ICARDA

Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula

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ICARDA

International Center for Agricultural Research in the Dry Areas

Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula

2014-2019

Final Report

In collaboration with NARS in Arabian Peninsula Countries

Ministry of Works, Municipalities Affairs and Urban Planning
وزارة الأشغال وشئون البلديات والتخطيط العمراني

Public Authority for Agricultural Affaires and Fish Resources, Kuwait

Ministry of Agriculture and Fisheries, Oman

Ministry of Municipality and Environment, Qatar

وزارة البيئة والمياه والزراعة
Ministry of Environment, Water & Agriculture
المملكة العربية السعودية

وزارة التغير المناخي والبيئة
MINISTRY OF CLIMATE CHANGE & ENVIRONMENT

Agricultural Research and Extension Authority, Yemen

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Contents

List of abbreviations and acronyms

ADFCA	Abu Dhabi Food Control Authority
ADOPT	Adoption and Diffusion Outcome Prediction Tool
AFESD	Arab Fund for Economic and Social Development
FFS	Farmers' field schools
GAP	Good agricultural practices
ICARDA	International Center for Agricultural Research in the Dry Areas
IFAD	International Fund for Agricultural Development
IPPM	Integrated production and protection system
MAF	Ministry of Agriculture and Fisheries (Oman)
MMAUP	Ministry of Municipal Affairs and Urban Planning (Bahrain)
NAES	National agricultural extension systems
NARES	National agricultural research and extension system
NARS	National agricultural research system
R&D	Research and development
RSC	Regional Steering Committee
RSCM	Regional Steering Committee Meeting
RTCM	Regional Technical and Coordination Meeting
SED	Smart extension diary
TWW	Treated wastewater

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Special thanks are due to the Ministry of Climate Change and Environment in UAE (previously, Ministry of Environment and Water) for hosting the ICARDA-APRP office in UAE.

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Foreword

The Arabian Peninsula (AP), which comprises seven countries- Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, and Yemen is characterized by low and erratic rainfall, high evaporation rates, and temperatures. Soil and water salinity is also high and can increase rapidly as a result of irrigation with brackish water.

From its headquarters in Aleppo, Syria, the International Center for Agriculture Research in the Dry Areas (ICARDA) has paid attention to the needs of AP countries since the late nineteen century, by addressing the need for strengthening cereal crops research (wheat and barley) and training. In 1995 ICARDA created an office in United Arab Emirates (UAE) to serve the seven countries of the Arabian Peninsula, and hence, APRP is born. Since its establishment, APRP was focusing on strengthening Agricultural Research and Human Resource Development in all AP countries. The water scarcity problem was given priority in all the research undertaken by the program, in collaboration with the National Agriculture Research Systems (NARS) of AP countries. For example, the shortage of feed for livestock was addressed by utilizing the adapted indigenous forage species, which utilize less water, compared with exotic forages. Therefore, the suitable indigenous forage species were collected in all seven countries and evaluated under field conditions for their water use efficiency. Buffel grass, which was developed from such research, is now well known among farmers and growers as forage, which uses less water compared with the exotic Rhodes grass. Similarly, the research on Protected Agriculture under controlled Greenhouse maximized farmers' yield and income with minimal water use. Moreover, the research on Protected Agriculture has emphasized the use of integrated production and protection management (IPPM), which resulted in healthier vegetables due to the minimum use of chemicals (fertilizers and pesticides) in the production process.

From the beginning of the APRP, research activities were grouped into three main areas: (a) irrigated forage and rangeland, (b) protected agriculture, and (c) human resource development through training and workshops. Between 2014 and March 2019, APRP conducted 10 specialized training courses, 15 workshops, and 80 field days, during which more than 1000 researchers, extension agents, and farmers from seven countries participated.

Furthermore, the program was successful in developing a network among scientists of AP countries, whereby they exchanged knowledge and experiences through regular meetings, traveling workshops, and conferences. The impact of this pillar is probably by far the most important than the two other pillars, which resulted in better understanding and cooperation among colleagues of the same field (Agriculture) in all AP countries. This is reflected in the voluntary comments registered by farmers/growers and administrators over the years.

This publication demonstrates the scope of research and human resources development over the period between January 2014 and March 2019. It highlights some of the accomplishments as the result of the collaborative efforts among the seven countries of the Arabian Peninsula, project donors, and ICARDA-APRP.

Aly Abousabaa

Director General

Background

The Arabian Peninsula countries – Bahrain, the United Arab Emirates, Kuwait, Oman, Qatar, Kingdom of Saudi Arabia (KSA), and Yemen – are facing great challenges in developing more sustainable land and efficient water usage while preserving their environments and heritages under the current rates of population growth. The issues of food security, water management, productivity, sustainability, and environment are closely interconnected. If the current inefficient practices continue, the consequences will include a rapid depletion of water resources, the extinction of native species, and rapid environmental destruction.

The exceptional socio-economic context and fragile environment of the Arabian Peninsula requires cautiously designed activities to address its agricultural development constraints. Furthermore, the emerging worldwide crises, such as global warming and increased water scarcity, amplify the importance of the research for development activities in this region, as other countries may experience similar problems in the near future.

Since its establishment in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA), through technical backstopping for its mandated crops and areas of research, has actively collaborated with the Arabian Peninsula countries. However, in 1995 this collaboration entered a higher level when ICARDA inaugurated its Arabian Peninsula Regional Program (APRP) office in Dubai. Since then, ICARDA, with the financial support of the International Fund for Agricultural Development (IFAD), the Arab Fund for Economic and Social Development (AFESD), and the OPEC Fund for International Development (OFID), executed numerous successful research-for-development projects. The achievements of ICARDA in the Arabian Peninsula are exemplified by the development of useful technology packages in rangeland rehabilitation, irrigated forages, on-farm water management, and protected agriculture.

In 2014, after the technology packages were proven successful in research stations and on private farms, AFESD and IFAD approved funding for a new ICARDA-APRP 4-year project to transfer these technologies to end-users for further development. The project, 'Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula', was designed to transfer the technology packages it had developed, enhanced, or simplified during prior ICARDA-APRP project phases. The AFESD grant was received by ICARDA on 2014, while the IFAD financial support started officially in February 2015. The present document covers the project activities, outputs, and achievements during this period of 2015-2019.

During the project's lifecycle, ICARDA, in collaboration with the national agricultural research and extension systems (NARES) in the seven Arabian Peninsula countries, managed to introduce the targeted technologies of the project to a larger number of 'pilot growers' in the region than originally anticipated. The technology packages had positive impacts on the welfare of the poor farmers in the region, on the management of natural resources, and on the environment. The project also emphasized the human resource development program; it included general training of members at ICARDA headquarters and specialized training programs in different Arabian Peninsula countries. In addition, researchers, extension agents, and growers received practical, hands-on training through such participatory programs as field days, on-the-job training, and farmers' field schools (FFS). During these five years, the project implemented 8 specialized training courses, 11 workshops, and 70 field days in which about 950 researchers, extension agents, and farmers participated.

A. Recipient organization

ICARDA received the IFAD grant on behalf of the NARS of the Arabian Peninsula countries. The project was carried out in full collaboration with the NARS.

B. Project goal and objectives

To contribute to Arabian Peninsula countries' food security, to conserve natural resources, and to improve the livelihoods of rural communities.

Project objectives:

- Test, enhance, and develop technology packages suitable for the Arabian Peninsula environment to increase crop and animal production while conserving natural resources
- Transfer and disseminate the improved technology packages to increase crop and livestock production and productivity, increase water use efficiency, and conserve natural resources
- Enhance the capacity of national and extension programs to promote the adoption of targeted technologies and enhanced communication among various stockholders.

B.1. Target groups

The project's main target groups were resource-poor farmers and livestock owners in the rural areas. The technology packages are vital solutions for overcoming the major challenges of the Arabian Peninsula related to water management, rangeland degradation, and forage production, and for generating additional income for farmers.

The adoption of the improved technology packages contributed to increasing farmer's incomes, especially in poorly-resourced communities, particularly in Yemen and Oman. It addressed the issues of the proper management of natural resources with an emphasis on water conservation in all participating countries.

A good example is the adoption of the integrated production and protection management (IPPM) package in Yemen where, as a result of adopting this technology, growers managed to not only reduce the use of hazardous agro-chemicals, but to also increase their net income by more than 12%.

B.2. Project components

The project activities consisted of three main components:

- Introduction and adoption of technology packages
- Problem solving, research, and impact assessment
- Capacity building and institutional strengthening.

C. Target countries

The specific project partners in each country were:

- Bahrain: Ministry of Municipal Affairs and Urban Planning (MMAUP)
- Kuwait: Public Authority for Agricultural Affairs and Fish Resources
- Qatar: Ministry of Municipality and Environment

- Oman: Ministry of Agriculture and Fisheries (MAF) and Sultan Qaboos University
- KSA: Ministry of Environment, Water and Agriculture and King Abdul-Aziz Science and Technology University
- United Arab Emirates (UAE): Ministry of Climate Change and Environment, UAE University, Abu Dhabi Food Control Authority (ADFCA), and the American University of Ras Al Khaimah
- Yemen: Ministry of Agriculture and Irrigation and University of Sana'a.

Transferring the project's targeted technology to end-users required good, strong links between the NARES in the Arabian Peninsula countries. Regional coordination and understanding are necessary to avoid the duplication of efforts and to optimize the use of limited research resources. Developing and strengthening a regional mechanism for the coordination and integration of activities related to technology transfer and raising the ability levels of the National Agricultural Extension Systems (NAES) of the Arabian Peninsula countries will further enhance and speed up the technology transfer process.

The ICARDA-APRP has successfully established and managed a regional network of NARS through a system of regional meetings, expert consultations, and the use of modern communication systems. The same mechanisms will be implemented to establish a regional network for NAES and to create a linkage between these two networks. This will establish a regional mechanism for transferring technology and providing feedback related to the on-farm activities of the research centers and expediting the problem-solving process. The ICARDA-APRP will provide suitable platforms, including regional meetings and workshops, for this network. This network will also help to introduce NAES to and train them on the latest agricultural extension approaches and methodologies suitable for transferring the project's targeted technology. With the expansion of the smart extension diary (SED) in each country, there is the possibility for communications between the NARES through this system. However, communications through SED require the cooperation and approval of all member countries.

To enhance the interaction among regional scientists, extension agents, and international scientific societies, the program will support and sponsor a number of the staff from the NARS and NEAS of the Arabian Peninsula countries to attend regional and international conferences and meetings to share their activities and achievements.

Cooperating partners included Ministries of Agriculture, agricultural authorities, universities, and agricultural research and extension institutions in the seven Arabian Peninsula countries.

C.1. Particular focus on Yemen

Throughout the implementation of project activities, special attention was given to Yemen where the agro-climatic, socio-economic, and security concerns required a different approach to successfully achieve the project targets. There was a greater focus on capacity building and training-the-trainers. The project's targeted technologies became more localized using available materials. The link between the APRP and other development projects, particularly those funded by IFAD, also were strengthened.

Despite the negative effects of the insecure situation in Yemen, ICARDA managed to build a strong partnership with the NARES in Yemen. Yemen researchers and extension agents attended all APRP regional training and capacity building outside Yemen. The target was training-the-trainer. Technical back stopping was provided continuously by these trainers to local growers using different participatory approaches, while ICARDA scientists had overall coordination. One of the success stories on training-the-trainers is the work on feed blocks and using alternative animal feed resources. Four female researchers from Yemen attended a training course in Oman on using agricultural by-products and feed blocks as alternatives to animal feed resources. On return, they conducted a number of on-the-job training course for rural women and growers on this issue. They have successfully designed a locally made press for feed blocks that is now used by local farmers to make them

Khateeb, Director General of Animal Health. H.E. the Minister Mahli expressed his deep appreciation for the efforts and the achievements already made and delivered by ICARDA through the IFAD- and AFESD-funded project, which have undoubtedly helped Yemeni farmers to improve their livelihoods and to face the challenges of this tough period in the country's history.

The ICARDA-APRP continues to work on strengthening its partnership with Yemen policy makers in the agricultural field to provide additional help to resource-poor growers more effectively.

- Dr. Azaiez Belgacem, the ICARDA-APRP Regional Coordinator, met with H.E. Othman Hussein Fayed Mahli, the Minister of Agriculture and Irrigation in the Republic of Yemen in Amman 25 January 2018. Also, the meeting was attended by H.E. Eng. Ali Gunid, the Deputy Minister for Planning and Information, and Dr. Abdulrahman M. Al

- A consultation meeting on Yemen was held in Amman, Jordan 23 November 2017 attended by managers and scientists from the Yemini Ministry of Agriculture and Irrigation (including two Deputy Ministers), the Food and Agricultural Organisation of the United nations (FAO), and ICARDA. The meeting identified priorities for the agricultural sector in Yemen and the comparative advantages of each partner. In addition, it identified ways to disseminate the technology packages already developed for assisting Yemen in the development and rehabilitation of the agricultural sector, particularly those relating to food security and capacity development.

C.2. Gender balance

The ICARDA-APRP paid serious attention to the participation of women in project activities and actively promoted gender-equality issues. Given the number of females (researchers, extension agents, and growers) attending APRP training programs and the numbers of female scientists and technicians participating in the program's research activities, about 25% of the APRP budget went to support gender issue and the involvement of women in the project. In almost all APRP activities, including research, technology transfer, and capacity building, women had a prominent and active involvement.

This was even more noticeable in the project activities in Yemen. One of the main project targets in Yemen was 'Enhancing the role of rural women by awareness and training through the development of income generation activities'.

D. Approval, effectiveness, and closing dates

The project grant implementation agreement between Arab Fund for Economic and Social Development (AFESD) and ICARDA started January 2014.

On the other hand, the project grant implementation agreement was approved and signed by the IFAD president 19 February 2019 and the ICARDA Director General 12 March 2015. The project closing date was 31 March 2019.

