International Virtual Experts Meeting on
Promoting Sustainable Agriculture
Development in Drylands
Riyadh, Kingdom of Saudi Arabia
10th August, 2020

FINAL REPORT

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Disclaimer

This report captures content from independent presentations during a workshop, in addition to content and context added by the authors. The report does not represent a consensus or endorsement by participants or G20 MACS.

Table of Contents

1. Section I: Executive Summary

High-level agricultural scientists from the G20 countries, invited guest countries, and international organizations hold the International Virtual Experts Meeting on Promoting Sustainable Agriculture Development in Drylands on August 10, 2020, to address the implementation measures and share best practices for enhancing sustainable agricultural production in drylands. During the event, the participants share their knowledge in the form of approaches, good practices, innovative solutions, or guidelines covering different aspects of drylands under the themes designed by the Ministry of Environment, Water and Agriculture, Kingdom of Saudi Arabia. Agriculture systems in drylands are complex socio-ecological systems characterised by human, social, natural, physical and financial capitals. Independent presentations by participants often highlighted that economic performance of the farming system in drylands could be scaled up by combining solutions co-designed with local communities in a systematic way, which mainly depends on various factors that may influence their short and long-term productivity. Overall, the long term strategic decision imparts a huge difference to the economic viability of the system. In this regard, it is the need of hour to benchmark current farming systems through water use efficiency of crop income/mm of rainfall over the cropping sequence in order to devise realistic system approach to achieve sustainable agricultural development in drylands.

2. Section II: Need for Global Collaboration about Drylands Development

Global challenges to food security and sustainability are arising because of growing human population in a context of natural resource constraints and our rapid transformation of Earth's natural systems, including the climate system. Providing adequate nutritious food for such a large population under challenging depleting natural resources and COVID-19 circumstances highlight the importance of the global food security issues. Currently, over 821 million people are suffering from hunger, and these people mostly residing in developing countries. If current trends continue, the number of hungry people will reach 840 million by 2030 (Figure 1)[1]. Zero Hunger is one of the Sustainable Development Goals (SDGs) of the United Nation, which compel us to rethink our growing, sharing and food consumption patterns. The Global agricultural productivity that is measured as Total Factor Productivity is alarmingly far below the United Nations SDGs target in low-income countries[2]. In this regard, Drylands attains special attention because of its tremendous contribution in global food security and nutrition by providing much of the world's grains, fruits, vegetables and livestock.

[1] World Food Programme WFP's Hunger Map 2020.

[2] Steensland A, Zeigler M. 2018. Global Agricultural Productivity Report® (GAP Report®) Global Harvest Initiative, Washington, D.C., October 2018.

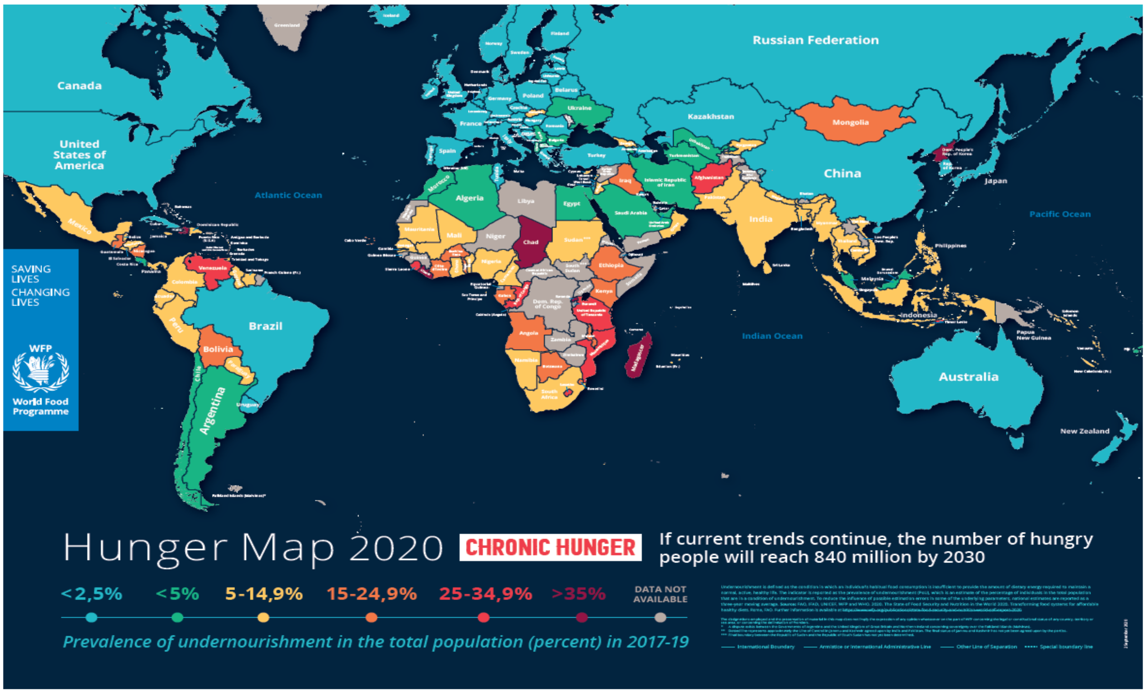

Figure 1. Hunger map 2020 (Source WFP 2020)

Drylands are large and significant that span all continents of the world (Figure 2). Globally 54 million km^2 or approximately 40 % of the land area is occupied by drylands, with about 30 % of this area being arid, 44 % semiarid, and 26 % in the dry sub-humid zone[3] . With 34 % and 15% of the drylands being located in Asia and Australia, respectively[4]. Furthermore, it has been estimated that 2.1 billion of the global population is inhabit and depend on drylands. Overall, these drylands support 44 percent of the cultivated systems of the world. The 30 percent of plants under cultivation are endemic to drylands. Overall, arid zones that are largely characterized as drylands contribute to 50 percent of the livestock production[5].

[3] WMO 2005. Climate and land degradation. Publication No. 989, 32 pp. World Meteorology Office, Geneva, Switzerland. ISBN 92-63-10989-3.
[4] Turner, N.C., Li, F.M., Xiong, Y.C. and Siddique, K.H. 2011. Agricultural ecosystem management in dry areas: challenges and solutions.Plant and Soil, 347(1-2), p.1.
[5] 2010–2020: UN Decade for Deserts and the Fight against Desertification. https://www.un.org/en/events/desertification_decade/whynow.shtml

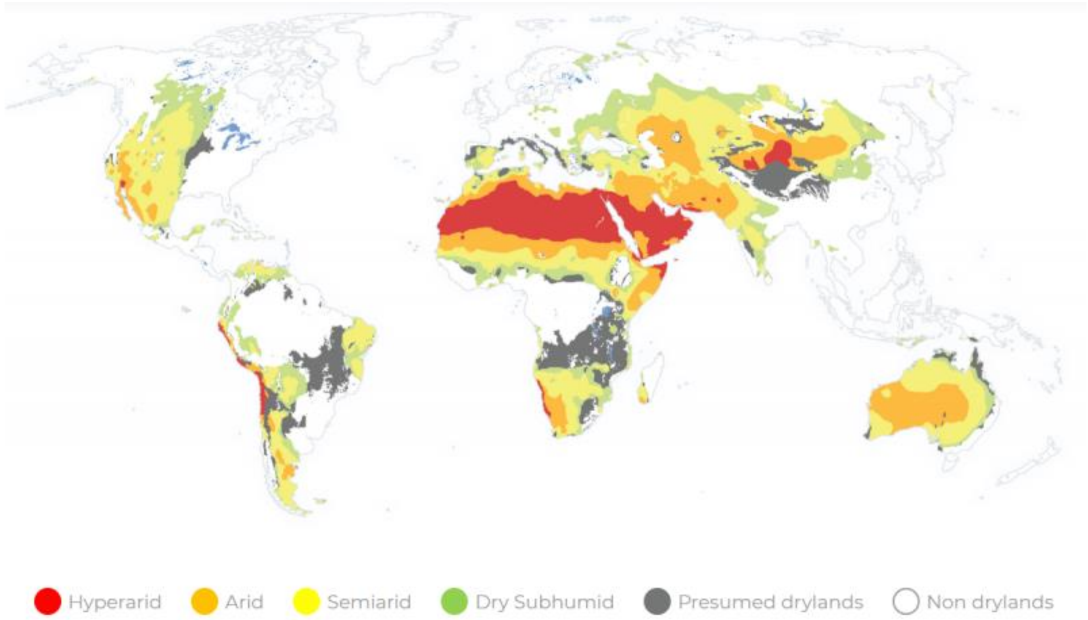

Figure 2. Distribution of Global Drylands from FAO report (USDA)[6]

Drylands have three primary economic functions: as rangelands (65% of the global drylands including deserts); as rain-fed farmland and irrigated farmland (25%); and as forest or sites for towns and cities (10%), which are growing rapidly. They include the world's driest places (hyper arid deserts such as the Rub' al Khali, Kingdom of Saudi Arabia, Atacama in Chile, and the Namib in southwest Africa) as well as the Polar Regions as shown in Table 1.

Table 1: Global statistics for the four types of drylands

Dryland sub-habitat	**Aridity index***	**Share of global area (%)**	**Share of global population (%)**	**Rangeland (%)**	**Cultivated (%)**	**Other (including urban) (%)**
Hyper-arid	< 0.05	6.6	1.7	97	0.6	3
Arid	0.05-0.20	10.6	4.1	87	7	6
Semi-Arid	0.20–0.50	15.2	14.4	54	35	10
Sub-humid	0.50–0.65	8.7	15.3	34	47	20
Total	**-**	**41.3**	**35.5**	**65**	**25**	**10**

* The ratio of precipitation to potential evapotranspiration. Source: Safriel et al. 2005[7].

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[6] FAO. 2019. Trees, forests and land use in drylands: the first global assessment – Full report. FAO Forestry Paper No. 184. Rome.

[7] Salirei, U., and Z. Adeel. 2005. Dryland Systems. Ecosystems and Human well-being: Current State and Trends. 623-662.

