extension needs assessment of the target regions for rainfed cereals across various agro-ecologies and framing systems including a workshop to discuss the results and recommendations.	2021	
		3. Development of cereals research strategy and methodology, discussion with stakeholders and preparation of the final document.	2021	
		4. Preparation of detailed program for strengthening Jazan Agricultural Research Center and establishment of Cereals Department.	2021	
		5. Staff hiring and capacity development.	2021-25	
		6. Infrastructure improvement.	2021-22	
		7. Supply of machinery and equipment.	2021-22	
		8. Establishment of experiments addressing the cereals farmers research needs.	2023-25	
		9. Extension activities addressing the cereals farmers extension needs.	2024-25	
17. Establishment of special program to select high quality	3.2.16. Establish smallholders' extension and applied research centres for	1. Inventory and collection of currently grown cereals varieties and landraces.	2021-22	1. Cereals Breeder (3 months) 2. Seed system Expert (3 months)
		2. Assessment of varietal needs for the target regions considering agro-ecology and the farming systems.	2021	

cultivars and high productivity plants.	cereals in the target regions. 1.6.9. Design and implement programme of promoting adoption of advance farming technology and management practices through the network of progressive farmers.	3. Development of detailed breeding strategy and methodology leading to proposal for breeding program establishment including the required staff, infrastructure, machinery and equipment, etc.	2021	3. Plant quarantine services Expert (1.5 months) in 2022
		4. Establishment of cooperation and partnership with national and international institutions.	2022-23	
		5. Evaluation of the collected and imported material, selection of the promising germplasm and establishment of on-farms testing for promising perspective varieties.	2022-25	
		6. Appraisal of the seed system and preparation of detailed report and proposal for its development.	2021	
		7. Realization of the seed system enhancement proposal.	2022-25	
		8. Appraisal of the quarantine system and preparation of detailed report and proposal for its development.	2022	
		9. Realization of the quarantine system enhancement proposal.	2022-23	
6, 9, 19. Introduction of modern equipment for land preparation, seeding and harvesting.	1.1.12. Identify and promote farm power and appropriate technology (machines and implements) suitable for smallholders in the target regions.	1. The initial step of this initiative is the review of the current status of mechanization of soil preparation, seeding, inputs application, harvesting, grain cleaning and processing and develop a mechanization proposal and plan with consideration of four rainfed crops (sorghum, millet, sesame and wheat) in the target regions and pilot governorates.	2021	1. Agriculture mechanization Expert (2 months)
		2. Review the current lease practices for agricultural machinery and equipment in KSA and modern inclusive lease practices outside of the country considering the type of machinery proposed by the previous implementation step. Development of guidelines for machinery lease arrangements including preparation of the lease draft agreement, monitoring, and evaluation procedure.	2021	
		3. Sourcing of the machinery according to the proposal and plan, its lease following the guidelines developed, utilization for cereals production enhancement and modern technology application.	2021-24	
		4. Conducting training on efficient and safe use of new machinery and application of new technologies targeting the users of machinery and equipment.	2021-25	
		5. Training, monitoring, evaluation, maintenance and adjustment of the machinery lease system.	2022-25	
2. Developing solutions for rain water harvesting and supplementary irrigation.	1.5.1-4; 1.5.10-14. Focus on irrigation and rain water use enhancement.	1. Study of the current irrigation practices and development of detailed proposal and work plan for irrigation with focus on target regions and pilot governorates. 2. Study of the rainwater harvesting technological practices and development of detailed proposal and work plan for enhancement including	2021 2921	1. Irrigation Expert (2 months) 2. Rainwater Harvesting / Irrigation Water Mgt Expert (3 months)

		terraces, check dams, small agricultural dams, storage tanks, groundwater recharge structures etc. with focus on target regions and pilot governorates. 3. Implementation of proposals for improvement of rainwater harvesting technologies and irrigation practices.	2022-25	
7. Establishing leasable silos and stores.	On request from MoEWA.			
12. Establishing Sesame oil factory and private mills for sorghum and millet flour.	On request from MoEWA.			
20. Providing programs for insuring/ mitigating loans burdens in case of natural disasters occurrence.	On request from MoEWA.			
Phase 2 (2022-2025)				
1. Using Fertilization Program.	1.1.2. Identify and promote conservation agriculture practices among smallholders for production of the targeted rainfed cereal crops.			
3. Enhancing crop rotation and using safe insecticides to control insects.	1.1.2. Identify and promote conservation agriculture practices among smallholders for production of the targeted rainfed cereal crops. 1.1.11. Develop and implement an IPM programme for control of sorghum, millet and sesame pests and diseases. 3.2.23. Develop a programme to ensure access of rainfed cereals small producers to pests and diseases control services.			
4. Providing training courses and awareness programs that aiming at raising and developing Farmers' Skills. **Priority 5.**	Across several activities.			
8. Empowering cooperative societies to sell members farmers products under joint trademark.	Activities 2.28; 3.1.4; 3.1.9; 3.1.10; 3.1.11; 3.1.12; 3.1.19; 3.1.20; 3.1.21 focusing to empower cooperatives.			
10. Seeds treatment and sterilization.	1.1.15. Establish and operate community seed system for the target crops in the target regions.			

11. Developing database to enhance manpower rotation across farms.	6.3.2. Carry out diagnostic assessment study of rural labour market for the target regions to develop appropriate measures to address rural unemployment and internal migration.			
14. Setting national standards to classify sorghum, sesame and millet quality.	6.3.3. Undertake comprehensive value chain analysis and development for the targeted commodities to design effective development strategies to support smallholders			
15. Establishing national online platform to sell and deliver grains.	3.3.20. Develop smallholder-adapted e-market information systems to enable access to useful, timely and transparent market and price information for improved decision making.			
16. Enhancing domestic product distinction by labelling “made in KSA”.	5.1.9. Facilitate development of infrastructure and logistics needed for production and processing of rural agri-food and traditional commodities.			
18.Enhancing using fixed price supply agreements.	Activities 3.3.11; 3.3.12; 3.3.13 focusing on contract farming and agreements.			

برنامج التعاون الفني بين وزارة البيئة والمياه والزراعة ومنظمة الأغذية
والزراعة للأمم المتحدة، الرياض، المملكة العربية السعودية
ص. ب.: 558 الرياض 11421
بريد إلكتروني: FAO-SA@fao.org

برنامج التعاون الفني بين وزارة البيئة والمياه والزراعة ومنظمة الأغذية
والزراعة للأمم المتحدة، الرياض، المملكة العربية السعودية
ص. ب.: 558 الرياض 11421
بريد إلكتروني: FAO-SA@fao.org