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Review of performance and achievements against outputs, by project component

A. Introduction and adoption of technology packages

The importance of the technology transfer element of this research and development (R&D) project has been appropriately recognized by national as well as international research funding organizations and the public sectors. Technology transfer is seen as an important mechanism for stimulating development processes, reducing poverty, and elevating a society's standard of living.

Given the importance of technology transfer, technology packages developed during the last phases of the APRP have been transferred to the farmers through a set of demonstration and pilot sites using participatory approaches, in collaboration with NARES. The 'pilot farmers' and NARES benefited from technical backstopping and support from the ICARDA specialists.

These technology packages were adopted at selected pilot sites and established on private farms to increase farmer-to-farmer interaction and speed up their adoption rates. The selection of the pilot sites was based on specific characteristics and conducted in close collaboration with the national programs in all seven Arabian Peninsula countries. Pilot growers were selected from the active farmers of the rural areas. In addition, the following characteristics for selection of pilot growers were considered:

- Easy access to the farm and availability of the required production facilities, such as greenhouses, irrigation networks, ETo.
- Willingness of the growers to participate and to follow the project recommendations
- Willingness of the growers to share the cost in terms of labor, production system, irrigation network, water, ETo.
- Willingness of the grower to share the information with other growers and for the farm to be used as a demonstration site for conducting field days and training courses.

Figure 1 provides an overview of the major achievements related to technology transfer. Technology transfer was considered the most important component of this project. **The project directly benefited about 1600 rural households. It is estimated that an additional 5500 rural households profited indirectly from the project's activities**. During the implementation period, technical back stopping was provided continuously by ICARDA using different participatory approaches, such as training-of-trainers, FFS, field days, and workshops. Several publications, technical notes, and training/field manuals were published and distributed. The project was able to provide more technology transfer opportunities than originally planned because of the NARES' in-kind contributions.

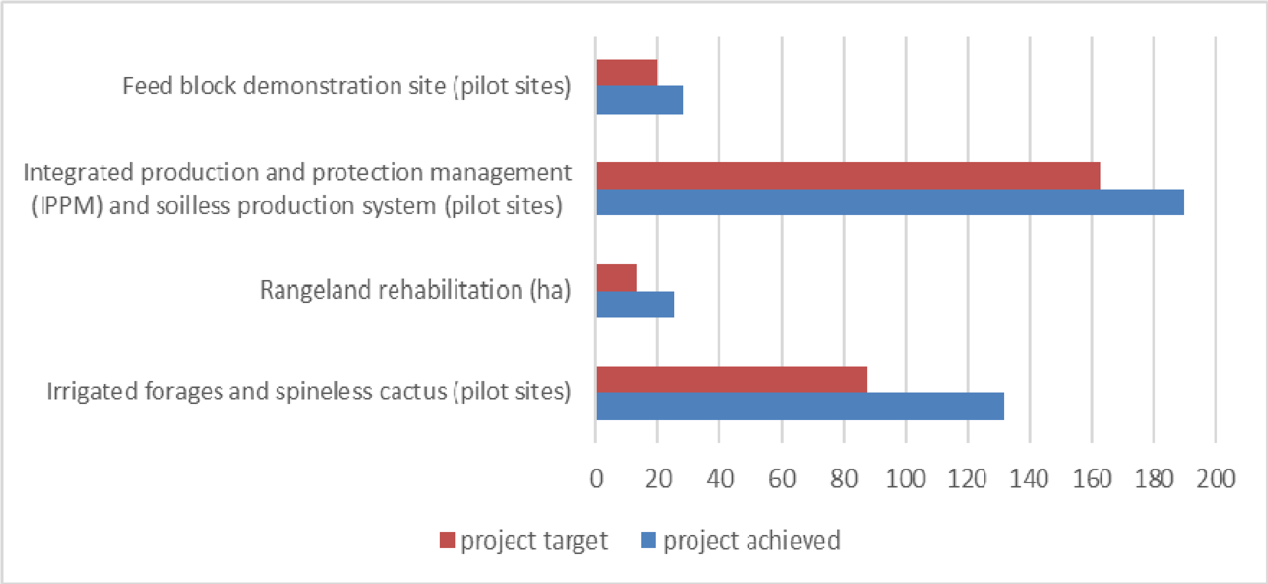


Figure 1. Number of targeted pilot sites and achievements (2014-2018)

Figure 2. A private farm in the UAE with a hydroponics production system

A.1. Promote an integrated production system for irrigated indigenous forage species and spineless cactus with high water-efficiency

A potential solution to water and rangeland problems in the Arabian Peninsula is to develop production and rehabilitation systems based on indigenous species already well adapted to the regional environment. Encouragement for the adoption of Buffel grass (*Cenchrus ciliaris)* and the legume Butterfly pea (*Clitoria ternatea*) instead of exotic Rhodes grass and alfalfa has led to a significant reduction of the amount of irrigation water required. Compared to indigenous species, exotic species are likely to suffer significantly if irrigation is reduced.

Similarly, spineless cactus is one of the best-adapted plants for arid and desert environments because of its special physiological and anatomical mechanisms that allow it to reserve water.

During the project, the use of indigenous forage species and spineless cactus for forage received close attention from the pilot farmers in Kuwait, KSA, Oman, Qatar, the UAE, and Yemen. The number of pilot farmers supported by the project exceeded 130. Moreover, the successes of these farmers encouraged other growers to adopt such technology. At the time of preparing this report, the number of farmers growing Buffel grass and spineless cactus is estimated to be more than 300.

In Yemen, where 40 growers adopted these technology packages by December 2018, despite a period of drought and the outbreak of the war in late March 2015, preliminary results showed that the green fodder yield obtained from Buffel grass at the first cut was 25 t/ha with a water use efficiency of 11.905 kg/m^3.

In Yemen, to improve productivity and diversify animal feed sources using an indigenous source of protein forage, the Butterfly pea was introduced to a number of pilot growers. The estimated area covered was about 0.5 ha for each grower. The average yield obtained per cutting was 6.45 - 7.40 t/ha with one or two irrigations, in a period of 35-60 days. The water productivity ranged between 2.91.5 kg/m^3 and 5.471 kg/m^3.

The average cost-benefit analysis for the irrigated forages Butterfly pea and Buffel grass were calculated from the data obtained from farmer's fields. The following graph shows and compares the income, cost of production, and net income of sorghum, Butterfly pea forage, and local Buffel grass as well as the Australian Buffel grass variety gayanda, which shows the highest net income per hectare compared to the others.

In **Yemen,** the production of Buffel grass and *Clitoria ternatea* (legume) were also monitored and compared to each other in the Lahej Governorate, Yemen. The water productivity of Buffel grass was 15.3 kg/m^3 while for Butterfly pea it was only 9 kg/m^3.

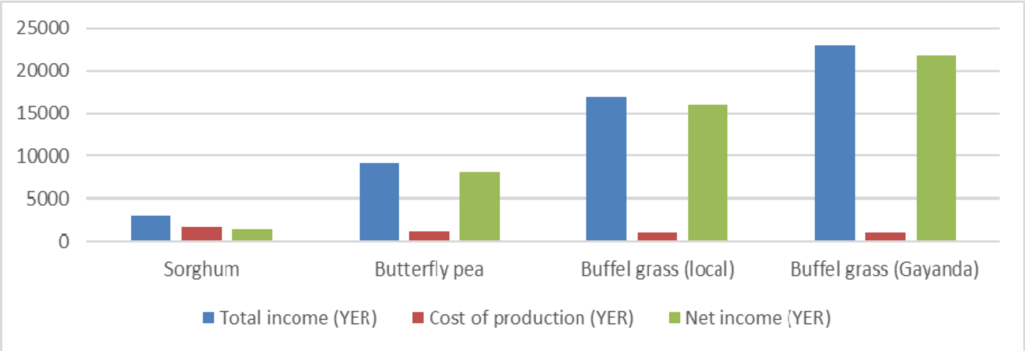


Figure 3. Comparison of the net incomes derived from four irrigated forage crops in Yemen (per ha)

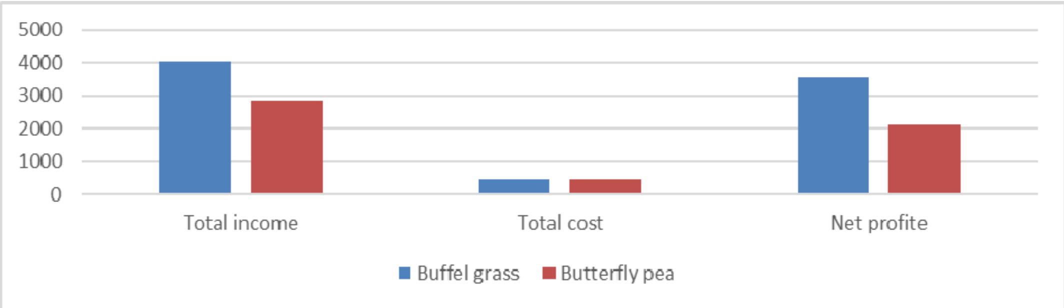


Figure 4. Cost of production, total income, and net benefit per ha for Buffel grass and Butterfly pea in Lahej Governorate (YER)

Figure 5. Butterfly pea, was introduced to five selected pilot growers in Yemen

In **Oman,** 44 pilot growers adopted Buffel grass. The estimated dry matter yield data, obtained by sampling, provided encouraging results. It showed that in the 20 farmers' trials, the minimum dry matter yield was 16.0 t/ha/year while the maximum was 23.1 t/ha/year – a mean dry matter yield of 19.15 t/ha/year. On average, 10 cuts could be taken per year, while for a majority 11 harvests/year were made. A demonstration of the *Cenchrus ciliaris* irrigation system and its benefits over Rhodes grass were explained to visiting farmers who were interested in growing *C. ciliaris* throughout the 2017 growing period. Good agricultural practices (GAP) were demonstrated to the surrounding farmers at farmers' field trials during the periodic visits. The aspects demonstrated were sowing, planting, irrigation, and harvesting for fodder and the seed of *C. ciliaris*. During the year, 1000 pamphlets were distributed to the farming community providing information on the package of GAP for *C. ciliaris* for fodder. A poster on *C. ciliaris* was displayed throughout the year.

In Qatar, 52 growers adopted Buffel grass and spineless cactus. The average size of the plots on each farm was about 2000 m^2. The maximum production of Buffel grass achieved was 70 t/ha of green matter for the variety bilola. In addition, about 5 tonne of spineless cacti were sent to a camel farm to evaluate its palatability and feeding value.

Figure 6. Buffel grass field and harvesting practice in Qatar

Figure 7. Feeding animals with spineless cactus in Qatar

Figure 8. Spineless cactus fruits in Qatar

In the northern **UAE,** five new growers introduced Buffel grass for an irrigated forage by December 2018. By the end of the project, more than 110 pilot growers, each with an area about 7.2 ha, had adopted Buffel grass.

In **KSA**, during the reporting period, indigenous grass species and spineless cactus were adopted by 13 pilot farms under rain fed conditions using water-harvesting techniques. The different techniques being used for water harvesting were contour and crescent furrowing as well as pitting.

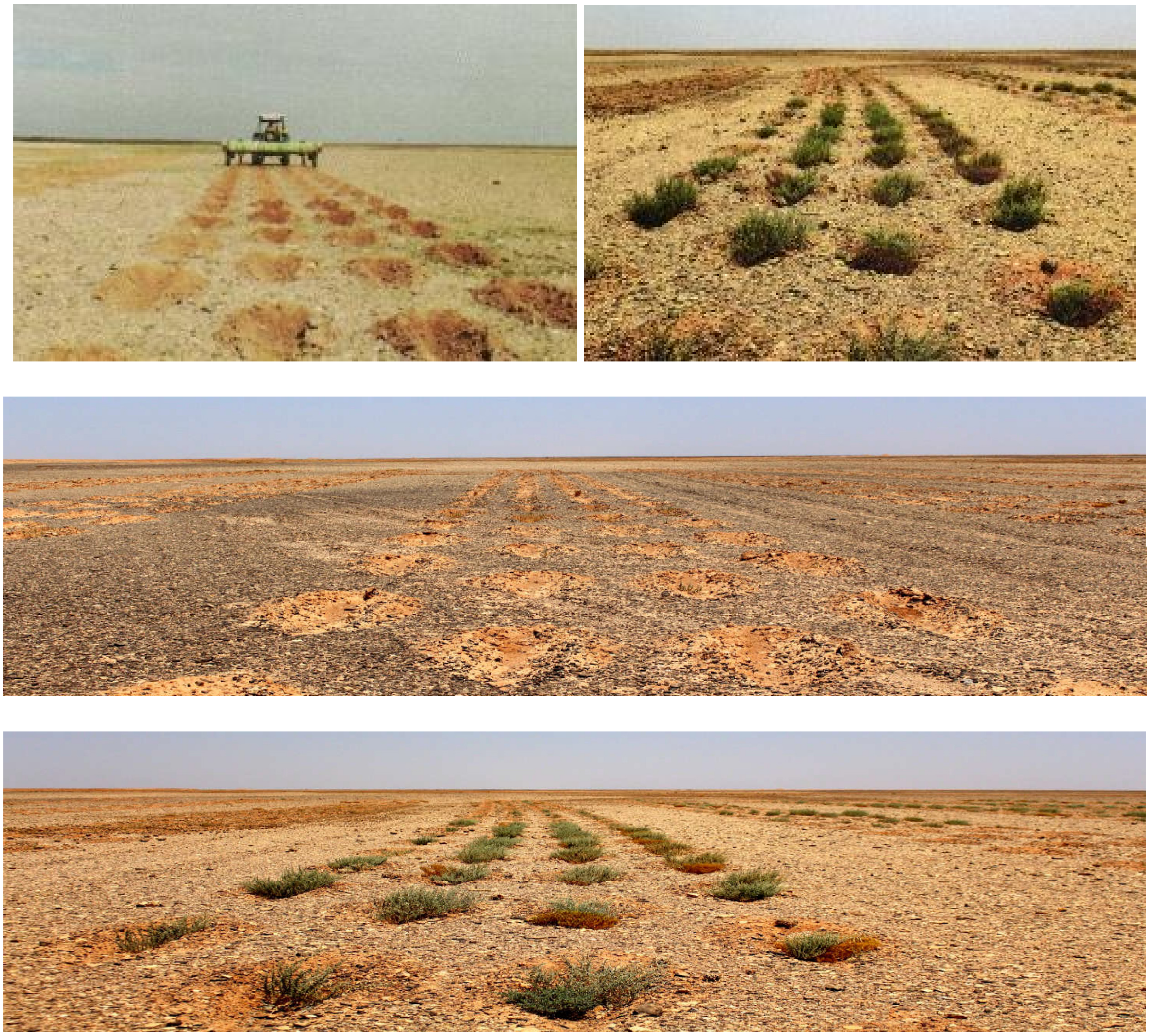


Figure 10. Grass species growth in one of the pilot farms in the KSA (above 2016, below 2017)

Again, in **KSA**, in 2017, a drip irrigation system was installed in a 2-ha field to complement irrigation for varieties of indigenous forages on a private farm. Similarly, Buffel grass was introduced to another pilot grower where a drip irrigation system was installed for a total area of 2160 m^2. In addition to Buffel grass the farm also planted *Panicum antidotale* (Blue panic grass), and local Buffel grass.