The harsh climatic conditions prevailing in drylands and its inherent vulnerability to climate variability adversely impact the sustainability of dryland agriculture given the very limited and highly variable resources for successful animal and plant production. The Agricultural Chief Scientists of G20 members during their ninth Meeting of Agricultural Chief Scientists (MACS2020) chaired by the Kingdom of Saudi Arabia in 2020 included the following paragraphs in the Communiqué to promote Sustainable Agriculture Development in Drylands[8].

5. We recognize the importance of developing sustainable agriculture including pastoralism, in drylands for livelihoods and ensuring global food security and nutrition. Agriculture in drylands faces substantial challenges in particular in the context of changing climate patterns, including the depletion of natural resources, as well as inadequate management practices and infrastructure that largely contribute to food insecurity and poverty. We encourage research and innovation to support the restoration of degraded agricultural lands and soils to underpin sustainable agriculture production opportunities in drylands as an important contribution to global food security and nutrition.

6. We support increased research collaboration on plant and animal production systems for sustainable agricultural advances, in particular in drylands based on a wide range of innovations and effective agricultural knowledge and innovation systems. This includes but is not limited to soil health management, modern smart irrigation technologies, improved crop varieties and promotion of animal and plant health. It also includes innovative plant and animal technologies and practices such as organizational innovations to promote agricultural production in a sustainable manner.

7. We recognize the need to support dryland agriculture through developing innovative research on agroecosystems and enhancing the research capacity of agricultural entities by building effective agricultural knowledge and innovation systems. To assist such capacity development, we encourage knowledge sharing

[8] Drylands are defined as "zones with an aridity index of less than 0.65"

across G20 members and international organizations and the dissemination of this knowledge through training and education programs for producers. We recognize the important role of training and capacity building in the ownership of innovations and the implementation of sustainable practices.

8. We welcome and support the proposal from the Kingdom of Saudi Arabia to organize an experts meeting on dryland agricultural systems later in the year, with interested G20 members, invited countries, and international organizations. It will enable experiences to be shared and contribute to an improved scientific understanding on increasing agricultural, including rangeland, productivity sustainably in drylands.

During the ninth G20-MACS2020, most of the participating G20 members expressed their opinion and acknowledged the importance of developing sustainable agriculture including pastoralism, in drylands for livelihoods and ensuring global food security and nutrition. They emphasized on the Systems Approach[9] as they are critical for sustainable agriculture development in drylands. Due to current unprecedented COVID-19 pandemic situation, Kingdom of Saudi Arabia organized VIRTUALLY an International Experts Meeting on Promoting Sustainable Agriculture Development in Drylands in Riyadh, Kingdom of Saudi Arabia on the 10th of August 2020, which mainly aimed at

- Highlight this issue at G20 level in order to advance knowledge for implementation measures for the policy makers;
- Improve knowledge and information sharing for enhancing agricultural production in drylands;
- Discuss developing appropriate measures to enhance productivity and sustainability in drylands;

[9] Systems approach is defined by the European Union Commission during 2016 as "meeting the challenges facing the agricultural and food and non-food systems means dealing with complexity and working in an integrated manner so that proposed solutions are fit for both the problem they address and the main objectives being pursued for the system as a whole"

- Knowledge sharing and information on sustainable agriculture in drylands research and development to improve knowledge of institutions and farmers.

In this Virtual event, more than 79 participants, which were specialists from research institutes, government officials, academia, international and regional organizations, nominated by the G20 members, guest countries and invited organizations participated by presenting 30 presentations in the form of approaches, good practices, innovative solutions, or guidelines covering different aspects of drylands under the following themes designed by the Ministry of Environment, Water and Agriculture, Kingdom of Saudi Arabia

- Key Risks, opportunities and system approach for sustainable agricultural development in drylands
- Enabling tools for sustainable agricultural development in drylands
- Abiotic factors affecting sustainable agricultural development in drylands
- Innovation, technology and adoption to enhance resource use efficiency

Threats

- Limited renewable water resources
- Unsustainable exploitation of natural resources (groundwater, pastures)
- Increasing costs of production, including energy, water and employment
- High risk and uncertainty in the sector due to climate factors, seasonal changes in demand
- High demand of agricultural inputs and their impact on price fluctuations at the global level
- Small-scale producers suffer from difficulties at the marketing level, which affects their profitability and the sustainability of their production
- Remoteness
- Reliance on physical labor related to limited mechanization

Opportunities

- Directing agricultural activities according to the comparative advantages of the regions in order to improve productivity and enhance environmental sustainability and economic return for the sector
- Institutional innovations by Restructuring the current institutional situation and the privatization of some tasks and services
- Benefit from the development of agricultural technologies, methods and systems worldwide
- Unifying the efforts in the field of research and development and adopting the results of applied research
- Strengthening the work of government associations and raising public investment in technology and infrastructure
- Trade Liberalization
- Rationalize subsidies on agricultural inputs
- Agricultural diversification
- Increase inflow of institutional credit to dryland agriculture
- Networks and collaborations.

Weaknesses

- Limited database of the agricultural sector
- Sub-optimal operating procedures in monitoring and control
- Weak supply chain infrastructure (limited cold storage in ports and markets, few post-harvest packaging facilities)
- Low marketing efficiency of vegetables and fruits
- Limited use of modern agricultural practices, especially at the level of small farmers and the livestock sector
- Deficiency in the performance of most agricultural cooperative societies
- Lack of organized multidisciplinary research approach

Strengths

- Large areas suitable for various types of agricultural activities
- It provides renewable water resources and a mild climate
- Successful activities with extensive experience and leadership at the regional and international levels
- Various and specialized human experiences
- Great biological diversity

Figure 3. SWOT Analysis implementing by the Ministry of Environment, Water & Agriculture, Kingdom of Saudi Arabia

The success in drylands in terms of agricultural production enhancement mainly depends on a realistic and strategic planning technique like SWOT analysis Strengths, Weaknesses, Opportunities, and Threats (Figure 3) in order to address the implementation measures and share best practices for enhancing agricultural production in drylands.

The recommendations provided by the participants, in addition to content developed after the meeting, are compiled in the form of a report to draw conclusions for future collaboration to Promote Sustainable Agriculture Development in Drylands. The final report of this live virtual event will be presented during tenth G20-MACS-2021 in Italy.

3. Section III: Elements contributing Sustainable development in Drylands

The biggest challenges for agriculture particularly in Drylands are the declining natural resources, and food and nutritional insecurity. The management of natural resources is critical not only because the livelihoods of millions of rural are directly connected to these regions but also because these areas will continue to play a crucial role in determining food security for the growing population and in reducing poverty in the coming decades. Restructuring the agricultural production in Drylands by introducing innovative Animal and Plant Production systems are obligatory in order to meet the challenge to produce 70 % more food and fiber by 2050. New opportunities lie in the knowledge-based newly developed modern technologies and advanced management of natural resources supported by innovative policies and robust methods of designing, implementing and evaluating detailed development pathways through resilience thinking approaches, Land Degradation Neutrality, Carbon farming policy and practices, Drought policy for water and land in drylands to enhance the resource use efficiency. In these areas, there is a tremendous potential to revamp agriculture sector by using highly modernized good production systems for plants and animals in order to achieve Sustainable Development Goals (SDGs) including poverty alleviation, achieve food security and promote sustainable agriculture, land degradation neutrality, to ensure Sustainable Consumption and Production Patterns. Such modern concepts will greatly help to turn marginal Drylands into productive fields through interdisciplinary collaboration by incorporating sustainable, integrated and innovative production model. In this regard, participants of Experts meetings mentioned but not limited to the following global Institutes, which are involved in the sustainable agricultural production in drylands

Table 2. Drylands related Institutions		
1	USDA Climate Hubs	USA
2	Nanaji Deshmukh Plant Phenomics Centre, IARI, New Delhi	India
3	Centre for Data Driven Breeding	UK
4	CGIAR Excellence in Breeding Platform	CIMMYT
5	Plant Drought Tolerance Test Center	Turkey

6	Canada-Saskatchewan Irrigation Diversification Centre (CSIDC)	Canada
7	National Animal Disease Referral Expert System (NADRES)	India
8	Hand in Hand Geospatial Platform	FAO
9	International Center for Biosaline Agriculture	ICBA
10	International Center for Agricultural Research in the Dry Areas	ICARDA
11	Arab Organization for Agricultural Development	AOAD

Agriculture system in drylands is a complex system comprising of many elements. We have complied this final report by enlisting the available technologies, improved practices and resocres for the following four important elements shared by the experts during the meeting, which are very much critical for sustainable agricultural production in drylands.

3.1 Role of Water to Contribute Sustainability in Drylands

World contains an estimated 1400 million cubic km of water. But only 0.003% of this vast amount, about 45000 cubic km, are "freshwater resources" that could be used for drinking, hygiene, agriculture and industry. In purely physical terms, only 8% of the world's freshwater running in the rivers and infiltrating into the aquifers are withdrawn for agriculture, cities and industries. It is estimated that about 50% of what could be called "reasonably accessible" water resources are already mobilized for human use. Irrigation represents less than 20% of cultivated land but contributes 40% to overall food production[10].

The most of the water withdrawal is from water stress areas (Figure 4)[11]. In these high freshwater withdrawal areas, water table has gone down substantially over the past few years. Unfortunately, these water stressed areas are the backbone for global food security. Dryland agriculture is practiced globally in these areas and is characterized by highly variable rainfall, water shortages, and frequent droughts. Therefore, it is very important to invest in the innovative modern irrigation technologies to promote efficient use of water to achieve sustainable agricultural

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[10] World Water Assessment Programme (UNESCO WWAP). Facts and Figures Irrigated Land. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/facts-and-figures/all-facts-wwdr3/fact-24-irrigated-land/

[11] https://www.indexmundi.com/facts/indicators/ER.H2O.FWAG.ZS

operations in drylands. These technologies can further enhance the effectiveness of the disaster risk reduction related interventions ongoing in most vulnerable countries.