Figure 11. Complementary irrigation for indigenous forages in KSA

A.2. Participatory technology development for rangeland management and rehabilitation

During the project, different techniques were used to monitor, rehabilitate and manage degraded rangelands in some countries of the Arabian Peninsula, including Yemen, Saudi Arabia and Kuwait. These techniques included water harvesting, reseeding, and protecting. A geographic information system was used to monitor the rehabilitation process. In Yemen, about 100 ha communal rangeland in Al-Thunib area were subjected to different management modes including rest (short term protection), reseeding indigenous *Cenchrus ciliaris*, light grazing and free grazing (control) according to a participative approach. Permanent transects and quadrats were established for monitoring-assessing the plant cover attributes dynamics. The preliminary results showed that there was a continuous and significant increase in the number of good pastoral plants mainly in the protected area during 2018 probably due to the very favorable climatic conditions with an important amount and distribution of rainfall. The beneficial effect of restoration is well observed in the significant regeneration of the palatable and high range value species mostly grasses as well as the key species of the plant community, *Acacia tortilis* (table 1).

Table 1. Increase in the number of plants in the rehabilitated and open grazed plots in Al-Thaneeb, Lahej, Yemen between 2016 and 2018

Species		Rehabilitated area			Grazed area		
	Palatability (p)	2016	2017	2018	2016	2017	2018
Aloe vera		220	225	249	250	320	320
Euphorbia fractiflexa		500	553	1,073	1,300	1,500	1,600
Acacia tortilis (old)	p	35	45	57	20	16	15
Acacia tortilis (new)	p	20	184	242	0	10	10
Alhagi Maurorum (old)		286	340	1,530	0	0	650
Panicum turgidum	P	20	176	800	0	150	181
Alhagi maurorum (new)	P	30	120	1250	0	56	312
Dipterygium glaucum	P	35	53	152	0	0	31
Cassia obovata	P	56	140	1625	0	97	500
Tephrosia putputea		458	584	3102	0	150	1781
Cymbopon olivier		17	280	739	0	0	0
Zygophllum simplex	p	30	220	5812	0	104	2875
Cadaba rotundifoloa		10	11	11	0	26	30
Aerva javanica			12	40	0	17	30
Acacia nilotica	p		5	17	0	5	10
Lycium shawii		5	11	11	0	0	11
Abution pannosum	P	3	6	25	0	0	0
Amaranthus Graecizans	P	0	50	183	0	0	0
Ziziphus spina-christi	p	0	4	27	0	0	0
Cenchrus ciliaris	p	34	350	4312	0	0	22
Citrullus colocynthis		0	10	50	0	0	67
Aloe lanata		0	0	150	0	0	0
Anticharis arabica	p	0	0	218	0	0	30

Figure 12. Some of the construction activities for an enclosed area at a pilot site in Yemen

This participatory research, where all stakeholders, including the community of farmers, are involved in the rehabilitation and grazing management of degraded rangelands, was undertaken mainly in KSA and Yemen. It provided an excellent start to assessing the likely potential of pastures, once rehabilitated and sustainably managed, to become contributors to the animal feed calendars during rainy seasons. Similarly, in Kuwait, in addition to the positive effect of protection on the ecological parameters, light grazing needs to be tested, at least in the vegetation rest period when overgrazing would not be harmful.

In **KSA**, rangeland rehabilitation, using water-harvesting techniques, was introduced at Mr. Hamdan Al-Hassan's farm. An area of 2 ha, with a gentle slope, was subjected to two different water-harvesting techniques (crescent and contour lines) and planted with native shrubs (*Salsola villosa*, *Atriplex leucoclada*, *Traganum nudatum,* and *Haloxylon persicum*). Although the season 2017/2018 was dry, the crescent technique seemed to be the more appropriate for rangeland rehabilitation compared to the contour line one. With the crescent technique, *Traganum nudatum* recorded the highest establishment rate (13%) followed by Atriplex leucoclada (1.5%).

Again, in KSA, 9 ha of rangeland were selected for two pilot farms where indigenous plant species were planted under different water-harvesting techniques and designs. Additionally, water harvesting and supplementary irrigation for 2 ha of rangeland at one pilot farm was planted with six fodder crop species and was supplied with a drip irrigation system.

Figure 13. Indigenous plant species were planted under different water-harvesting techniques at two pilot farms in KSA

A.3. Using agricultural and agro-industrial products as alternative animal feed resources

Feed blocks are cost-effective food supplements that are produced mostly from agricultural by-products. The general formula for feed blocks includes binders, a preservative, a mixture of ingredients that contains the desired nutrients – nitrogen, minerals, vitamins, and one of many energy-rich agro-industrial by-products, such as molasses. In different regions or countries, the proportions of these substances may vary, as well as the main component of the block. The main ingredient may differ between date pulp, rice bran, and poultry waste in Iraq, tomato pulp and olive cake in Tunisia, brewery grains and olive cake in Jordan, or molasses in Morocco. Feed blocks aid small-scale farmers as conventional feed – such as barley grain or bran – are often expensive. Using agricultural by-products also increases water productivity.

Figure 14. Since 2015 in Oman, more than 8000 feed blocks have been produced annually and distributed among growers

A feed block manufacturing unit was established by the NARS in Oman at the Rumais Agricultural Research Station. The equipment, which includes a pan mixer and a heavy-duty hydraulic press, was manufactured locally. The production capacity of this unit is estimated at 1-2 tonne/day. More than 8000 feed blocks have been produced annually and distributed among growers. Different formulas have been developed based on locally available feed and by-products. These have been tested at the station as well as in on-farm trials. Two formulas of medium hardness and high compactness were selected to be produced on a large scale. These formulas included 95% local ingredients.

The work in Oman is expanding as the government is supporting companies for adopting such technology developed by young graduates.

In **Yemen,** more than 30 simple manual feed block machines were developed and distributed among the pilot growers between 2016 and 2018. In addition, six on-the-job training workshops were organized in which more than 150 agriculture extension agents and growers were trained on feed block production. The training addressed dealing with the use of agricultural by-products for the manufacture of feed blocks and the way to produce balanced formulas and diets. Because of security problems and as most of the men are involved in the war, most of the trainees were women.

Table 2. Feed blocks formulas produced and tested for hardness and compactness

Ingredients	Formula1	Formula 2
Dates not suitable for human consumption	25%	25%
Dry sardine	8%	7%
Wheat bran	34%	37%
Whole barley grains	5%	5%
Dibis (date syrup)	5%	5%
Urea	4%	4%
Calcium sulphate (plaster of Paris/gypsum)	2%	5%
Bentonite clay	6%	7%
Quick lime	6%	0%
Minerals and vitamins premix	0.2%	0.2%
Salt	4.8%	4.8%

Figure 15. Field day on feed block production at a pilot farm in Yemen

In the UAE and Qatar two feed block manufacturing units were established as well. In the UAE, one feed block unit was established at Al Dhaid Agricultural Research Center in collaboration with the Ministry of Climate Change and Environment. Ten simple feed block units were developed and distributed among local growers. The simple manual machine was fabricated locally. A technical field guide has already been produced.

In Qatar, a semi-industrial feed block unit was established. Other countries' scientists, including Yemen's, visited this facility.

Different formulas for feed block production from locally available materials, which include Buffel grass, date palm residue, spineless cactus, and quinoa, were evaluated.

Figure 16. Feed block production in UAE

A.4. Integrated production and protection management (IPPM) and soilless production systems

The extensive use of chemicals to control diseases and pests in greenhouses results in complex problems of insect resistance and health and environmental hazards. Crops can be protected by control measures that avoid heavy reliance on pesticides, thereby reducing the use of hazardous chemicals. These control measures are part of an IPPM program, which was developed by the APRP and implemented in all Arabian Peninsula research stations and on private pilot farms.

In Yemen, IPPM techniques were introduced and successfully practiced by farmers. These measures involved keeping the relative humidity low, covering with insect-proof nets, using plastic mulch, and irrigating sparingly. Plants were strong, healthy, and had low incidences of pests and disease.

Among the beneficial effects of the ICARDA-APRP in the region was that soilless production, hydroponics was well accepted by farmers in all the Arab Peninsula countries. Aware of the importance of the soilless system in improving crop yield while saving water, NARES in the Arabian Peninsula countries developed different financial and technical support tools to encourage the adoption of soilless systems by farmers.

In **Yemen**, the IPPM technical packages for protected agricultural crops have been implemented at 15 greenhouses on 13 farms in the northern highlands, particularly in the governorates of Sana'a and Amran. All the results have been collected and evaluated from an economic perspective. The irrigation efficiency of the IPPM greenhouse was about 38.1 kg/m^3 compared to the control greenhouse's 27.2 kg/m^3. A real difference was noticed in productivity under the integrated management system, reaching 6400 kg for the greenhouse, while the productivity of the control greenhouse for the same area under traditional farm management was

5292 kg (i.e. productivity per square meter under the IPPM system rose from 14.7 kg to 17.4 kg). Overall, it was noted that growers were impressed with IPPM and the adoption rate is increasing significantly. The adoption of integrated management techniques has increased significantly over the last few years in Yemen (Figure 17).

Figure 18. Using IPPM techniques in Yemen

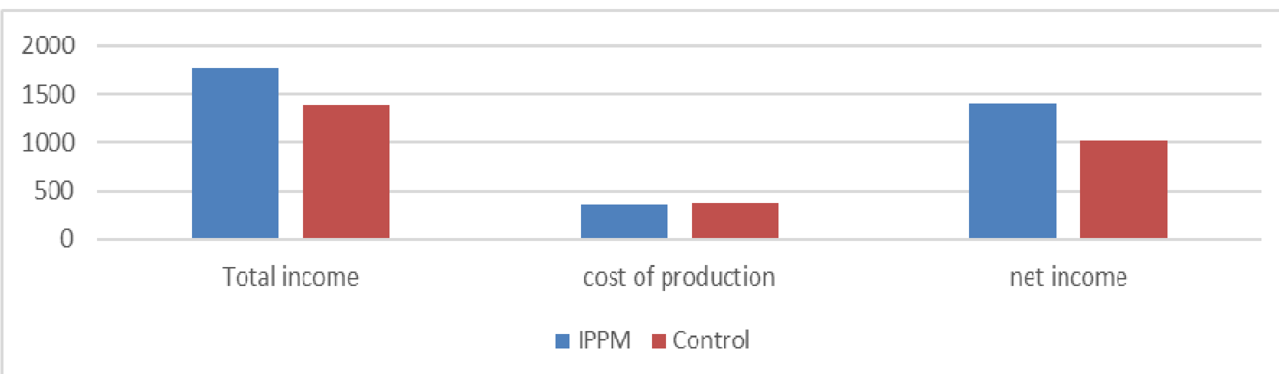


Figure 17. Total income, cost of production and net income (YER 000) of a tomato crop in Yemen with IPPM and a control greenhouse

IPPM in Yemen resulted in a significant reduction in agro-chemical spraying. The IPPM greenhouse needed to be sprayed four times while the control greenhouse needed to be sprayed 27 times. (Table 3).

Table 3. Number of sprays in the IPPM and control greenhouses, Yemen

Total number of sprays	Spider	Fungicide	Pesticide	
4	1	2	1	IPPM
27	7	8	12	Control

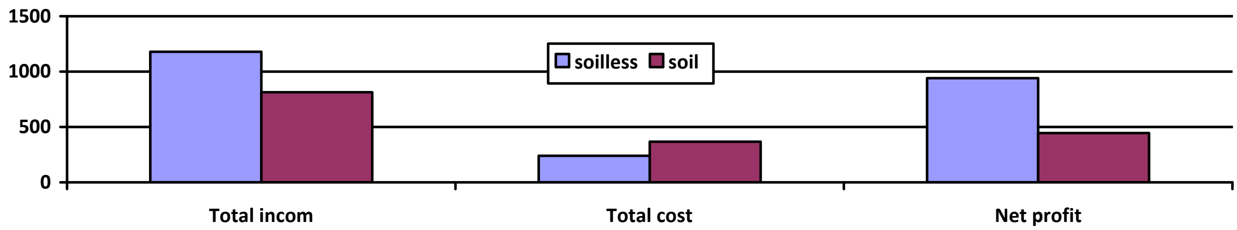


Figure 19. Total income, cost of production, and net profit (YER 000), for soilless and soil-based production systems in greenhouses (9m x 42.5 m) in Yemen

In Yemen, during the reporting period, the soilless production system was introduced at 12 private farms. The production records show a great improvement in water saving and growers' incomes. The IPPM greenhouses used 3.5 times more irrigation water per unit of area compared to soilless greenhouses. Similarly, the net profit for soilless production was more than twice that of the soil-based production systems (Figure 19).

In **Bahrain** in the period between 2014 and 2018, a number of new farmers joined the program and some of the previous farmers extended the area under soilless systems on their farms.

By December 2018 more than 20 farmers had adopted these agricultural techniques because they found soilless systems to be a solution to the challenges they were facing on their farms. These challenges were mainly the limited area of cultivable land and scarce irrigation water. In Bahrain using the hydroponics system, growers are planting a variety of greenhouse crops including tomato, cherry tomato, zucchini, beans, cucumber, sweet melon, strawberry, and cut flowers. Growers are receiving technical support through a series of field visits and hands-on training sessions.

Figure 20. Cucumber crop in a soilless production system in a farmer's field, Yemen

Figure 21. Field days at a soilless production system in a farmer's field, Bahrain

In 2018 alone, about 85 farm visits were arranged with the NARS and ICARDA researchers and scientists. In addition, some field days were conducted in the recently established agricultural incubator center. Here the pilot and new farmers met together to encourage the latter to adopt the soilless culture system on their farms.

In **Kuwait,** pilot growers who adopted the soilless production system recorded a cucumber yield of 13 kg/m^2 and a water productivity of 34.11 kg/m^3. During the reporting period (2015-2019) 20 new pilot growers adopted these techniques in Kuwait.

Figure 22. Tomato production on a private farm in Kuwait (UP) after adoption of soilless production system and (down) using soil-based production

In Oman, 45 pilot growers had adopted the soilless production systems promoted by this project. The APRP project, in collaboration with the MAF, provided them with seeds, perlite, pots, plastic sheets (mulch), fertilizers, conductivity and pH meters, yellow sticky traps, bio-insecticides (Vertemic, Evisect S, Clippers, and Abamactin), and fungicides (Previcure, Tachigaren, and Ortos). The cucumber production records for a single crop reached to 15 kg/m^2 and 128 kg/m^3 for yield and water productivity receptively. The pilot farms were visited monthly by research teams from the vegetable research laboratories in all governorates in which farmers had been selected. These visits provided opportunities to give advice, solve any problems, and answer farmers' questions.

Figure 23. Tomato crop under a soilless production system (left) and before adoption of this method, in soil (right)

In **Qatar**, 16 new pilot growers adopted the soilless production system during 2014-2018. Scientists from the Agricultural Research Department provided any necessary technical backstopping for the farm managers and technicians.

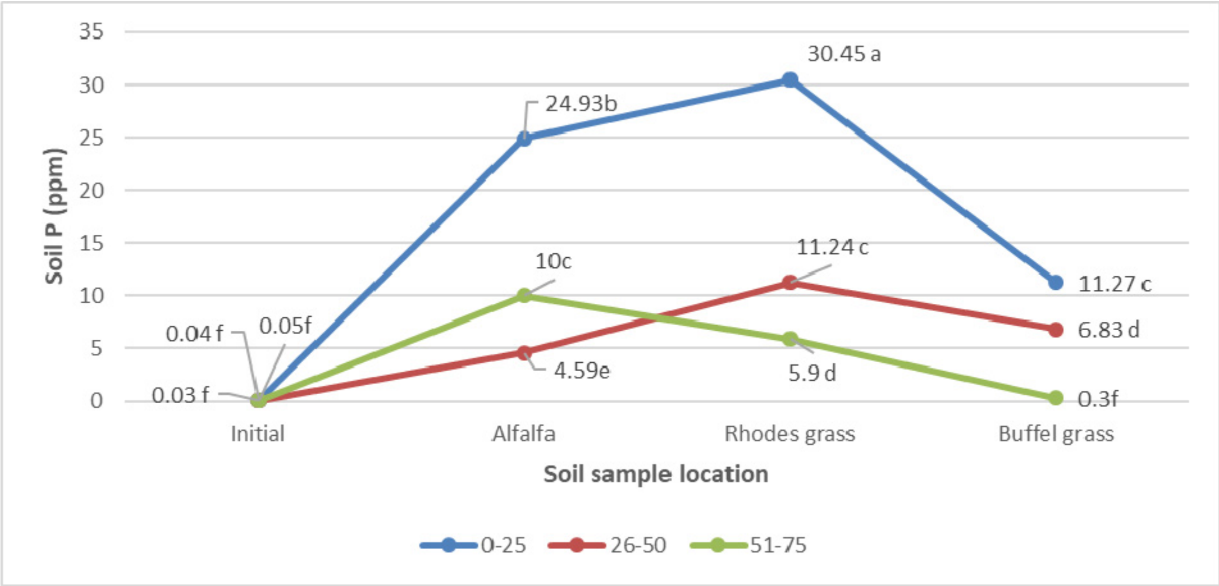
In **KSA,** 18 growers and one new pilot grower adopted IPPM and soilless culture during the reporting period. Recommendations were provided by the NARS during visits to the IPPM farms. These recommendations included the use of insect-proof nets and double doors. These helped to increase production by from 10 to 20%.

B. Problem-solving research

B.1. Use and improve the efficiency of treated wastewater (TWW) for irrigating forages and evaluate the effect of TWW on forage quality, as well as soil and water.

In the **UAE**, in order to investigate the effect of recycled wastewater effluent on the soil's chemical properties and the heavy metal uptake of selected forages, an experiment was undertaken at Dhaid Research Station, UAE, during 2014, 2015, and 2016. Alfalfa, Rhodes grass, and Buffel grass, grown in a randomized complete block design with four replications were irrigated using recycled wastewater. Four composite soil samples, taken from three random spots from three soil layers (0-25, 26-50, and 51-75 cm), were collected from the experimental site before the start of the study and again after 21 months from the planting date. These were used to assess the status of macro and heavy elements in the soil, in the forage tissues, and in the measured yields. Chemical analysis included soil nutrients and wastewater parameters (i.e. conductivity, sodium, calcium, magnesium, organic matter, phosphorus, and potassium) and heavy metals (i.e. copper, lead, zinc, nickel, chromium, cobalt, iron, and mercury).

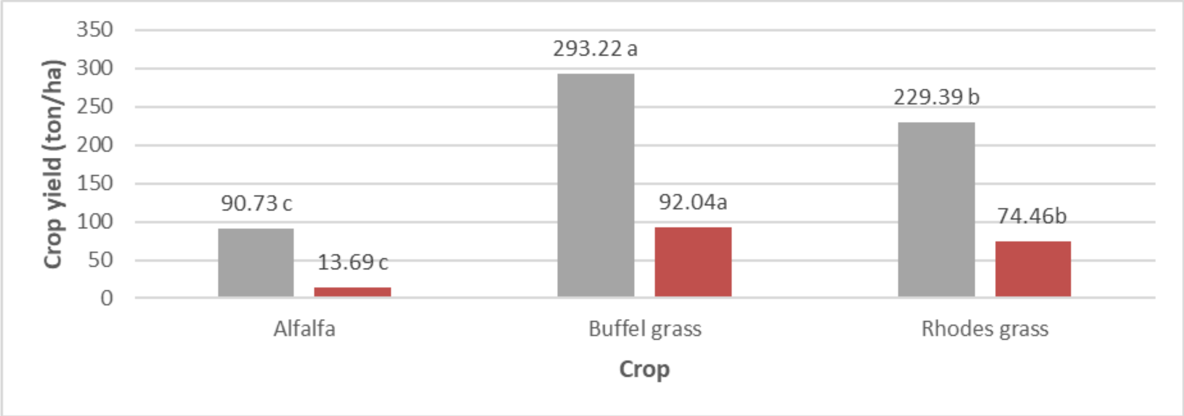
Recycled wastewater irrigation significantly increased the soil's chemical properties, especially in the surface layer (0-25 cm) and in the crop nutrient content. Results suggest that Sharjah effluent is suitable for the irrigation of forages as its quality, except for sodium and chlorine, conforms to international standards for wastewater irrigation. After 21 months of irrigation using recycled wastewater, soil salinity conductivity had increased in the soil profile by 223% with Buffel grass, 418% with Rhodes Grass, and 299% with alfalfa. The highest total dry weight yield from 14 cuts during the study period was recorded for Buffel grass, 91.04 tonne/ha. This was followed by Rhodes grass, 74.46 t/ha, and alfalfa, 13.63 t/ha. Irrigation with wastewater showed significant increases in zinc, iron, and molybdenum concentrations in the soil and copper and iron concentrations in the plant tissues. However, the concentrations of all the elements in the soil and plants were lower than the toxicity thresholds, except for iron and nickel. The sources of the nickel in the plant tissues were the soil and irrigation water. ICARDA recommends regular monitoring of recycled wastewater and soils and appropriate management measures are required to mitigate the negative effects of sodium and salts accumulations through the leaching of these salts from the soil.



Total N% a–f, P < 0.05, LSD = 0.005 K a–i, P < 0.05, LSD = 8.1

Mn a–h, P < 0.05, LSD = 1.04 P a–f, P < 0.05, LSD = 1.23

Figure 24. Nutrient accumulations in the soil profile planted with different forages in comparison to the initial conditions



Fresh weight a–c, P < 0.05, LSD = 3.19

Dry weight a–c, P < 0.05, LSD = 0.4

Figure 25. Total fresh and dry yield weights for different forage crops irrigated with recycled wastewater during the 2014 and 2015 growing seasons

Figure 26. Soil and crop sampling and recording of yields

In **Oman**, the effect of tertiary treated wastewater on the production quantity and quality of Rhodes (*Chloris gayana*) and Buffel (*Cenchrus ciliaris* L) grasses was checked. The experiment was conducted at the treated wastewater research farm in Rumais, Barka, Oman. It consisted of two irrigation treatments (full irrigation and 50% deficit irrigation) with two grass species (Buffel and Rhodes) as the sub-main treatments in completely randomized block design with four replications. Both grasses were irrigated with a drip irrigation system using tertiary treated wastewater. They were planted in 4 m x 4 m plots. The distance between drippers was 30 cm and between lines was 25 cm. The fertilizer was added as per research recommendations.

The irrigation treatments were:

- Full irrigation (100% of reference evapotranspiration [ETo])
- Fifty percent deficit irrigation (50% of ETo).

The seedlings of Buffel and Rhodes grasses were planted 8 March 2016. Both grasses were harvested at the same time at 50% flowering. A frame of 1 m x 1 m was used to take the samples from each plot.

The height of the grasses and their fresh and dry matter weights were recorded at each harvest. Samples from both Buffel and Rhodes grasses were collected for chemical analysis, especially for heavy metals. Soil samples were collected before planting from two depths – 0-30 cm, 30-60 cm – for physical and chemical analysis. Also, soil samples were collected at the end of the experiment and analysed for heavy metals.

The average results of 14 harvests of both Rhodes grass and Buffel grass are shown in Figure 27. The average water productivity is shown in Figure 28. The results confirmed that the fresh weight, dry matter, and water productivity of Buffel grass are higher than those of Rhodes grass. Buffel grass irrigated with 50% of the water requirements produced higher fresh and dry matter yields than the Rhodes grass that was irrigated with 100% of the water requirements. The water productivity of Buffel grass was higher than that of the Rhodes grass under both 50% and 100% of water requirements regimens.

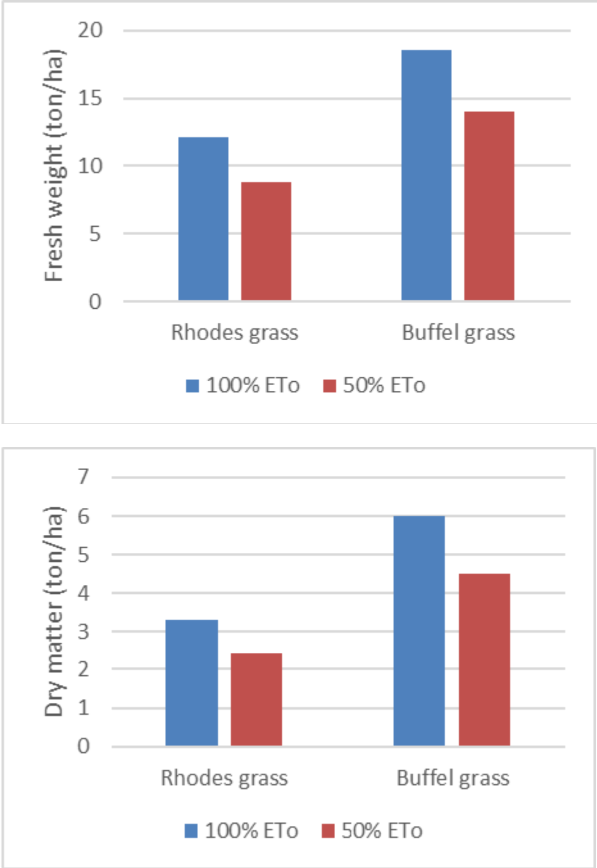


Figure 27. Average fresh weight (left) and average dry matter (right)

Preliminary analysis showed that the heavy metal concentrations in all the soil, plant, and water samples were very low and below the maximum allowed level. At the end of the experiment, soil, plant and water samples were collected and sent for laboratory analysis for their final heavy metal concentrations.