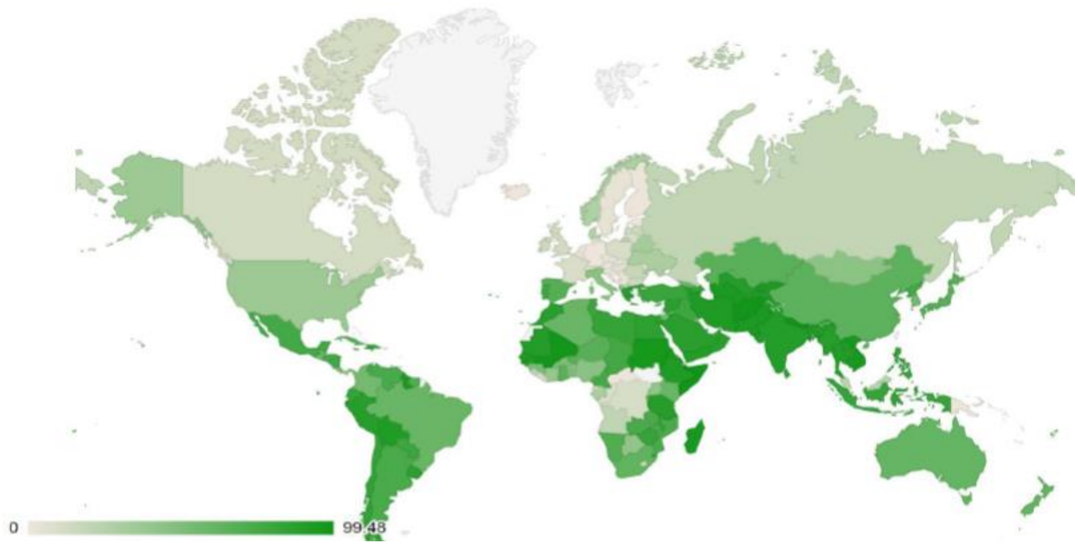

Figure 4. Annual freshwater withdrawals, agriculture (% of total freshwater withdrawal)[12]

3.1.1 Water-related Opportunities to Develop Sustainability in Drylands

Change in seasonal patterns may require new production system rather than optimizing the existing ones. Models help to explore the performance of the production system through simulation. These simulations can be used to identify best management practices in dry and arid environments. Furthermore, modelling helps to identify trade-offs between run-off-erosion and system productivity. From water distribution point of view, each type of cropping systems demands a separate MODEL FOR WATER DYNAMICS.

The participants during the Experts Meeting pointed out the following opportunities, which may contribute to safeguard depleting water resources through efficient resource utilization.

[12] https://www.indexmundi.com/facts/indicators/ER.H2O.FWAG.ZS

3.1.1a Good Practices

- CANOPY MANIPULATION through appropriate intercropping, and maintaining appropriate plant density is found to be a viable strategy to develop drylands agriculture. Plant density and intercropping contribute significantly by enhancing water use efficiency through increasing water transpiration from the plants, which ultimately leads to the increase in the yield of the crop.
- PLASTIC FILM MULCHING is an innovative solution, which has played an important role in Chinese agriculture owing to its effects on soil warming, moisture conservation and weed control. In China, the use of plastic film mulching able to produce more grains per unit area, which ultimately led to an average increase of 45.5 % crop yield along with 58 % water use efficiency, and contributed to 3.0×10^7 metric tons of crop production in 2012 [13]. Despite the benefits of plastic film mulch technology, widespread use has generated large amounts of mulching plastic waste (referred to as 'white pollution) that opens new avenue for research to develop thick or degradable plastic mulches.
- DEEP TILLAGE[14], which mainly aimed to fracture the compacted soil without disturbing the top soil is critically important to improve soil porosity, water infiltration, and ultimately minimize the runoff. In addition, zero tillage[15]/no tillage/nil tillage further improve rainfall water storage.
- COVER CROPS[16] to store moisture under the stubbles and protect the fallow soil before the cash crop is an old time technology, which is equally effective now to improve soil infiltration, and crop performance by gaining maximum benefit of rainfall water though prolonged moisture availability rather than lost through evaporation.

[13] Sun et al., 2020. An overview of the use of plastic film mulching in China to increase crop yield and water use efficiency, National Science Review, , nwaa146, https://doi.org/10.1093/nsr/nwaa146.

[14] Deep tillage is performing tillage operations below the normal tillage depth to modify the physical or chemical properties of a soil.

[15] No-tillage (also zero tillage) is a minimum tillage practice in which the crop is sown directly into soil not tilled since the harvest of the previous crop. Weed control is achieved by the use of herbicides and stubble is retained for erosion control. It is typically practised in arable areas where fallowing is important. (Source OECD).

[16] Erbacher et al., 2019. Cover crops can boost soil water storage and crop yields. GRDC Update Papers.

3.1.1b Modern Technologies

- Currently, RNA-seq approach has been successfully widely used to understand the mechanisms behind various biotic and abiotic stresses in different crop species. In this technologically advanced era, research should focus on better understanding of the molecular mechanisms involved in drought tolerance using RNA-seq approach and the potential candidate genes that can be utilized in breeding programs[17].
- Lands covered by sand dunes and sediments carried by wind have been transformed into intensive agriculture, especially with the spread of DRIP IRRIGATION. In areas with similar features, covered with sand dunes or covered with wind sediments, these areas can easily be converted to agriculture if enough water provided for drip irrigation.
- VARIABLE RATE IRRIGATION (VRI) applies precise amounts of water at the right time and this technology has shown tremendous potential for sandy drylands. This technology increase 15 % water use efficiency compared with traditional Uniform rate Irrigation. In addition, VRI helps to distribute water evenly in the soil profile in order to avoid crop water stress during the season.
- The tools developed as a result of REMOTE SENSING allow irrigator to view data in form to make informed decisions. These developments revolutionized this sector by tremendously enhance the irrigation water productivity. However, much needs to be done on the cost effectiveness and adoption of these inventions through extension services.

3.1.1c Collaborative Efforts

- United States Drought Monitor[18] is produced through a partnership between the University of Nebraska and federal agencies and works collaboratively to support state, tribal, local, and private sector approaches to managing drought risks and impacts. Such kind of novel tools and resources are critically important

[17] Bhogireddy et al., 2020. Genome-wide transcriptome and physiological analyses provide new insights into peanut drought response mechanisms. Scientific Reports. 10:4071. https://doi.org/10.1038/s41598-020-60187-z
[18] https://droughtmonitor.unl.edu/

to advance drought science and stimulate our preparedness to tackle the challenged faced by the drylands.

- The North American Drought Monitor (NADM) is a cooperative effort between drought experts in Canada, Mexico and the United States to monitor drought across the continent on an ongoing basis. The NADM is based on the highly successful United States Drought Monitor, and as such, is being developed to provide an ongoing comprehensive and integrated assessment of drought throughout all three countries.

The technologies disclosed by the participants in the Experts Meeting are compiled in the form of a table. Different aspects of each technology are provided in the Table 3.

Table 3. Opportunities to facilitate International Research Collaboration to cope with water scarcity issue in drylands

Categories determinations were made by the host 2020 MACS team, and shared with every participant for feedback

No	Name	Category	Country	Degree of Innovation	Risk	Level of Contribution to drylands	Status	Adoption	Timescale to delivery
1	Cover crops	Good Practices	Australia/South Africa/China	Low	Low	Middle	In fields	Quick	Short
2	Zero tillage/No tillage/Nil tillage	Good Practices	Australia/South Africa	Middle	Low	Middle	In fields	Quick	Short
3	Deep tillage	Good Practices	China		Low	Middle	In fields	Quick	Short
4	Canopy manipulation	Good Practices	China	Low	Low	High	In fields	Quick	Short
5	Plastic film mulching	Good Practices	China	High	Middle	High	In fields	Quick	Short
6	Rain water harvesting	Good Practices	South Africa/Turkey	Middle	Middle	Middle	In fields	Moderate	Middle
6	Irrigation scheduling	Good Practices	Canada	Low	Low	High	In fields	Moderate	Middle
7	Modelling Water Dynamics	Modern Technology	Italy	High	Middle	High	R & D	Moderate	Middle
8	Laser leveling	Modern Technology	India	High	Low	High	In fields	Quick	Short
9	Micro irrigation techniques	Modern Technology	India	High	Low	High	In fields	Quick	Short
10	Drip Irrigation	Modern Technology	Saudi Arabia/Turkey	High	Low	High	In fields	Quick	Short
11	Sprinkler Irrigation	Modern Technology	Saudi Arabia	High	Low	High	In fields	Quick	Short
12	Pressure-Sprinkler water use	Modern Technology	USA	High	Low	High	In fields	Quick	Short
13	Solar Energy Irrigation System	Modern Technology	Turkey	High	Low	High	In fields	Quick	Short
14	Pressurized Irrigation Systems	Modern Technology	Turkey	High	Low	High	In fields	Quick	Short
15	Variable Rate Irrigation (VRI)	Modern Technology	Canada	High	Low	High	In fields	Moderate	Middle
16	Remote sensing	Modern Technology	Canada	High	Low	High	In fields	Moderate	Middle
17	Low Pressure Pivot Irrigation System	Modern Technology	Canada	High	Middle	High	In fields	Quick	Short
18	SCADA – Supervisory Control and Data Acquisition	Modern Technology	Saudi Arabia/Canada	High	Low	High	In fields	Quick	Short
19	United States Drought Monitor	Collaborative Efforts	USA	High	Low	High	In fields	Quick	Short

3.1.2 Recommendations/Guidelines for water use efficiency based on the solutions for sustainable development in Drylands, compiled from independent presentations

- Drylands are complex, which are supporting different types of production systems. Each type of system demands a separate model to fulfill the water requirements.
- A key challenge that will need to be addressed are the many socio-economic, environmental and institutional barriers to adoption, which can be highly context-specific.
- Adaptation choices and risk management actions across temporal and spatial scales and contexts will need to build on robust methods of designing, implementing and evaluating detailed development pathways. Such pathways, yet to be fully elucidated, must strengthen climate-resilience and limit trade-offs between different actors.
- Education and training is vital to promote the implementation of good practices including zero tillage, mulching, intercropping, cover crops in order to protect depleting water resources through their efficient utilization for maximum benefits.
- Modelling simulations can help scientists, policy makers and other stakeholders assess the potential environmental and socio-economic impacts of a wide range of management practices and other interventions, including in the face of climate risk and other socio-economic trends.
- It is necessary to develop strategies co-designed with local communities to scale up the traditional irrigation infrastructure with the modern innovative technologies in order to enhance the water productivity.
- It is indispensable now to allocate more budget on the irrigation R & D mainly focusing on the ways to enhance water use efficiency and how to revamp irrigation infrastructure in drylands
- Local, regional and global collaboration is vital to tackle water scarcity in drylands.