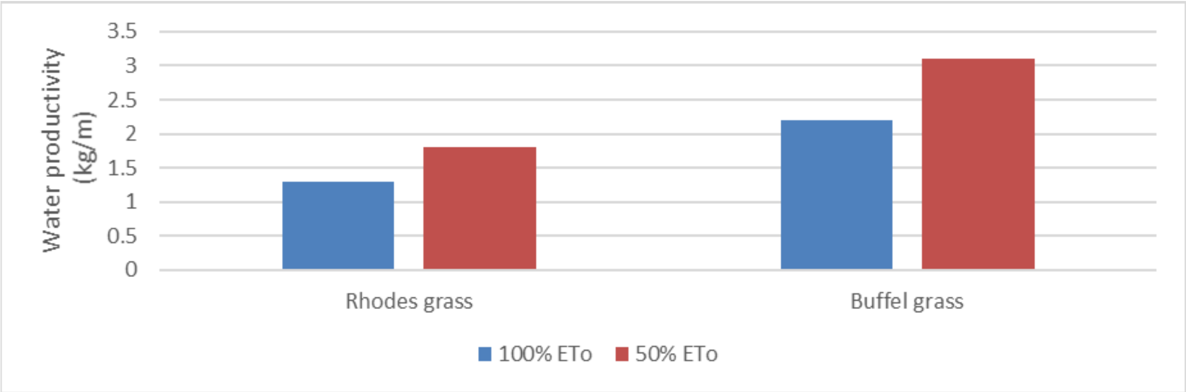


Figure 28. Average water productivity (kg/m³)

Figure 29. Plant growth of Buffel grass (left) and Rhodes grass (right)

B.2. Enhance the yield and water productivity of irrigated forages and spineless cactus

Studies of the yields of different spineless cactus accessions were conducted in Yemen in the northern, and southern highlands areas. The studies covered 38 accessions introduced by ICARDA as well as one local accession. The results indicated that the local accession has the highest yield. In Taez, the local accession produced 142 new pads which was followed by accession 69248 with 102 new pads.

In a collaboration between ADFCA and ICARDA, a spineless cactus mother plot was developed in the Baniyas Research Station The mother plot was supplied by ICARDA 2014 with 40 accessions from different climatic zones around the world. After receiving the 40 single pad cactus accessions from ICARDA, they were kept in the nursery for another six months for adaptation and multiplication. Then in November 2015, plant at six pad stage were transplanted to the main field with 1.5 x 1.5 m spacing.

Growth indicators were recorded in January 2014. The number of new pads per plants was selected as the main growth indicator. The results indicated that the following accessions produced the highest number of new pads per plant; accession Nil-I, 38, accession Nil-II, 33, accession R-14, 31, accession Nil-III, 31, accession 69245, 28, accession 73056, 28, and accession 69198, 28 (see Figure 30).

In Qatar, a comparative study was conducted for the selection of cactus accessions that have the potential for both fruit production and for animal feed. The study showed that the average number of new pads per year should be more than 37 while the number fruits should be more than 10 per year per plant.

The responses of the five selected spineless cactus ecotypes to different irrigation levels was studied in the UAE in 2014. Growth indicator readings were collected, and a statistical analysis was undertaken. There were no significant differences between the irrigation level effects on cactus growth indicators because the plants were still young.

The results showed that the cultivars OF1 Hetapentica 69233 and O. Tomentosa 69210 produced the highest numbers of new pads and total area per plant when using 75% of the crop water requirement. This indicator shows that these accessions have a higher production with less irrigation water than their estimated water requirements (Et) (see Tables 4 and 5) while the accession No. 4321 had the lowest production.

Table 4. Number of new pads per plant for selected cactus accessions under different irrigation levels for one year at Dhaid Research Station

Accessions	Irrigation levels			
	50% ETo	75% ETo	100% ETo	Mean
O.F.1 Hetapentica 69233	3.8	3.2	4.8	3.4
O.F.1 Sbeitla 69242	3.3	3.6	3.8	2.4
4321	2.2	2.2	2	2.4
O. Tomentosa 69210	2.7	2.2	4.4	1.6
Carfen-1 69198	2.5	1.8	3.2	2.4
Mean	2.6	3.6	2.4	

LSD accession = 1.3; LSD irrigation =1.31; LSD interaction = 1.79

Table 5. Total area of new pads (cm^2) per plant for selected cactus accessions under different irrigation levels for one year at Dhaid Research Station

Accessions	Irrigation levels			
	50% ETo	75% ETo	100% ETo	Mean
O.F.1 Hetapentica 69233	1,130.8	922.5	1,628.4	841.7
O.F.1 Sbeitla 69242	995.6	1,086.1	1,104.8	796
4321	572.8	541.1	501.3	676
O. Tomentosa 69210	726.5	474.5	1,254.2	450.9
Carfen-1 69198	638.4	408.4	925.2	581.6
Mean	686.5	1,082.8	669.2	

LSD accession = 157.3; LSD irrigation = 762.9; LSD interaction = 664.3

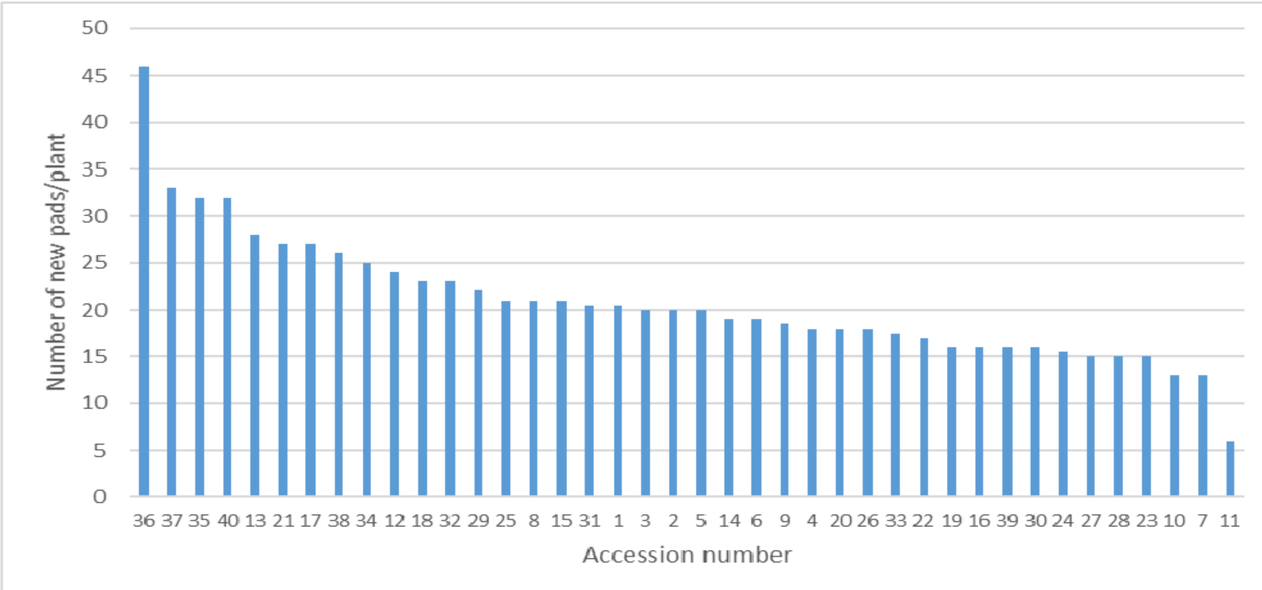


Figure 30. Number of new pads per plant for 40 cactus accessions grown at the Baniyas Research Station, UAE

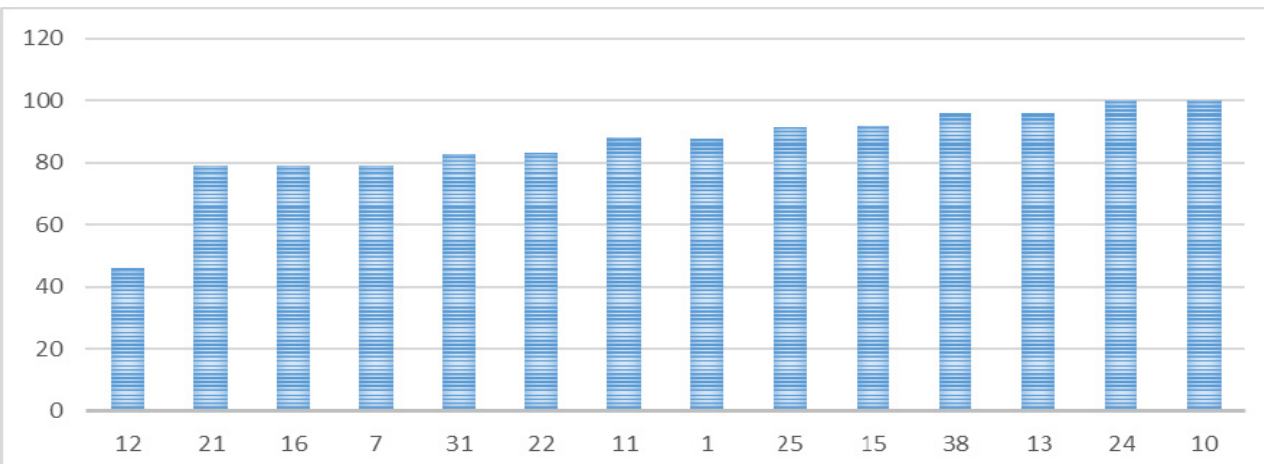


Figure 31. Survival rate for different spineless cactus accessions in KSA

In **KSA**, a study was conducted to enhance the integrated production system for spineless cactus. The study was carried out in an experimental field of the Rangeland and Camel Research Center, where about 2800 m^2 of land was allocated to it. Fourteen spineless cactus accessions were planted and studied to determine which had the better yield and water productivity under Saudi's climatic conditions. The results showed that accessions #10 and #24 had the highest survival rates, while the lowest survival rate was for accession #12 (see Figure 31).

The responses of the Buffel and Rhodes grasses to different irrigation levels using a line-source sprinkler irrigation system was studied in Oman. The objectives were to measure and compare the differences in Buffel grass and Rhodes grass yields in response to different irrigation regimes. Data collection included the records of irrigation water, yield, soil moisture, and metrological data. Four irrigation treatments, 40%, 65%, 100%, and 125% of ETo, for the two-grass species, Buffel and Rhodes, were investigated as the sub-main treatments in a strip plot design with four replications. The average annual total amounts of water applied (m^3/ha) were 10,728, 17432, 26,819 and 33,524, for the four irrigation treatments, respectively. The results indicated that Buffel grass had a significantly higher dry production weight and water productivity than Rhodes grass at all irrigation levels.

Irrigation at 65% of ETo for Buffel grass had the highest water productivity value 0.95 kg/m^3 . To get the same water productivity with Rhodes grass, this would require irrigation at 125% ETo level (Figures 32 and 33). The average soil salinity build-up, at a soil depth of 60 cm, for Rhodes grass which was under 65 and 100% ETo irrigation treatments were increased by 150 to 200% in comparison to Buffel grass soil during summer season

Again, in **Oman**, the forage productivity response of Buffel grass at different plant densities (in terms of row-to-row spacing) and doses of nitrogen were studied. The Buffel grass stubble from the mother plot at Rumais was planted in a randomized complete design at Wadi Hibi Research Farm, Sohar. The spacings between rows were 1.0 m, 0.5 m, and 0.25 m. Nitrogen was applied at three dosages, 0 kg, 400 kg/ha/year, and 800 kg/ha/year. The plants were under a drip irrigation system. All crop husbandry practices were carried out as per guidelines of FAO. The observations of plant height (cm), green fodder yield (t/ha/cut), and dry matter (%) were taken for 12 cuts after the treatments were applied on an experimental plot after the first cut harvest.

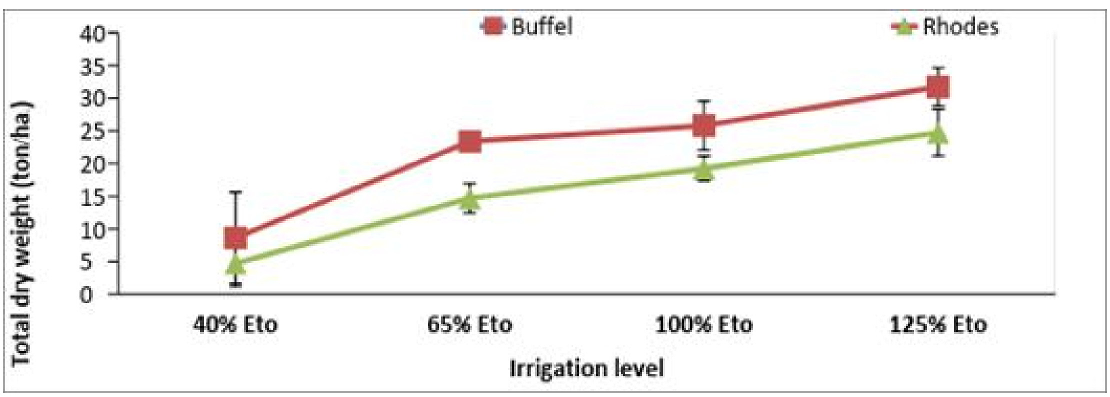


Figure 32. Total dry weight (t/ha) for Buffel and Rhodes grasses under different irrigation levels in a line-source experiment at Rumais Research Station, Oman for the 2013-14 growing season

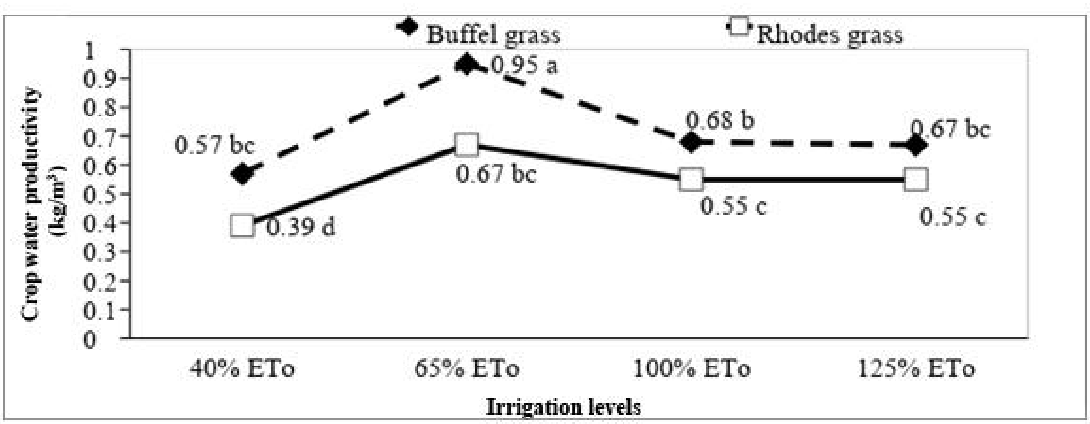


Figure 33. Crop water productivity for Buffel grass and Rhodes grass under different irrigation regimes at Rumais Research Station, Oman

Figure 34 General view of the experiment 2 weeks after one of the cuttings of Buffel grass at the Agricultural Research Station, Sohar

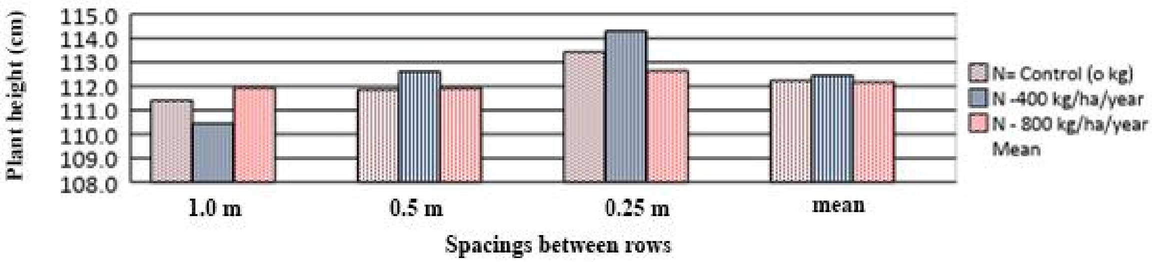


Figure 35. Mean response of Buffel grass to row spacing and nitrogen dose in respect of plant height (cm) over 12 cuts

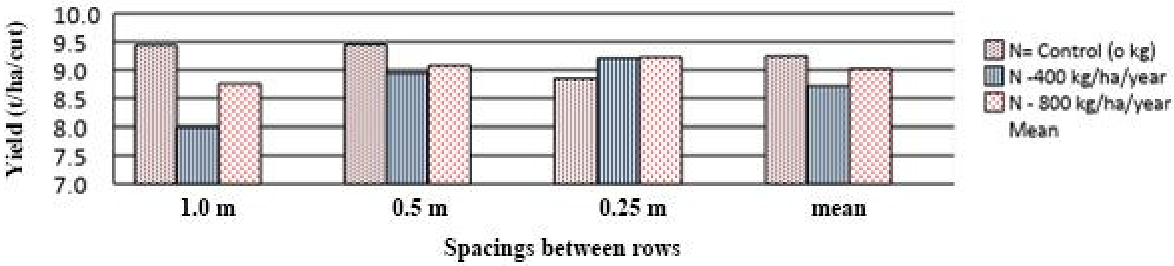


Figure 36. Mean response of Buffel grass to row spacing and nitrogen dose in respect of green matter yield (t/ha/cut) over 12 cuts

The general performance of *Cenchrus ciliaris* in the plots of all the treatments was stable, but less than satisfactory as under experimental conditions we would expect 25-30% more yield than was realized in the experiment. The plant stand was reduced to about 80-85% in all the plots. Hence, there was no improvement in yields from the seventh harvest cut onwards. The treatments were similar and found to be not significant ($p > 0.05$). It was recommended that the experiment be repeated as it is very important to confirm the influence of plant density (in terms of spacing and amount of nitrogen fertilizer applied) on the growth parameters and yield of *C. ciliaris*. However, the yield levels of between 9 and 12 t/ha/cut appear to be acceptable and stable in performance (see Figures 34, 35, and 36).

The on-farm productivity of *C. ciliaris* was found to range from 9 t/ha/cut to 12 t/ha/cut from the 12 harvest cuts studied. In view of the above results, *C. ciliaris* can be a sustainable alternate fodder crop in the Sultanate.

In **Qatar**, a study of the production of three Buffel grass varieties 1) Gayandah, 2) USA, and 3) Biloela under the stated conditions was conducted. The study also compared the productivity of the these varieties with that of one of the local Buffel grasses. The production records show that the Biloela variety has a significantly higher yield compared to the other varieties (see Figures 37 and 38).

Figure 38. Buffel grass in Agricultural Research Systems, Qatar

Again, in Qatar, *Clitoria ternatea* was under study for its adaptation to the local environment. The seeds were planted 25 March 2017 (Figure 39). Average seed germination was observed, and transplanting was done 15 September 2017. The germination rate was high. The first harvest was taken 20 October 2017, when the yield was 3.4 kg/m^2.

Figure 39. Clitoria ternatea *at the Agricultural Research Station, Qatar*

In the **UAE** a study was started in December 2017 for the perennial legume *Clitoria ternatea* on its adaptation to the environment of the UAE and to encourage farmers to adopt it as a source of protein that is less water consuming than alfalfa. The study was designed on a complete split random design with three-irrigation levels and three replications (see Figure 40).

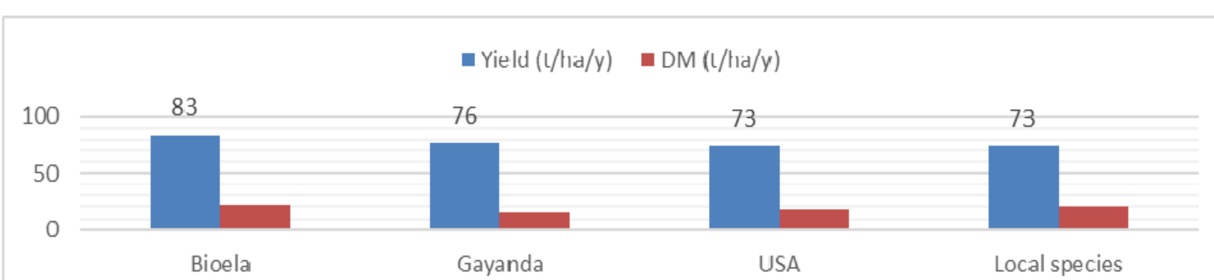


Figure 37. Yield and dry matter production (t/ha/year) of four varieties of Buffel grass in Qatar

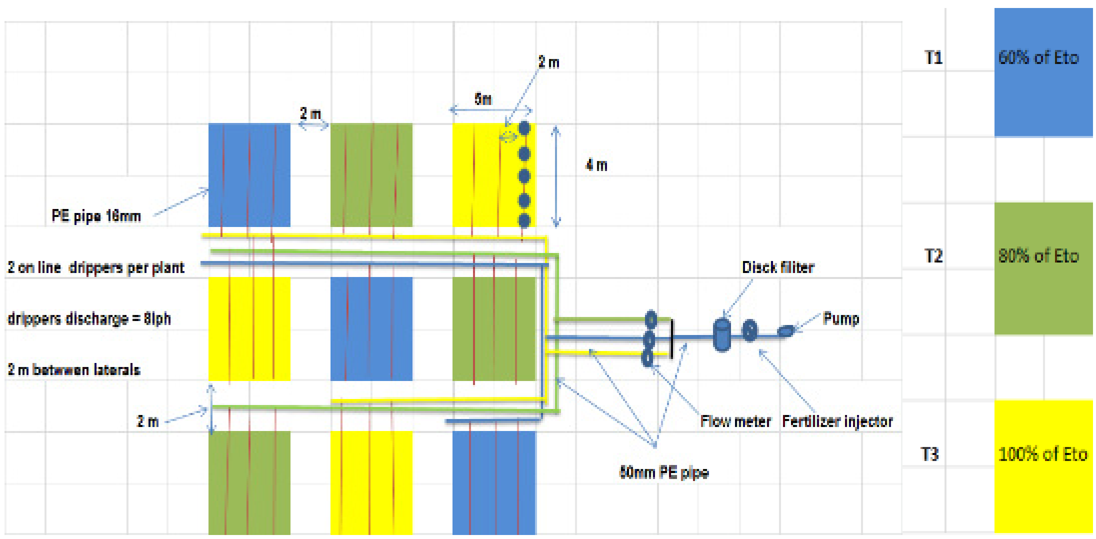


Figure 40. The experimental design to determine the response of C. ternatea *to different irrigation regimes*

Again, in the UAE, a study was conducted in Nov. 2017 on 13 different types of barley with high heat and drought tolerant genotypes developed by ICARDA. The experiment aims to select the genotypes presenting the best adaptation performance to the UAE environmental conditions.

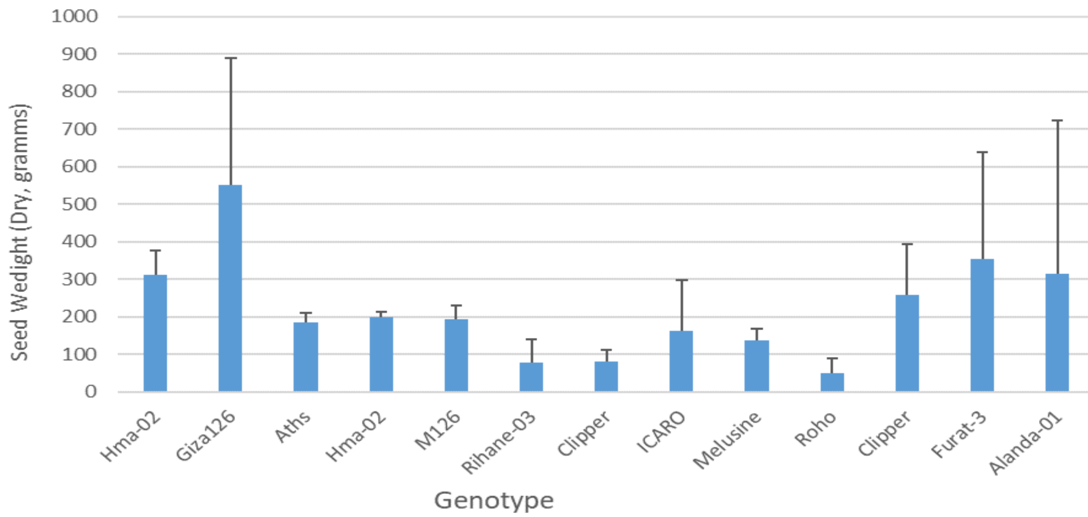


Figure 41. Yields of different barley Genotypes, UAE

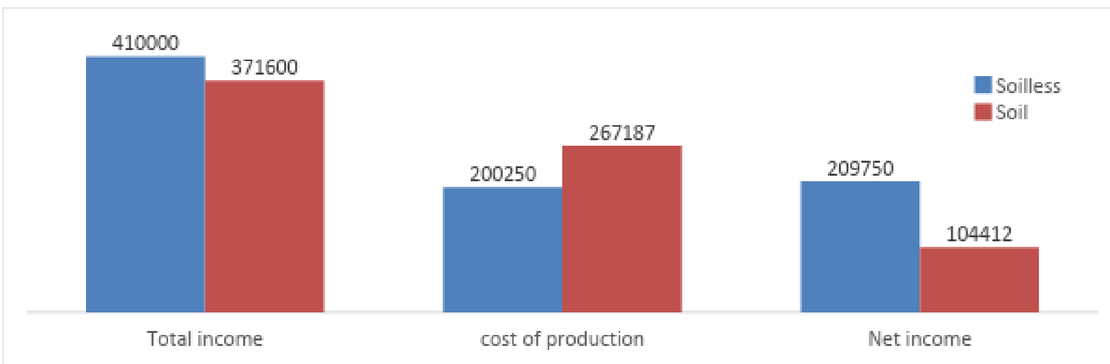


Figure 42. Comparison of total income, cost of production, and net income, in Yemeni Rials, for the soilless cucumber production system in Yemen

B.3. Improve water use efficiency and productivity of vegetable crop production systems under protected agriculture using IPPM, soilless culture, and other innovative technologies

To study and adopt the soilless production system for cucumber, ICARDA and the NARS conducted an experiment from November 2013 to March 2014 at the northern high land Research Station, Yemen. Two greenhouses of the same size and shape were selected with a soilless production system installed in one and the other being maintained as the control. The results show that the water productivity in the soilless production system was 73.9 kg/m^3 while that in the conventional soil production system was 20 kg/m^3. A cost-benefit analysis showed that the net income of those using the soilless system was 65% higher than that of those using the conventional soil system (see Figure 42). The depreciation costs for the irrigation system, plastic mulch, net, and greenhouse structure were included in the study.

In **Oman**, a cooled greenhouse and a shaded net house, each covering 270 m^2, were used to evaluate the performance of cucumber production using soilless growing techniques, in a closed system, for two planting seasons, November-February, and, March-May 2017. Four varieties of cucumber were used, Alexandra F1, Dipo F1, Reema F1, and Kirto F1. In the first planting season, November-February, no significant differences were observed between the cooled greenhouse and the shade net house in the number of fruits/m^2, average fruit weight (gm), and yield (kg/m^2) for all varieties in both the cooled greenhouse and the shaded net house. During the second planting, March-May, significant differences, $p < 0.05$, were recorded between the cooled greenhouse and the shaded net house in the number of fruits/m^2, average fruit weight (gm), and yield (kg/m^2). Fruit numbers (/m^2) varied from 89 to 101 with the cooled greenhouse having the higher number (101). However, the heaviest weight of fruit was produced in the shaded net house, 109.3gm. The highest yield was achieved with the cooled greenhouse, 10.74 kg/m^2, while the shaded net house produced 9.62 kg/m^2.