3.2 Role of Soil to Contribute Sustainability in Drylands

Soils are an essential non-renewable largest terrestrial natural resource hosting 95 percent of global food production. They are providing essential ecosystem services, which are important for water regulation and supply, climate regulation, biodiversity conservation, carbon sequestration and cultural services. However, soils are under pressure from increases in population, higher demands for food, competing land uses, and environmental variability. While fertile soils supply essential nutrients to plants to enhance their productivity, declines in soil fertility have long been a major concern of agriculturalists due to direct impacts on crops in terms of reduced productivity. Soil fertilization by adding optimal synthetic and organic fertilizers is an important soil fertility enhancement technique for sustainable production of agricultural commodities in drylands. Historically, the application of fertilizers in addition to improved management practices are known as the major driver for global green revolution. The Ministerial Declaration of the G20 meeting of Argentina (2018) emphasized the importance of developing and enhancing actions to promote soil health in addition to the utilization of soils in a sustainable manner. The landscapes prevailing in drylands especially in the arid and semi-arid areas of the world are facing low productivity due to reduced soil fertility. The success in drylands in terms of agricultural production mainly depends on numerous factors and among them soil fertility management is critically to revamp agriculture in drylands.

3.2.1 Soil-related Opportunities to Develop Sustainability in Drylands

Soil organic carbon and nutrients are declining over the time. The best performance of the soil mainly depends on the health of the soil. The participants during the Experts Meeting pointed out the following technologies, which may contribute to a healthy soil to achieve full potential in drylands.

3.2.1a Good Practices suggested by participants

- In drylands topsoil is prone to drying, therefore, soil nutrients stratification is very important to enhance nutrient availability and plant uptake to tackle impeded root growth and reduced diffusion of immobile nutrients. In this regard, DEEP PLACEMENT OF FERTILIZERS is an opportunity to enhance nutrient acquisition and utilization under challenging drylands. However, in order to achieve maximum yield benefits, it is essential to understand the effects of climatic conditions, soil management, and plant–soil interactions before adopting deep fertilizer practice.

- ORGANIC MULCHING, which is actually performed by covering the bare surface of soil through the temporary layer of bark chip etc. is an important approach to conserve soil water in order to regulate soil temperature, improving soil fertility, reduce weed growth, and enhancing visual appeal. The correct incorporation of this approach can dramatically improve soil productivity.
- COVER CROPS for soil health, reducing erosion, extending grazing, reducing inputs and increasing yields.
- LIGHT GRAZING AND GRASSLAND RESTORATION has potential to improve soil health and resilience through an increase in SOC and microbial community responses related to nutrient cycling[19].
- The use of REED SCREENS as farmers participatory approach at the height of 1-2 m with 8-10 times space between the height of the reed screen to stop soil erosion by reducing the velocity of wind and stabilize the sand dunes is found to be an important approach not only to stop desertification but also regain soil organic structure and successfully converted into pastures, irrigated farming, fruits growing and bee keeping activities.

3.2.1b Modern Technologies

- LANDPKS is a global tool that is available in the form of a free mobile app to discover the potential of your land and monitor change over time. This mobile application helps your mobile device for soil identification,

[19] Ghimire et al., 2019. Soil organic matter and microbial community responses to semiarid croplands and grasslands management. Applied Soil Ecology 141: 30–37.

land cover and soil health monitoring, land management and farm record keeping, and more[20].

- The RANGELAND HYDROLOGY AND EROSION MODEL (RHEM) is a newly conceptualized, process-based erosion prediction tool specific for rangeland application, based on fundamentals of infiltration, hydrology, plant science, hydraulics, and erosion mechanics. This tool provides sound, science-based technology to model and predict runoff and erosion rates on rangelands and to assist in assessing rangeland conservation practice effects[21].
- A large amount of water during irrigation is lost due to preferential water flow. In this case, water is moved from root habitat to deeper layers of soil as a result upper layer of soil is not moistened. That leads to non-productive dryness losses. In this regard, construction of ARTIFICAL SOILS in urban lands, and arid territories is very important in order to decrease the non-productive water losses.

3.2.1d Collaborative Efforts

- The GLOBAL SOIL PARTNERSHIP (GSP) is a globally recognized mechanism established in 2012. Their mission is to position soils in the Global Agenda through collective action. Their key objectives care to promote Sustainable Soil Management (SSM) and improve soil governance to guarantee healthy and productive soils, and support the provision of essential ecosystem services towards food security and improved nutrition, and sustainable development. The GSP is an open, interactive, responsive and voluntary partnership which includes FAO Member countries and GSP partners - Governmental Organizations, Universities, Civil institutions, Research centers, Soil science societies, UN agencies, NGOs, Private companies, Farmer associations, and Donors[22].
- **Land Degradation Neutrality** (LDN) has been defined by the Parties to the Convention as: “A state whereby the amount and quality of land

[20] https://landpotential.org/
[21] https://apps.tucson.ars.ag.gov/rhem/
[22] http://www.fao.org/global-soil-partnership/en/

resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems". To date, over 120 countries have engaged with the LDN Target Setting Programme. LDN represents a paradigm shift in land management policies and practices. It is a unique approach that counterbalances the expected loss of productive land with the recovery of degraded areas. It strategically places the measures to conserve, sustainably manage and restore land in the context of land use planning[23].

The technologies disclosed by the participants in the Experts Meeting are compiled in the form of a table. Different aspects of each technology/approach are provided in the Table 4.

[23] https://www.unccd.int/actions/achieving-land-degradation-neutrality

Table 4. Opportunities to facilitate International Research Collaboration to cope with soil health management in drylands

Categories determinations were made by the host 2020 MACS team, and shared with every participant for feedback

No	Name	Category*	Country	Degree of Innovation	Risk	Level of Contribution to drylands	Status	Adoption	Timescale to delivery
1	Deep placement of fertilizers	Good Practices	Australia	High	Low	Middle	In fields	Quick	Short
2	Canopy manipulation to improve soil health	Good Practices	China	Middle	Low	High	In fields	Quick	Short
3	Organic mulching	Good Practices	China/South Africa	Middle	Low	Middle	In fields	Quick	Short
4	Green manuring	Good Practices	China	Middle	Low	Middle	In fields	Quick	Short
5	Modelling impact of soil tillage	Good Practices	Italy	High	Middle	Middle	R & D	Moderate	Medium
6	Reed-screens	Good Practices	Turkey	Middle	Low	Middle	In fields	Quick	Short
7	LandPKS	Modern Technology	USA	High	Low	High	In fields	Quick	Short
8	Rangeland Hydrology and Erosion Model Web Tool (RHEM Web Tool)	Modern Technology	USA	High	Low	High	In fields	Quick	Short
9	Livestock integration in cropping systems	Modern Technology	USA	Middle	Low	Middle	In fields	Quick	Short
10	Artificial soils	Modern Technology	Russia	High	Middle	Middle	R & D	Moderate	Medium
11	Plant Growth Promoting Rhizobacteria (PGPR)	Modern Technology	Argentina	Middle	Low	Middle	R & D	Moderate	Medium
12	Global Soil Partnership	Collaborative Efforts	FAO	Middle	Low	Middle	In practice	Moderate	Medium
13	Land degradation Neutrality	Collaborative Efforts	Australia, over 120 countries have engaged with the LDN Target Setting Programme	High	Low	High	In practice	Moderate	Medium

3.2.2 Recommendations/Guidelines to improve soil health for sustainable development in Drylands, compiled from independent presentations

- Allocation of budgets for promoting and exchanging Research & Development to provide innovative solutions to improve the productivity of the soil.
- Capacity building of the farmers through traditional extension services and modern electronic extension platforms are critically important to inform the farmers about the good practices.
- Tailored strategies will be required in tandem with public policy.
- Facilitate collaboration to share good practices, success stories, and modern technologies to convent drylands into productive production systems that fully support sustainable production and soil fertility to increase crops production.
- Potential social, economic or environmental trade-offs of practices and technologies need to be assessed prior to implementation (e.g. climate resilience, health and wellbeing, inclusiveness, gender equity, etc.).

3.3 Role of Plant Resources to Contribute Sustainability in Drylands

Plants are irreplaceable assets indispensable for economic growth, social services, environmental sustainability, human health and nutrition. They are providing food to the humanity since ages in the form of whole grains, cereals, fruits and vegetables. They are crucial for our existence by providing oxygen for all living organisms, medicines, shelter and clothing. Dryland agriculture encompass significant proportion of grasslands, agricultural lands, forests and urban areas contributing to global food security. These drylands support 44 percent of the cultivated systems of the world. The 30 percent of plants under cultivation are endemic to drylands. Globally, diverse cropping systems have been practiced on drylands. There are large gaps in profitability in different parts of the world. The economic performance of the production system varies with areas. Therefore, it is important to introduce those production systems, which best suit the particular demands of the particular area for maximum economic returns.

3.3.1 Plant Resources-related Opportunities to Develop Sustainability in Drylands

More food in future will be required to fulfill the emerging food demands. In this regard, revamping agriculture in drylands has become very important due to vast areas of lands globally occupied by the drylands. The participants of the Experts meeting discussed range of solutions from simple to high-tech options in order to make drylands more resilient to contribute in global food security and nutrition.

3.3.1a Cropping Systems

- CONSERVATION AGRICULTURE[24] plays a major role in mitigating climatic issues through better soil water retention and improved soil health. This farming system is equally capable of improving productivity have been developed as disclosed by G20 members in their presentations.

[24] A system avoiding or minimizing soil mechanical disturbance (no-till) combined with soil cover and crop diversification, is considered a sustainable approach to resource-conserving agricultural production.

- Greater DIVERSITY IN CROPPING SYSTEMS through the use of crop species and/or varieties adapted to mean rainfall and available water or introducing alternative crops or varieties, or intercropping or agroforestry due to environmental variability and issue of sustainability in order to develop more productive farming systems.
- CLIMATE RESILIENT VILLAGES for Drought Proofing is an innovative model mainly aimed to develop sustainable agricultural development in drylands by focusing on the performance of six key areas including 1) Weather based agro-advisories on the basis of real-time contingency planning, and weather monitoring, 2) Efficient water application techniques, 3) stress tolerant diversified intercropping system, 4) improving soil health by green manuring, 5) reducing the carbon footprint through recycling and livestock management, and 6) capacity development.
- SELF-SUSTAINING FOOD PRODUCING PLATFORM is an example of Future farming system, which might be economically feasible with future technology advancements in light, energy, genetic improvement, nutrition, machine learning and artificial intelligence etc.
- Protected Agriculture is very much promising production system for drylands: Net-houses allow vegetable production in desert conditions 8-9 months of the year with high yield. Net benefits same as cooled greenhouses in 12 months due to energy savings.
- The adoption of ORGANIC AGRICULTURE[25] practices could contribute greatly to the targets set by the Sustainable Development Goals (SDGs), as it is a small and large scale farming that successfully practiced throughput the world due to high economic benefits when markets exist. Globally, the demand for organic products is on the rise, and during 2018 organic foods sales cross 100 billion USD mark. The latest available data showed that organic farmland continues to

[25] ORGANIC AGRICULTURE is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system (Codex definition)

expand up to 186 countries on 71.5 million ha at the end of 2018, representing a growth of 2.9 percent or 2 million hectares compared to 2017. Australia has the largest organic agricultural area (35.7 million hectares), followed by Argentina (3.6 million hectares), and China (3.1 million hectares).

3.3.1b Modern Technologies

It is essential to integrate crop physiology, genomics and breeding approaches to dissect complex drought tolerance traits to understand the molecular basis of drought tolerance and develop the next-generation crops for our changing climatic patterns.

- The establishment of GENETIC RESOURCES is a good basis for future research to develop drought stress tolerance crop varieties for sustainable agricultural development in drylands.
- Drought tolerance or adaptation to water shortage is a complex trait where several genetic factors (genes, transcription factors, microRNAs) and proteins, hormones and metabolites can interplay. These factors can be involved in shaping root system architecture, affecting transpiration efficiency or drought signaling pathways. The polygenic nature of this trait, along with its environmental interaction, urges the need to apply all available technologies. A reliable phenotyping method at field level, a deep genome understanding and precision mapping will help in revealing the genetic, epigenetic, transcriptomic, and metabolomic bases of different traits associated with drought-resistance in crops, which can be applied in crop breeding. There are two different approaches to attain drought tolerance: 1) improve plant capacity in accessing water, 2) increase water use efficiency (transpiration efficiency), which means producing sustainably with the available water (even if it is scarce). These different plant strategies to cope with water availability involve different set of genetic factors. GENOME EDITING is a tool that will help next generation breeding to accelerate the development of drought tolerant crops.

- GENOMIC SELECTION[26] based on genotyping-by-sequencing (GBS) data is a promising strategy to accelerate the biomass yield of the target crop. However, better understanding how well genomic selection models can predict yield in germplasm/reference populations other than those for which they were defined would help to clarify the cost of incorporating Genome Selection models into a breeding program.
- The GENOMIC SELECTION for biomass yield is promising, based on its moderate prediction accuracy, moderate value of cross-population predictions, and lack of sub-population genetic structure. Genome-wide association results confirmed the complexity of the yield trait and the limited scope for searching individual Quantitative trait locus (QTLs) with overwhelming effect on it. Some of our results concerning GBS procedures, single nucleotide polymorphisms calling strategies, missing data imputation methods and statistical models for genomic selection can contribute to better design of genomic selection experiments for alfalfa and other crops with similar mating systems and commercial cultivar targets.
- The use of HYPERSPECTRAL SENSORS to fully understand the interactions between plants and the incident light is essentially important to discover the physiological and biochemical properties of the plants to develop drought tolerant crop varieties.
- Plant phenotyping for drought tolerance based on leaf gas exchange is complex and time consuming and can show poor repeatability due to the high stomatal sensitivity to small changes in environmental conditions. So, the THERMAL SENSORS have generated an opportunity for thermal imaging that emerged as a non-invasive promising technique to monitor remotely and non-destructively crop's water status based on the inverse relation between leaf temperature and transpiration rate.
- Chlorophyll fluorescence is directly related to plant photosynthesis and the physiological state of vegetation. Thus, chlorophyll fluorescence has been used

[26] Annicchiarico et al. 2015. Accuracy of genomic selection for alfalfa biomass yield in different reference populations. BMC Genomics 16, 1020. https://doi.org/10.1186/s12864-015-2212-y

as a powerful, non-destructive and reliable tool in plant physiology for understanding the primary events of photosynthesis and the effects of stress on photochemistry. The close relationships between the fluorescence and soil water contents through FLORESENCE IMAGING demonstrated that fluorescence can detect early water stress.

- The PHENOTYPING PLATFORM is a unique facility and is the world's first glasshouse designed to trial crop systems to develop water efficient, more productive, and superior crop varieties at pilot scale under a multi-sensor gantry including RGB CAMERA to Measure growth, biomass, development, stress; HYPERSPECTRAL CAMERA for (Visible NIR E-Series) biomass, physiology, pigments, water status, stress, diseases, vegetative indices, and (SWIR (short wave infrared) to measures water content or water distribution; FLIR CAMERA (Thermal imaging) for the measurement of heat and rate of transpiration; FLUORESCENCE CAMERA to measure photosynthetic parameters; and LASER SCANNER to measure growth, geometry, organ-resolved information.
- Recently researchers and extensionists have developed GRASS-CAST that uses over 30 years of historical data about weather and vegetation growth—combined with seasonal precipitation forecasts—to predict if rangelands in individual counties are likely to produce above-normal, near-normal, or below-normal amounts of vegetation for grazing. This tool helps the ranchers to anticipate how much grass is expected to grow to improve the management decisions[27].
- Plant selection also plays a role in increasing farming systems resilience. For example, Anameka™ Oldman saltbush is a long-lived, woody rangeland shrub from Australia, which has been selected by CSIRO-led research for its higher feeding energy value and growth from over 60,000 Oldman saltbush plants. It is tolerant of very dry, infertile and/or saline soils and has been found to improve both environmental health and profitability within sheep and cattle systems in arid and saline areas. Anameka™ Oldman saltbush was successfully commercialised in 2015 and sales are increasing by 250% per year[28].

[27] https://grasscast.unl.edu/
[28] https://ecos.csiro.au/saltbush/

- The Agricultural Production Systems sIMulator (APSIM) is a comprehensive model developed to simulate biophysical processes in agricultural systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. It is also being used to explore options and solutions for the food security, climate change adaptation and mitigation and carbon trading problem domains. From its inception twenty years ago, APSIM has evolved into a framework containing many of the key models required to explore changes in agricultural landscapes with capability ranging from simulation of gene expression through to multi-field farms and beyond. The APSIM initiative was established in 2007 to promote the development and use of the science modules and infrastructure software of APSIM. The Foundation Members of the APSIM initiative are CSIRO, the State of Queensland and The University of Queensland. AgResearch Ltd., New Zealand became a party in 2015 followed by the University of Southern Queensland in 2017. In March 2020, Iowa State University, US, became a member. The model is available for download at the following link: https://www.apsim.info/[29].

3.3.1c Collaborative Efforts

- FATIMA PROJECT is a collaborative European Union project to address effective and efficient monitoring and management of agricultural resources to achieve optimum crop yield and quality in a sustainable environment. It covers both ends of the scale relevant for food production, viz., precision farming and the perspective of a sustainable agriculture in the context of integrated agri-environment management. It aims at developing innovative and new farm capacities that help the intensive farm sector optimize their external input (nutrients, water) management and use, with the vision of bridging sustainable crop production and fair economic competitiveness. FATIMA is being implemented and demonstrated in 7 pilot areas representative of key European intensive crop production systems in Spain, Italy, Greece, Czech Republic, Austria, France, and Turkey.

[29] https://www.apsim.info/

- LUBILOSA (LUtte BIologique contre les LOcustes et les Sauteriaux) was a joint research project (1989-2002) led by CABI with Partners: IITA, GTZ, CILSS/ AGRHYMET/ DFPV, and donors (CIDA, DFID, DGIS, SDC, USAID), which aimed to develop a biological alternative to chemical control of locusts and grasshoppers. They have isolated Metarhizium acridum isolates after passing through all the necessary steps to develop the commercial biopesticide Green Muscle. In this project, Plant Protection Services of Benin, Niger, Mali, South Africa, Sudan, Ghana, Chad, Senegal, Gambia, Burkina Faso, Agriculture and Agri-Food Canada, Universities of Basel, Reading and Bath collaborated. The product Green Muscle is currently produced and available from the biological control manufacturer Éléphant Vert. (CABI Biotic collaboration)
- THE PACTE PROGRAMME is a 6 year initiative (2018-2023) started at six different sites to strengthen the capacity of local actors through 56 million Euro investment for Sustainable management of natural resources, Economic development of marginal rural territories, and Improvement of local governance. The actors of this program are mainly involved in the Production and exchange of knowledge, Citizen Debate on issues and priorities, Co-design, concerted planning, implementation, Monitoring and evaluation.

3.3.1d Biotic Factors

- The diversity of plant pests and diseases is daunting[30]. Their worldwide expansion has become an important cause for the loss of biodiversity. Among pests, the invasive alien pest species have long history of disease epidemics and pest outbreaks due to the absence of natural controlling agents. There is a scientific overwhelming consensus on the detrimental impacts of alien pest species[31]. Preventing the spread of plant pests and diseases significantly contribute towards environmental and economic resilience against biotic stresses by reducing the need for synthetic agrochemicals.

[30] Bebber, D.P., Ramotowski, M.A. and Gurr, S.J., 2013. Crop pests and pathogens move polewards in a warming world. Nature climate change. 3(11): 985-988.
[31] Boltovskoy, D., Sylvester, F. and Paolucci, E.M., 2018. Invasive species denialism: Sorting out facts, beliefs, and definitions. Ecology and evolution. 8(22): pp.11190-11198.