The study was expanded in 2015-2016 when ICARDA and the NARS used cucumber production systems with soilless growing techniques and closed systems, to evaluate the performance of cucumber varieties in a cooled greenhouse versus a shaded net house at the Agriculture Research Station, Jimah, Al-Dakhliyah Governorate. Four varieties of cucumber were studied, Alexandria F1, Dipo F1, Reema F1, and Kirton F1. They were studied in a randomized complete design with four replications. The seedlings were transplanted 6 January 2016. The results showed significant differences, $p < 0.05$, in fruit numbers and yield (tonne). It was found in that in the cooled greenhouse and the shaded net house no significant effects were recorded in average fruit weight (g) between the varieties. Fruit yield varied from 5.2 to 6.4 tonne in the cooled greenhouse and from 4.9 to 5.6 tonne in the shaded net house.

The records showed that the net house saved about 77% of the water and proved 10% more profitable than the cooled greenhouse (Table 6).

Table 6. Economic data for the cooled greenhouse and shaded net house for cucumber production

Cooled greenhouse			Shaded net house		
Input	Quantity	Cost (OMR)	Input	Quantity	Cost (OMR)
Seed	1000	50	Seed	1000	50
Calcium	38 kg	12.16	Calcium	38 kg	12.16
NPK 12:12:36	48 kg	36.5	NPK 12:12:36	48 kg	36.5
Magnesium	5 kg	2.2	Magnesium	5 kg	2.2
Iron chelate	0.4 kg	2	Iron chelate	0.4 kg	2
Nitric acid	4 L	4	Nitric acid	4 L	4
Fungicides	1 L	10	Fungicides	1 L	10
Insecticides	1 L	10	Insecticides	1 L	10
Irrigation water	30 m^3	15.8	Irrigation water	31 m^3	16.4
Cooling pad water	106.5 m^3	56.1	Cooling pad water	0	0
Electricity		33	Electricity		3
Insect trap	10 peace	6	Insect trap	10 peace	6
Total yield	5800kg		Total yield	5300kg	
Net Cost		237.76	Net Cost		152.26
Income		580	Income		530
Net profit		342.2	Net profit		377.7

OMR – Rial

In **Qatar**, the NARS, in collaboration with the APRP, studied different high-value vegetable crops under soilless systems. Tomato, cucumber, pepper, and strawberries were raised in different growing systems. The cucumber and strawberries were planted in perlite while the tomato and pepper were planted in gravel. The productivity in gravel was lower than the previous records of production in perlite. For example, tomato production in perlite has a record of 19 kg/m^2 in Qatar, while in gravel the productivity declined to 12 kg/m^2. The research activities then focused on crop production in perlite under different production systems. The study was conducted for two years for tomato and pepper varieties using the hydroponics system. For this study, three varieties of tomato and four verities of pepper were planted in three greenhouse structures covered by net, polyethylene plastic, and polycarbonate. Figures 43 and 44 present the average production for the two years.

Figure 45. Tomato and pepper under study using hydroponics in Qatar

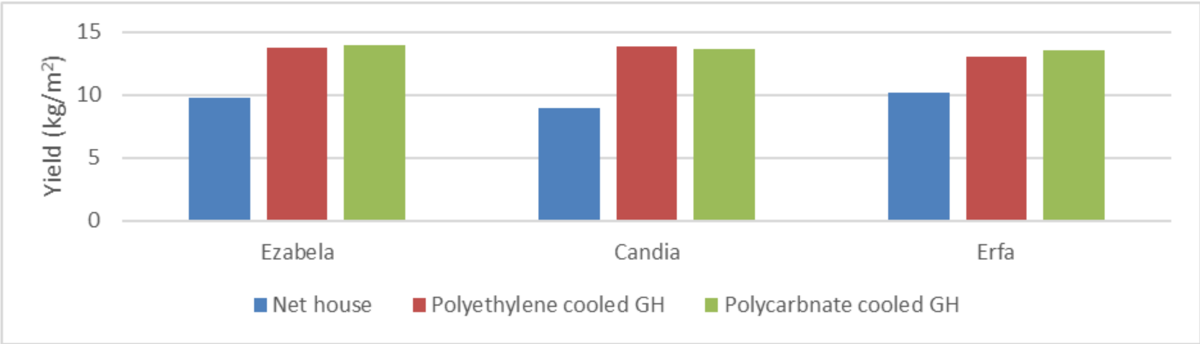


Figure 43. Tomato yield (kg/m^2) using hydroponics under different greenhouse structures

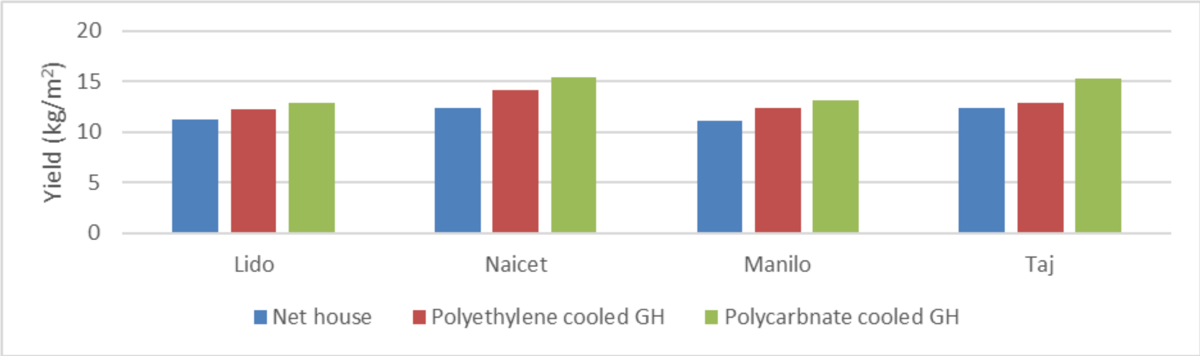


Figure 44. Pepper yields (kg/m^2) using hydroponics under different greenhouse structures

Figure 46. Pepper production in a soilless system in Qatar

In **KSA**, an experiment was conducted to study cucumber production using different growing media, perlite, sand, and gravel. Total production per plant in perlite was 6.1 kg, that in sand was 5.1 kg, and that in gravel was 6.5 kg.

Collaborative research activities continued with more attention focused on water productivity. In 2014 and 2015, the project started with green beans under protected agriculture. The plants were transferred to a polycarbonate cooled green house, 9 m x 40 m, 30 November 2014, and the study was continued in 2015. The yield was 4 kg/m^2 and water productivity was 13 kg/m^3. There are no records for green bean yields in KSA. However, previous ICARDA studies showed that the average yield for green beans was about 5kg/m^2 and water productivity was about 11 kg/m^3. The water productivity of cucumber under an open soilless production system with three different growing media (perlite, gravel, and white sand) was studied as well. The study used cucumber under an open soilless production system with three different growing media, perlite, gravel, and white sand. The study was conducted in one greenhouse with the production area divided into three equal areas. Figure 47 presents the yield and Figure 48 the water productivity of cucumber for the different growing media tested.

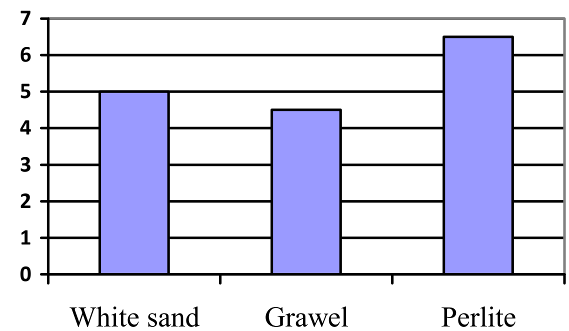


Figure 47. Yield (kg/m^2) of cucumber in different media in KSA

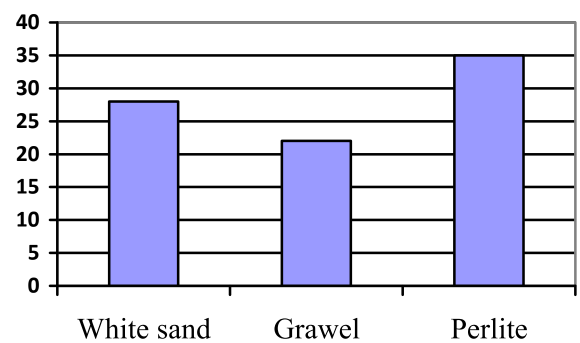


Figure 48. Water productivity (kg/m^3) of cucumber in different media in KSA

In the **UAE**, following a training course on vegetable post-harvest, ICARDA-APRP organized a field trip for the invited expert Dr. Ngoni Nenguwo, Post-harvest Specialist from the World Vegetable Center, to visit a number of the farms in the UAE for a quick appraisal of the post-harvest status for main greenhouse vegetable crops.

The following recommendations were developed for improving the post-harvest status:

The first suggestion was to test a portable fan that can be used to blow air through a stack of produce. If the fan is placed in a cooler part of the greenhouse, then the fruit will be quickly cooled down to the prevailing temperature. A diagram of a portable fan that can be used as a forced air cooler is provided in Figure 49. Figure 50 is a photograph of the actual unit.

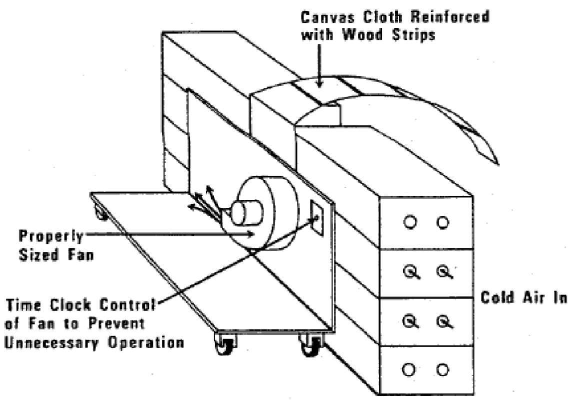


Figure 49. Diagram of a portable fan that can be used in a cold room

Figure 50. Photograph of a fan and its flexible cover used for pre-cooling vegetables in a cold room

The fan should be placed on a wooden frame with wheels and have a flexible cover that will enclose the crates of vegetables and force air through them. If the portable fan is placed in a cold room, then it will act as a pre-cooling device. This would allow farmers to create one cold room that can be used for both pre-cooling and storage. The possibility of using solar energy for the portable fan should be tested, too. A simple prototype cooler model has been developed and is currently being tested in West and East Africa. It may also be suitable for the Arabian Peninsula during periods of low humidity.

The second recommendation is to try using evaporative cooling cabinets within the greenhouse to store the vegetables after harvest. A simple type of cooler has wooden shelves with hessian material for the walls that are kept wet. Since the humidity in the greenhouse is between 40% and 50%, the cooler can lower the temperatures by at least 4-5°C and the humidity will increase to 80% or more.

This was also followed by a study conducted by ICARDA and the NARS to review the status of the post-harvest practices for greenhouse vegetables in the UAE. About 52 growers from central, northern, and eastern regions of the Emirates participated in this study. Data was collected through direct interviews using a standard questionnaire. The study aimed to:

- Identify the main post-harvest techniques that are used by growers in the UAE
- Estimate crop losses after the harvest in different greenhouse vegetable value chains in target areas.

The main greenhouse vegetables in the UAE consist of cucumber and tomato. In general, the soilless production system could produce double the yield of the conventional soil-based production system. Regardless of production system, growers who follow the IPPM techniques are achieving higher yields. The study showed that about 90% of growers do not apply any post-harvest techniques. Interviews with the growers revealed that their main crop losses after the harvest, within the existing greenhouse vegetable supply chain, happen during transportation of the crop to the vegetable markets. In fact, most of the growers do not store the product on their farms; they ship it directly after the harvest to the market. Therefore, post-harvest losses are minimal on the farm. Based on the interviews with retailers at the Dubai Fruit and Vegetable Market, it would seem that growers are losing about 5-10% of their crops during transportation. To reduce these shipping losses, the packing and mode of transportation, as well as the transportation time, are very important. Most of the growers are using 20 kg plastic baskets for the handling and shipping of crops. However, the study showed that the growers would prefer to change the weight, shape, and size of the baskets for better handling. Figure 51 summarizes growers' feedback on the plastic basket as a packing container. Availability and low cost are the primary reasons growers use the 20 kg plastic basket.

About 39% of growers operate a non-covered truck where crops are in direct sunshine. This can significantly damage and reduce crop quality, especially during the hot seasons. Although growers already use the shaded and cooled area inside a greenhouse for temporary storage of the crop before sending it to market, a portable fan can also be used to blow air through the stack of produce. If the fan is placed in a cooler part of the greenhouse, then the fruit will be quickly cooled down to the prevailing temperature.

In the **UAE**, green bean production has been studied under two different soilless production systems, vertical and flat. The green bean is an important vegetable crop grown in the open field and under greenhouse conditions in the Arabian Peninsula. Previous ICARDA studies show that in this region, the yield of green beans raised in a cooled greenhouse is about 6 kg/m^2/year and water productivity is about 10 kg/m^3/per year. In the UAE, total annual consumption of green beans has been calculated at about 5122 tonne, of which only 1543 tonne are local products. To cover the deficit the UAE imports about 3579 tonne of green beans with an estimated value of US$3,141,000. Soilless production systems provide a good alternative solution for producing this high-value vegetable crop in the region while addressing the general regional constraints to agricultural development.