- Adoption of climate resilient agronomic practices like shifts in dates of sowing, use of climate resilient/drought tolerant crops/ use of intercrops and need based insecticide application to manage the crop pests. (India biotic)
- During quiet periods (known as recessions) Desert Locusts are usually restricted to the semi-arid and arid deserts of Africa, the Near East and South-West Asia that receive less than 200 mm of rain annually. This is an area of about 16 million square kilometers, consisting of about 30 countries. As of June 2020, the current upsurge is affecting 23 countries in East Africa, the Near East, and Southwest Asia potentially impacting 42 million people.
- The emerging agri-chemical formulations for biopesticides are alternate tools against harmful synthetic agrochemicals for biosecurity and biosafety. Recent research findings showed that biopesticides, Insect growth regulators (IGRs), and new chemistry insecticides have shown tremendous potential to translate laboratory-based research into application as alternate strategy for promoting plant health and overcoming serious environmental problems from synthetic chemicals. In this regard, a system approach like Integrated Pest Management (IPM) is the best way forward to reduce the economic and environmental impacts of biotic factors.

The technologies disclosed by the participants in the Experts Meeting are compiled in the form of a table. Different aspects of each technology/approach are provided in the Table 5.

Table 5. Opportunities to facilitate International Research Collaboration to cope with plant resources in drylands

Categories determinations were made by the host 2020 MACS team, and shared with every participant for feedback

No	Name	Category	Country	Degree of Innovation	Risk	Level of Contribution to drylands	Status	Adoption	Timescale to delivery
1	Protected Agriculture/Green houses	Cropping System	Saudi Arabia/IFAD	High	Medium	High	In fields	Moderate	Medium
2	Cropping pattern	Cropping System	Saudi Arabia	Middle	Low	Middle	In fields	Quick	Short
3	Crop diversification	Cropping System	France/South Africa	Middle	Low	Medium	In fields	Quick	Short
4	Climate Resilient Villages for Drought Proofing	Cropping System	India	High	Low	High	In fields	Moderate	Medium
5	Conservation Agriculture	Cropping System	South Africa/India	Middle	Low	Medium	In fields	Moderate	Short
6	Climate-Smart Agriculture	Cropping System	South Africa	High	Low	Medium	In fields	Moderate	Medium
7	Crop Integration	Cropping System	Brazil	Medium	Medium	Medium	In fields	Moderate	Medium
8	Intercropping	Cropping System	Brazil/IFAD	Medium	Medium	Medium	In fields	Moderate	Medium
9	Organic Agriculture	Cropping System	Germany	High	Low	High	In fields	Moderate	Medium
10	Self-sustaining Food Producing Platform	Cropping System	Mexico	High	High	Medium	R & D	Moderate	Medium to Long
11	Halophytes	Cropping System	IFAD	Medium	Medium	Medium	In fields	Moderate	Medium
12	Grass-Cast	Modern Technologies	USA	High	Low	High	In fields	Quick	Short
13	Genome Editing	Modern Technologies	Argentina	High	High	Middle	R & D	Slow	Medium to Long
14	Modelling agricultural production in arid systems	Modern Technologies	Italy, Australia	High	Middle	Middle	R & D	Moderate	Medium

No	Name	Category	Country	Degree of Innovation	Risk	Level of Contribution to drylands	Status	Adoption	Timescale to delivery
15	Genomic selection/Genome-wide selection	Modern Technologies	Italy/Turkey/UK	High	High	Medium	R & D	Moderate	Medium
16	PAGE (promotion of alleles by genome editing)	Modern Technologies	UK	High	Medium	Medium	R & D	Moderate	Medium to Long
17	Hyperspectral sensors	Modern Technologies	UK	High	Medium	Medium	R & D	Moderate	Medium
18	Thermal sensors (UK)	Modern Technologies	UK	High	Medium	Medium	R & D	Moderate	Medium
19	Fluorescence imaging (UK)	Modern Technologies	UK	High	Medium	Medium	R & D	Moderate	Medium
20	Phenotyping platform	Modern Technologies	UK	High	Medium	Medium	R & D	Moderate	Medium
21	Genetic Resources	Collaborative Efforts	Germany	High	High	Middle	R & D	Slow	Medium
22	FATIMA Project	Collaborative Efforts	Turkey	High	Low	High	In fields	Quick	Short
23	Microbial Insecticides	Biotic factors	India/CABI	High	Medium	Medium	In fields	Moderate	Medium
25	Semiochemicals	Biotic factors	India	Middle	Medium	Medium	In fields	Moderate	Medium
26	Biocontrol agents	Biotic factors	India	High	Medium	Medium	In fields	Moderate	Medium
27	Green Muscle	Biotic factors	CABI	High	Medium	Medium	In fields	Moderate	Medium
28	Genomic selection (CAMA Project)	Collaborative Efforts	Italy/Algeria/Morocco	High	Low	High	R & D	Moderate	Medium
29	Plant selection – drought and salt tolerant (e.g. Anameka™ Oldman saltbush)	Modern Technology	Australia	Medium	Low	High	In fields	Medium	Short
30	Agricultural Production Systems sIMulator (APSIM)	Modern Technology	Australia	High	Low	High	R & D	High	Short

3.3.2 Recommendations/Guidelines for Plant Resources based on the solutions for sustainable development in Drylands, compiled from independent presentations

- Encourage Research & Development collaboration to integrate crop physiology, genomics and breeding approaches to develop crop varieties resistant to abiotic stresses and biotic factors.
- Data collection and generation, such as field data, household surveys, and data from modelling simulations are crucial to help better understand the agricultural sector in Drylands.
- Capacity building programs to promote good production system for sustainable agricultural development in drylands
- Improving the rangeland resource management practices in the drylands
- Research in the management of tame and native pasture and grazing lands in drylands.
- Large uncertainties remain as to climate futures and the exposure and responses of the interlinked human and natural systems to climatic changes over time. These need to be further studied.
- Promotion of on farm good practices among the farmers
- Development of plant diseases and pests surveillance system
- Promoting Integrated Pest Management (IPM) programs to manage biotic stresses in drylands
- Developing nanoformulations of biopesticides, and promoting use of Insect Growth regulators and new chemistry insecticides to control pest populations
- Creating awareness of available, accessible and affordable sustainable plant health solutions at the advisory service provider and farm level
- Phenotypic platforms are the good beginning to trial the crop systems under managed conditions (e.g. in glasshouse).

3.4 Role of Animal Resources to Contribute Sustainability in Drylands

Sustainable food supply is mandatory to meet the emerging food demands for growing masses of the population in order to eliminate hunger and malnutrition. Overall, arid zones that are largely characterized as drylands contribute to 50 percent of the livestock production[32]. In dryland countries, livestock sector plays a very important role. These systems contribute to the economy and resilience of many communities and provide a rich source of highly bioavailable micronutrients that can be vital to people's health, especially in low income. Livestock are also part of culture and social traditions and can play a key role in the identity construction of individuals, clans, and ethnic groups. These systems are simultaneously important providers of ecosystems services, such as the maintenance of biodiversity and carbon storages, as compared to other land uses. We also acknowledge that animals compete for resources with other uses such as croplands, energy production, forests and urban areas. Livestock rearing can also be associated with deforestation and land degradation, and contribute to greenhouse gas emissions. Animal production can also negatively impact on human health (e.g. due to products over-consumption and animal-derived diseases. Animal health is crucial for the production of food for human consumption. Biotic factors are important threats to farmer's livelihoods especially in developing countries where farming is the main source of income. Their prevalence impart huge economic losses, which risk the global food security at all levels including house hold, national and global. By keeping in mind the contribution of livestock, there is a pressing need to develop durable, appropriate, affordable, inclusive, climate-resilient and environmental friendly livestock management and production system for drylands.

[32] 2010–2020: UN Decade for Deserts and the Fight against Desertification. https://www.un.org/en/events/desertification_decade/whynow.shtml

3.4.1 Animal Resources-related Opportunities to Develop Sustainability in Drylands

Livestock tremendously contributed to rural development. Therefore, it is very important for each country to get the benefit of the emerging livestock related innovative solutions to uplift this sector for the economic prosperity and rural development. During the Experts meeting, participants highlighted the importance of emerging solutions and technologies to uplift this sector under dryland conditions.

3.4.1a Breeds Improvements

- GENOMIC SELECTION offers an opportunity to build common ground between biotechnology and quantitative genetics. Quantitative genetics is the study of the genetics of complex traits that are controlled by a large number of loci and whose regulation often involves non-genetic factors. Sequencing and resequencing of crop and animal genomes provide the opportunity for identification of genome-wide genomic polymorphisms and correlative relationships between variants and complex traits. The potential of CRISPR–Cas9 for genome editing in theory will provide new ways of validating causative effects, particularly for traits that exhibit complex modes of inheritance. Furthermore, simulation studies have recently shown how genome-editing technology can be coupled with genomic selection to double the rate of genetic gain as compared with genomic selection conducted in isolation[33].
- The new approach for deploying genome editing in breeding programs, referred to as PAGE (promotion of alleles by genome editing), has considerable potential for acceleration of genetic gain in plant and animal improvement programs. In animal breeding, the cost of genotyping and resequencing has reached a point where producers and multipliers, in addition to members of the breeding nucleus, can be genotyped and have sequencing information accurately imputed for a modest investment.

[33] Hickey et al., 2017. Genomic prediction unifies animal and plant breeding programs to form platforms for biological discovery. Nature Genetics. 49, 1297-1303. https://doi.org/10.1038/ng.3920.

3.4.1b Good Practices and Production Systems suggested by participants

- Practice ADAPTIVE LIVESTOCK MANAGEMENT by adjusting livestock numbers in response to fluctuating forage production conditions is necessary to realize any potential for long-term soil C stock increases[34].

- CLIMATE SMART LIVESTOCK SYSTEM is very important to make livestock more resilient and smart. In this regard, Feed and water management, Rotation grazing and storage of feed to be used across seasons, Offset of GHG emissions through land restauration and enhancement of soil carbon storage, and Management of heat stress and droughts (destocking) could contribute tremendous to develop productive livestock system.

- Rangeland soils lose large amounts of C quickly when severely degraded or converted to other land uses, whereas large increases in soil C are difficult to achieve. Keeping rangelands intact is the single most important action for maximizing soil C stocks.

- LIVESTOCK MIGRATION as coping strategy. In the arid and semi-arid regions, migration an important traditional survival strategy that has been developed by the people to cope with the seasonal changes through nomadic and transhumance systems. It allows humans and livestock to use the vast natural resources in a landscape without overexploiting specific sites. Dryland development policies should recognize and enable pastoral mobility as a strategy for climate change adaptation and sustainable land management.

- Rapid advances have been seen in the production and trade of organic foods especially cereals, textile and horticultural products. However, ORGANIC LIVESTOCK PRODUCTION systems are not nearly so developed. The vast drylands have shown tremendous potential to develop a site to practice ORGANIC LIVESTOCK PRODUCTION by converting them into grasslands as the success story of the case of Australia. Organic and low input management of

[34] Sanderson et al., 2020. Cattle, conservation, and carbon in the western Great Plains. Journal of Soil and Water Conservation. 75 (1) 5A-12A. DOI: https://doi.org/10.2489/jswc.75.1.5A

tame and native pasture in drylands has great potential to support sustainable agriculture development.

3.4.1c Technological Advancements

- The Sustainable Southwest Beef team is evaluating Raramuri Criollo cattle, precision technologies, and tradeoffs among beef supply chain options from pasture to plate to enhance ranch and rangeland resilience in the Southwestern US. The project engages ranchers, educators, and students in collaborative research and Extension to develop a decision support dashboard and train the next generation of researchers and producers[35].

- Promote RESEARCH, INNOVATION AND TECHNOLOGY in areas of animal health to enhance our ability to forecast the emergence of future threats and to develop disease resistant livestock breeds.

- DIGITAL INNOVATIONS in the form of Sensors, smart wearable devices and robotics have generated enormous opportunities in livestock farming. By utilizing these innovations, we can create virtual visuals and physical pictures of an organism in order to optimize production and resilience under harsh dry environmental conditions.

- VIRTUAL FENCING[36] is an animal-friendly fencing system that enables livestock to be confined or moved without using fixed fences. CSIRO's patented virtual fencing technology uses collars with coordinates, wireless technologies and sensors to control the location of livestock without the need for an actual fence, which ultimately improved the labor efficiency and reduced capital investment in fencing. This technology has the potential to enhance productivity and profitability through improved feed utilization and better matching of animal demands to feed supply and quality. Furthermore, virtual fencing improved environmental and sustainability outcomes such as reduced overgrazing and better weed control and nutrient management.

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[35] https://southwestbeef.org/
[36] https://www.csiro.au/en/Research/AF/Areas/Livestock/Virtual-fencing

- Feeding practices such as feeding livestock a SEAWEED supplement called FutureFeed (which uses a variety of Australian seaweed) could simultaneously help to secure global food security and fight climate change by reducing greenhouse gas emissions[37].

- GEOGLAM Rangelands and Pasture Productivity (RAPP) Map[38] is the spatial data platform for the Rangeland and Pasture Productivity activity which is part of the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) initiative. This online tool (GEOGLAM RAPP Map) gives access to information about the status and productivity of world's pastures and rangelands. It provides time-series data on the vegetation and environmental conditions, allowing national and regional tracking of the resources which sustains livestock production. This global effort brings together space agencies, associated institutional frameworks, in-situ networks, rangeland ecologists, and the pasture productivity modelling community[39]. RAPP Map is supported by CSIRO and through funding from the Australian Government's National Landcare Programme.

- G-RANGE is a global rangeland model that simulates generalized changes in rangelands through time. Spatial data and a set of parameters that describe plant growth in landscape units combine with computer code representing ecological processes to represent soil nutrient and water dynamics, vegetation growth, fire, and wild and domestic animal offtake. The model is spatial, with areas of the world divided into square cells. Those cells that are rangelands have ecosystem dynamics simulated. A graphical user interface allows users to explore model output. This model of moderate complexity has been developed as a joint effort between Colorado State University, CSIRO, ILRI and CCAFS, and was built upon Century & SAVANNA models[40]. It is available for download at www2.nrel.colostate.edu/projects/grange.

[37] https://www.csiro.au/en/Research/AF/Areas/Food-security/FutureFeed
[38] http://map.geo-rapp.org/
[39] https://research.csiro.au/foodglobalsecurity/our-research-2/pastures/geoglam-rapp/
[40] www2.nrel.colostate.edu/projects/grange

- CROP LIVESTOCK ENTERPRISE MODEL (CLEM)[41] is a bio-economic model provided with APSIM Next generation developed by CSIRO that can guide whole-of-farm decision-making. It integrates livestock, pasture, and crop production with labour and economic resources, simulating farm enterprises at a range of scales, from large agribusinesses to subsistence smallholdings. CLEM can account for and output multiple variables including crops, animals, economics, residue, products, labour, nutrition, feed, water and greenhouse gases. It has built-in user-friendly graphics[42]. The model is developed for Agriculture researchers and provides tool to assist with building and running the model as well as exploring results. The model is designed to use best available data in data poor environments such as use other pasture and crop production models, field data, or even expert opinion. The model is designed to meet the current and future requirements of researchers considering a wide variety of farming systems from subsistence small-holder farms in developing countries to extensive beef systems in northern Australia. Available for download at www.apsim.info/clem[43].
- INTEGRATED MODELLING APPROACHES, such as partial equilibrium models of countries' agriculture (e.g., LUTO, Land Use and Trade Off Model) or general equilibrium models of the global economy (e.g., GTEM, Global Trade and Environment model) can help understand how climate change, population growth and economic development can impact international trade and demand for animal outputs.
- The development of GLOBAL SPATIAL DATASETS help to characterize food systems worldwide. For example, combining global rangeland biomass productivity datasets with socio-economic information to identify the rangeland communities potentially the most at risk under climate change[44]. Providing global gridded maps of nutrient production and nutrient diversity for different

[41] https://www.apsim.info/clem/Content/Home.htm
[42] https://research.csiro.au/foodglobalsecurity/data-and-tools/models/clem/
[43]www.apsim.info/clem
[44] Godde et al., 2020. Global rangeland production systems and livelihoods at threat under climate change and variability. Environmental Research Letters, 15(4), 044021.

farm sizes. The collection includes data for production levels of 41 major crops, seven livestock, and 14 aquaculture and fish products and vitamin A, vitamin B_{12}, folate, iron, zinc, calcium, calories, and protein as well as food production diversity indices; the Shannon diversity index [H], the Modified Functional Attribute Diversity (MFAD), and species richness [S][45].

3.4.1d Biotic Factors

- Animal diseases impacting economy -117 diseases (OIE, 2020) and 60% of human pathogens are of animal origin. Over 20% of animal production losses are linked to animal disease. It is the need of hour to focus on the Epidemiology, Surveillance (Disease risk mitigation), Innovative Research (Rapid diagnostic techniques), and Vaccine development (Disease prevention), Public Awareness and Education (Knowledge transfer).

- Big data approach coupled with expert knowledge and machine learning can be applied to other emerging diseases for improvement in understanding, prediction, and management of vector-borne diseases. Translation of this knowledge can be made to improving animal and human welfare, and aiding food security to assist in development of early warning strategies that are currently based primarily on climate or environmental predictions based on only a few variables[46].

- EFFICIENT ANIMAL HUSBANDRY MANAGEMENT will ensure correct livestock nutrition and good health and welfare (reduced susceptibility to parasitism and infectious disease). Furthermore, Change in farming practices by MIXED LIVESTOCK FARMING - sheep, goat, cattle, poultry and camel - reducing the damage caused by disease outbreaks which may affect particular species, minimize multiple risks.

[45] Herrero et al., 2017. Farming and the geography of nutrient production for human use: a transdisciplinary analysis. Lancet Planet Health, 1 (1), e33–42.
[46] Peters et al., 2020. Big data–model integration and AI for vector-borne disease prediction. Big data–model integration and AI for vector-borne disease prediction. Ecosphere, 11(6), p.e03157.

- Vesicular stomatitis viruses (VSVs) cause a condition known as vesicular stomatitis (VS), which results in painful lesions in equines, cattle, swine, and camelids, and when transmitted to humans, can cause flu-like symptoms.
- Development of National/Regional level DISEASE FORECASTING SYSTEM is very important to tackle biotic stresses. It will facilitate the demarcation of disease specific eco-pathogen of the country/region based on the high, medium and low disease frequencies observed over the long period.
- CSIRO Resilience, Adaptation Pathways and Transformation Approach (RAPTA) guidelines package offers practical advice to design, implement and assess interventions, whether they are related to policies, projects, programs, strategies or other types of decisions. The approach is readily tailored to meet different intervention needs, building on and challenging familiar design, implementation and evaluation processes from a systems perspective to put concepts of resilience, adaptation pathways and transformation to work. Outputs such as models or plans are valuable, however the processes of participating, appreciating new perspectives, and learning to design and implement agile and effective interventions are just as important[47].

3.4.1e Collaborative Efforts

- The collaborative efforts need to involve ranchers, researchers, and policy makers working together to improve decision-making for a twenty-first century ranch that produces livestock, conserves native species, stores C, and provides other goods and services desired by society.

The technologies disclosed by the participants in the Experts Meeting are compiled in the form of a table. Different aspects of each technology/approach are provided in the Table 6.

[47] https://research.csiro.au/eap/rapta/

Table 6. Opportunities to facilitate International Research Collaboration to cope with Animal Resources in drylands

Categories determinations were made by the host 2020 MACS team, and shared with every participant for feedback

No	Name	Category	Country	Degree of Innovation	Risk	Level of Contribution to drylands	Status	Adoption	Timescale to delivery
1	Genomic selection	Breeds Improvements	UK	High	High	Medium	R & D	Moderate	Low
2	PAGE (promotion of alleles by genome editing)	Breeds Improvements	UK	High	Medium	Medium	R & D	Moderate	Long
3	Organic Livestock Production	Production System	Germany	High	Low	High	In fields	Moderate	Medium
4	Climate Smart Livestock System	Production System	FAO	High	Low	High	In fields	Moderate	Short
5	Practice Adaptive Livestock Management	Good Practices	USA	High	Low	High	In fields	Quick	Medium
6	Livestock Migration	Good Practices	India	Low	Low	Medium	In fields	Moderate	Medium
7	Mixed Livestock Farming	Good Practices	India	Medium	Low	Medium	In fields	Moderate	Medium
8	Conditioned Feed Aversion (CFA)	Good Practices	South Arica	Low	Medium	Medium	In fields	Moderate	Medium
9	Digital innovations in livestock farming (Sensors, digital technology and robotics)	Technological Advancements	UK	High	Medium	High	R & D	Moderate	Medium
10	Precision Ranching	Technological Advancements	USA	High	Low	High	In fields	Quick	Medium
11	Integrated Farm systems Model	Technological Advancements	USA	High	Low	High	In fields	Quick	Medium

12	Virtual Fencing	Technological Advancements	Australia	High	Low	Medium	R & D	Moderate	Medium
13	GEOGLAM RAPP Map	Technological Advancements	Australia	High	Low	High	In fields	Quick	Medium
14	Crop Livestock Enterprise Model (CLEM)	Technological Advancements	Australia	High	Low	High	R & D	Moderate	Short
15	Vector-borne diseases early-warning strategies	Biotic Factors	USA	High	Low	High	In fields	Quick	Short
16	Efficient Animal Husbandry Management	Biotic Factors	India	Medium	Medium	High	R & D	Moderate	Medium
17	Insect-Vector Management	Biotic Factors	USA	Medium	Low	Medium	In fields	Quick	Short
18	G-range global rangeland modelling	Technological Advancements	Australia	High	Low	High	R & D	Quick	Short
19	Resilience, Adaptation Pathways and Transformation Approach (RAPTA)	Conceptual framework	Australia	High	Low	High	R & D	Quick	Medium
20	Integrated modelling approaches (e.g. general or partial equilibrium modelling)	Technological Advancements	Australia	High	Low	High	R & D	Quick	Short
21	Global spatial datasets	Technological Advancements	Australia	High	Low	High	R & D	Quick	Short

3.4.2 Recommendations/Guidelines for Animal Resources based on the solutions for sustainable development in Drylands, compiled from independent presentations

- Policy level decisions to encourage climate smart livestock farming systems.
- Development of National level disease monitoring and surveillance of important livestock diseases.
- Genetic improvement/ development of disease resistant breeds
- Development of Market-based risk management mechanisms.
- Devising national regulations for organic production
- Training and education about livestock management
- Strengthening disease surveillance system with special focus on vulnerable regions sharing international borders and hot spots of emergence of new disease outbreaks.
- Early warning systems and improved climate information can help farmers to take appropriate actions in a timely manner depending on expected weather conditions.
- Facilitate collaboration to share the knowledge to enhance the productivity of livestock in drylands
- Improve rangeland nutrition for livestock while reducing greenhouse gas (GHG) emissions and improving rangeland health.
- Livestock mobility in drylands is key to take advantage of forage spatial and temporal variability and should be supported. Indeed, this mobility has been greatly constrained since the mid- to last-twentieth century in developing countries due to changes in land tenure and land use policy, including land privatization and increased land competition.
- Data collection and generation, such as field data, household surveys, and data from modelling simulations are crucial to help better understand the livestock sector in Drylands.

- Political and institutional forces affect the livestock sector's vulnerability. Tailored strategies will be required in tandem with public policy
- Sustainable development must account for pandemic risk.

4. Section IV: Conclusion

The economic performance of the farming system in drylands is influenced by numerous factors. The approach used to address the challenges in drylands lead to the best and worst production system in drylands. Therefore, it is the need of hour to develop system approach to find a local solution to address the global issue by bridge the knowledge gap of farmers, ranchers, and agricultural sector partners by providing access to a wide-range of tools and resources to enable sustainable agriculture in drylands. In this regard, the role of interdisciplinary collaboration whether local, regional or international for research and development is very important along with Community-based schemes to revolutionize drylands agriculture by improving resilience and productivity of crops and livestock in drylands through providing real time ongoing support to farmers for decision making on individual entities by carefully blending local knowledge with modern science and technology that account for all dimensions of sustainability including environmental, social, and economic.

5. Section V: Appendix

5.1 Agenda of the Experts Meeting (Monday, 10 August 2020)

TIME	Session	Presenter	Duration
14:00 – 14:05	**OPENING SESSION (5 MIN)**		
	1. Welcoming Address (Kingdom of Saudi Arabia)	Prof. Suliman Ali Al-Khateeb	5 min
14:05 – 14:40	**SESSION 1. KEY RISKS, OPPORTUNITIES AND SYSTEM APPROACH FOR SUSTAINABLE AGRICULTURAL DEVELOPMENT IN DRYLANDS (35 MIN)**		
	1. Systems agronomy in northern Australia's maturing agriculture	Dr. David Lawrence (Australia)	7 min
	2. Innovations to enhance agroecosystem resilience and adaptation to climate change in drylands of China	Prof. Wang Yaosheng (China)	7 min
	3. Modelling dry farming systems: a roadmap for tool development	Dr. Marcello Donatelli (Italy)	7 min
	4. Holistic View and Future opportunities to Promote Sustainable Agriculture Development in Drylands: The Case of the Kingdom of Saudi Arabia	Dr. Mohammad Almutari (Kingdom of Saudi Arabia)	7 min
	5. Collaborative US research highlights: Providing a range of tools and resources for sustainable agriculture in drylands	Dr. Laura Schreeg (USA)	7 min
14:40 – 16:05	**SESSION 2. ENABLING TOOLS FOR SUSTAINABLE AGRICULTURAL DEVELOPMENT IN DRYLANDS (85 MIN)**		
	1. Genome editing for drought tolerance and crop production sustainability	Dr. Sergio Feingold (Argentina)	7 min
	2. Breeding for diversified cropping systems: Example of sorghum based systems in Central North zone of Burkina Faso	Dr. Myriam Adam (France)	7 min
	3. Enhancing drought stress tolerance by harnessing genetic resources	Dr. Gwendolin Wehner (Germany)	7 min
	4. Genetic enhancement and natural resources management for enhancing productivity, sustainability and resilience in drylands	Dr. D.K. Yadava (India)	7 min
	5. Developing drought-tolerant legume crops by agro-ecological and genomic approaches	Dr. Paolo Annicchiarico & Dr. Luciano Pecetti (Italy)	7 min
	6. Drought tolerance improvement in plants: An integrated view from breeding to genomics	Mr. Enes YAKIŞIR (Turkey)	7 min
	7. Agricultural transformation in the drylands: Role of Data & Disruptive technologies	Prof. Wayne Powell (UK)	7 min
	8. Crop breeding for drought-resistance varieties using smart sensors	Dr. Shamal Mohammed (UK)	7 min
	9. Appropriate Technologies for Soil and Water Management: South African Examples	Prof. Sue Walker (South Africa)	7 min
	10. Artificial soil for urban greening and urban farming	Mr. Konstantin Romanenko (Russia)	7 min
	11. Soil & water researches in adaptation to climate change: Turkey Case	Mr. Alican EREN (Turkey)	7 min

TIME	Session	Presenter	Duration
	12. Irrigation in Canada: Improving water productivity through Research and Development	Mr. Evan Derdall (Canada)	7 min
16:05 – 16:25	**SESSION 3. BIOTIC FACTORS AFFECTING SUSTAINABLE AGRICULTURAL DEVELOPMENT IN DRYLANDS (20 MIN)**		
	1. Emerging biotic stresses affecting crops and animals and their management under drylands	Dr. N. Bakthavatsalam (India)	7 min
	2. Pests & Diseases Challenging Animal's Health in Drylands: ARC-OVR Perspectives	Dr. Mohammed Sirdar (South Africa)	7 min
	3. Locust and grasshopper management in drylands: Can biological control be considered as a viable solution?	Dr. Ulrich Kuhlmann & Dr. Belinda Luke (CABI)	7 min
16:25 – 17:35	**SESSION 4. INNOVATION, TECHNOLOGY & ADOPTION TO ENHANCE RESOURCE USE EFFICIENCY (70 MIN)**		
	1. Exploring valuable traits in beneficial rhizobacteria for development of bio-inputs in Argentina: A Sustainable solution to enhance crop productivity in drylands	Dr. Julia García (Argentina)	7 min
	2. Australian rangelands – Towards resilient systems under climate change	Dr. Cécile Godde (Australia)	7 min
	3. Integrated systems in Brazilian semi-arid: tools for adapting to climate change	Dr. Diana Signor Deon (Brazil)	7 min
	4. Platforms for concerted territorial planning: Climate change adaptation programme for vulnerable rural territories (PACTE) of Tunisia	Dr. Sylvie Morardet (France)	7 min
	5. Upscaling potential of Organic farming to enhance resilience and contribute sustainability in the drylands	Prof. Gerold Rahmann (Germany)	7 min
	6. Self-sustaining Food Producing Platform	Mr. David Enríquez (Mexico)	7 min
	7. Scenarios for climate smart livestock systems in drylands	Dr. Henning Steinfeld (FAO)	7 min
	8. Drylands of NENA Region: Integrated Approaches and Sustainable Natural Management to Enhance Resilience and Food Security	Mr. Rachid Serraj and Ms. Vera Boerger (FAO)	7 min
	9. Integrating and scaling innovations for dryland agriculture	Prof. Jacques Wery (ICARDA)	7 min
	10. High and Low tech innovations to enhance resilience of small scale farmers	Mr. Shantanu Mathur (IFAD)	7 min
17:35 – 18:25	**Discussion**		**50 min**
18:25 – 18:30	**Closing Remarks**	Prof. Suliman Ali Al-Khateeb	**5 min**

5.2 Participants of the Experts Meeting

In this International Virtual Experts Meeting on Promoting Sustainable Agriculture Development in Drylands, 74 participants from nineteen G20 members, one Guest country, and six International Organizations took part in this virtual event.

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