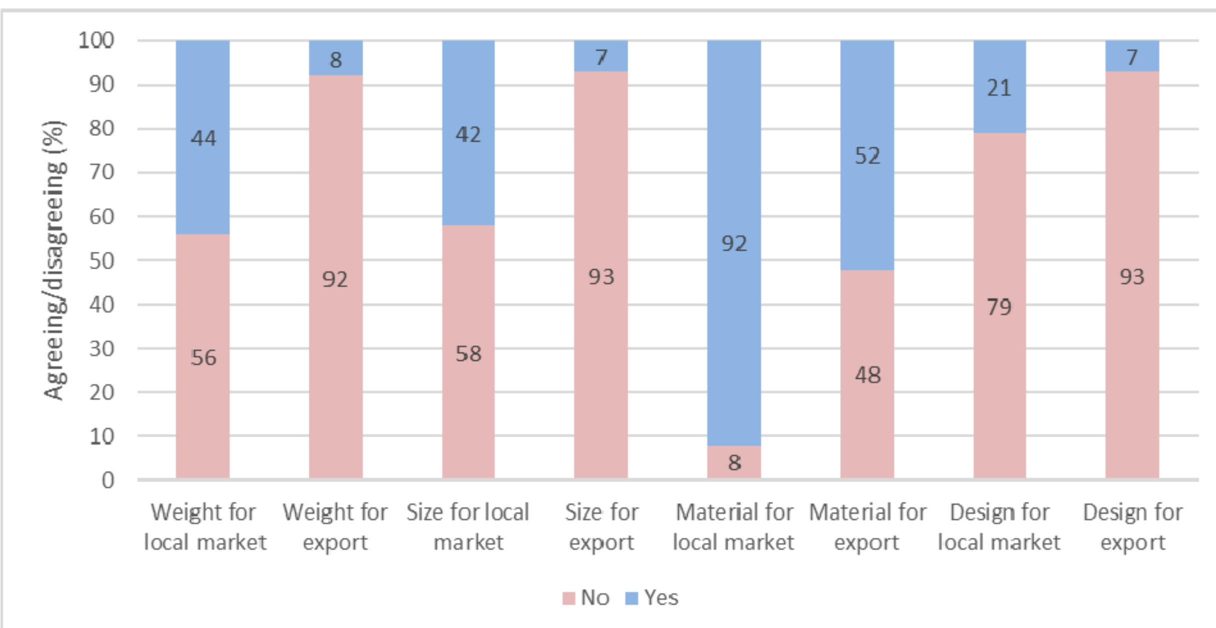


Figure 51. Growers' points of view on the suitability of plastic baskets for packing greenhouse crops

These constraints include a harsh environment, lack of suitable soil, and the shortage of water resources. Different green bean varieties required different production systems. This study compared the yields and incomes from dwarf and long beans grown using a hydroponics system in the UAE. For dwarf beans, the vertical soilless system was used, while long beans were planted following a flat soilless production system.

Figures 52 and 53 show the weekly evolution of the yield of both bean varieties and the variation in this parameter in relation to plant density. After assessing the production records and completing a partial income analysis, it seems that dwarf beans produce higher yields and income than long beans (see Table 6). Although the vertical system required an extra AED2.03 cost per square meter of greenhouse, AED0.55 of running and AED1.48 of investment cost, it generated a AED2.98 per square meter of surplus in gross income. The increase in income is a result of the higher yield, despite the price for short beans being lower in the market. Dwarf bean yields reached a peak of 1.98kg/m^2 while the long bean yield was half this at 0.98kg/m^2. Dwarf beans not only produce more, but also start production earlier and continue to produce one week longer than do long beans. This early and long production period helps to catch-up on the higher price of long beans in the market at the beginning and end of the season.

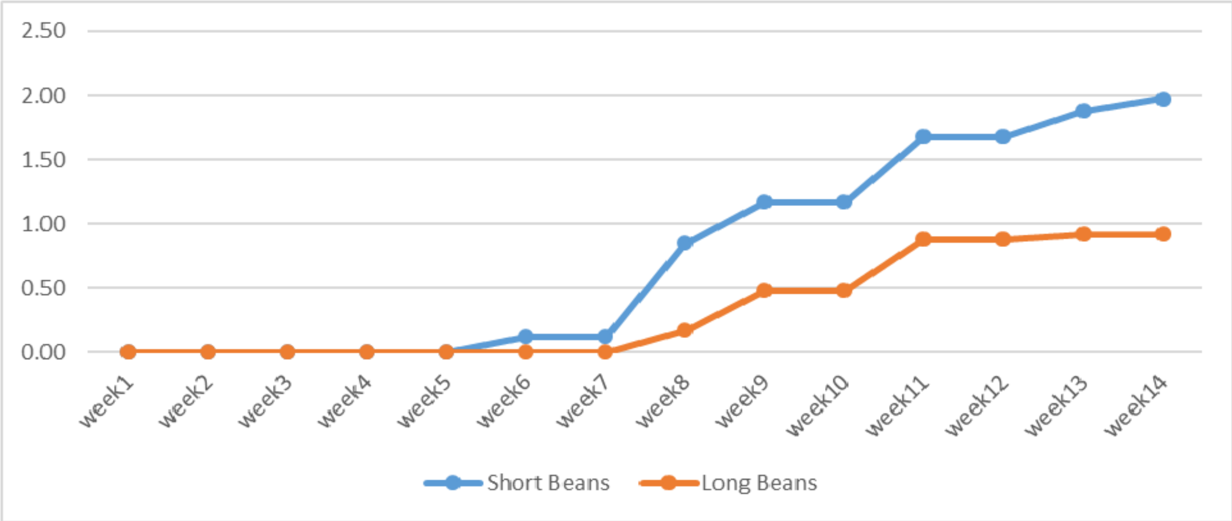


Figure 52. Cumulative yields of short and long beans for two-production systems in UAE

Figure 53. Comparing plant density (plant/m^2) and yield (kg/m^2) between dwarf and long beans

Table 7 Costs and net profit per season per m² of greenhouse for the production of bean varieties (AED)

	Dwarf (short)	Long	Difference
Total income m²	8.91	5.92	2.98
Current cost of production			
Seeds	1.71	2.90	-1.19
Fertilizer	3.27	1.54	1.74
Current cost of production/m²/season	4.98	4.43	0.55
Investment cost			
Pots	0.88	0.28	0.60
Media	1.11	0.39	0.72
Irrigation system	0.66	0.50	0.16
Total investment cost/m²/season	2.64	1.17	1.48
Net profit/season/m²	1.29	0.32	0.96

B.4. Improve the efficiency of cooling systems by using renewable energy

In the **UAE**, ICARDA and American University of Ras Al Khaimah, continued research activity on a new cooling system for greenhouses. The new system is designed to require minimum changes to the existing ones, but to increase sustainability and enhance adoption rates in the region. It aims to enhance the current cooling system. The study used a compact evaporative cooling system connected to a solar-generated electrical supply, to provide spot cooling for the cucumber crop.

Figure 54. Cucumber crop inside a greenhouse with spot cooling

The primary results show some positive effects. A cucumber crop was planted early in September and adapted to the system. The water used for the cooling system during September and October was recorded at about 4 L/day/m². This is about 50% less than the amount of water consumed in a normal pad and fan system during the same period. It is about one-third the average amount of water consumed in the cooling system used for tomato production in Al Dhaid. However, some modifications to the system are needed, especially in the air distribution tube, to enhance the efficiency of cooling and allow planting of the complete greenhouse (four lines instead of two). The average production records until the end of November show about 0.5 kg of cucumber/plant/harvest.

B.5. Biological control inside a greenhouse

ICARDA and the UAE conducted a joint research activity on the use of biological controls inside cucumber-planted greenhouses. The preliminary results of the study conducted between 15 April 2018 and 24 June 2018, appear very promising. A number of local beneficial insects were used, including aphid lion, mirid predatory bug, lady beetle, and robber fly, to control economic pests to cucumber under greenhouse conditions, such as trips and white fly. The results show that the infestation of white fly decreased from 87.5 to 17.5% and that for trips from 52.5 to 10% as a result of releasing aphid lion and mirid predatory bug. Although the biological agent population was not that high because of the heat and the treatment of alfalfa crops on the farms, they produced good results.

B.6. Develop an animal feed calendar using indigenous forage species, spineless cactus, and alternative feed resources

To conserve the limited water resources in the region, while producing enough food for the increasing human population, it is necessary to improve the water productivity of animal feed resources I addition to using alternative feed resources, such as feed blocks. The need to improve the use of crop residues and by-product has received considerable attention in recent years. However, there have been few studies on the availability of agricultural residues and by-products in relation to their potential for feeding livestock.

The ICARDA-APRP, in collaboration with the NARS of the Arabian Peninsula countries, has started a study on the availability of agricultural by-products and residues in the Arabian Peninsula that can be used as animal feed resources. For agricultural by-products at the farm level, the crop yield per area per annum is used to estimate the yield of the crop residue and by-products. For each crop, a constant factor for calculating crop residue based on the crop yield will be developed. As these factors are highly variable and should be determined regionally, data on the yields of different crops and their by-products will be collected at each farm using an interview and questionnaire. The first step was to develop a questionnaire to be sent to the NARS in the UAE, Kuwait, Qatar, and KSA for pre-testing. After modifications and estimation of the number of questionnaires required, data will be collected from all Arabian Peninsula countries.

In Oman, the MAF conducted a study on the availability of agricultural by-products in the Sultanate. The inventory of locally crop residues and agro-industrial by-products available in Oman was estimated from:

- Previous studies implemented in Oman on the use of agro-industrial by-products in the feeding of ruminants
- Data obtained from the Agriculture and Fisheries Statistical Yearbook, 2011.

Table 8 presents the estimated crop residues and agro-industrial by-products in Oman.

In Yemen, 1 September 2018, a practical training was conducted for 20 growers in the Lahej area, using a manually-operated machine for the production of feed blocks from the available agricultural by-products. During the course 25 blocks were made.

Table 8. Crop residues and agro-industrial by-products in Oman

Item	Quantity (000 tonne)
I. Crop residues	
Wheat straw	2.126
Barley straw	2.871
Corn stalk	40.245
Others	11.153
Vegetable crop residues	44.96
Banana crop residues	24.633
Coconut fruit by-products	3.500
Pruned branches of ornamental trees	10.000
Date frond leaves	150.000
II Agro-industrial by-product	
Wheat bran	120
Date pulp	5.000
Date stone	5.000
Dates not suitable for human consumption	27.000
Dried sardine	25.000

This was followed by laboratory tests on feed block samples. There were some slight differences between the block samples arising from the materials used for each. The moisture ranged between 7.2-7.4%, crude protein 15.1-17.4%, raw fiber 11.8-16%, and raw ash 20.7-24.7%.

In Yemen again, a survey was conducted on the availability of agricultural by-products in the Abyan and Lahej areas. The total agricultural crop residues in Lahej and Abyan were estimated at 46,192 tonne/year. This constitutes about 11.5% of the total production of crops grown. Sorghum occupies first place in terms of the amount of waste – 36.9% of the total waste. It was followed by bananas at 18.1% of the agricultural crops in Abyan and Lahej.

In both Qatar and UAE, in addition to training the researchers and extension agents on the steps for producing feed blocks, different balanced formulas were tested in the presence of the farmers. The results were presented for the different farm by-products (with a focus on date palm waste).

Figure 55. Banana by-products in Yemen used to feed animals

B.7. Rangeland rehabilitation and water-harvesting techniques

In Yemen, to determine the best methods for rainwater harvesting, a study was continued at Lahej during the period 2016 to 2018. The study comprised five experimental water-harvesting designs which were geometric shapes – a control (no shape), lines, triangles, squares, and crescents (A, B, C, D, E) and six replicates. The results showed that the highest plant density was recorded for treatment E (crescent) with an average of 671 plants. This represents an increase of 88.6% compared to the control treatment (A). Treatment A recorded the lowest percentage increase (34.55%). The highest percentage of pastoral plants was recorded for treatment E (30%), followed by treatment B (24%), while the control treatment was the lowest (13%). The pastoralists included 42 pastoral plants, 23 of which were parasitic, and 15 new plants were recorded for the first time in 2018.

Studies on rangeland rehabilitation and monitoring also continued in Kuwait and KSA.

In Northern KSA, ICARDA scientists, in collaboration with the NARES, selected 5 ha of rangeland at the Bsita Research Station in September 2015 as a relevant site for a long-term, on-station experiment on rainwater harvesting technologies and their roles in the regeneration of bare rangeland vegetation. The objective was to implement the proposed water-harvesting trial to study the performance of six native rangeland plants under three water-harvesting techniques – a semi-circle, a V-shape, and Nigari – using an equal area of catchment and a cultivated area ratio of 8:1 for all treatments. The cultivated area was calculated using equation (1)

$$\frac{C}{CA} = \frac{(WR-DR)}{DR \times RC \times Eff} \quad (1)$$

Where:
C is the cultivated area (m^2); CA is the catchment (m^2); WR is the crop water requirements (mm); DR is the design rainfall (mm); RC is the runoff coefficient (ranges from 0.1 to 0.5); and Eff is the water-harvesting efficiency factor (ranges from 0.5 to 0.75);

A split plot design, with three replicates of each treatment and type of rainwater micro-catchment structure was adopted and planted in November 2016 with the seeds and seedlings of six perennial pastoral species – *Atriplex halimus, Atriplex leucoclada, Traganum nudatum, Salsola tetandra, Salsola villosa, and Halaxon persicum*. The preliminary results demonstrate that because of severe drought the seeds did not germinate across the three types of micro-catchment and the survival rates of seedlings were very low. The crescent-shaped micro-catchment recorded the best average survival rate at 0.062%. This was followed by the V-shaped micro-catchment at 0.006%. None of the seedlings planted in the square-shaped catchments survived.

Figure 56. Water-harvesting techniques after the first precipitation event at the experimental site

In **Kuwait**, monitoring-assessing the dynamics of plant cover attributes in a in a short term protected (revival of hema system) degraded rangeland site at Al-Wafa was conducted in close collaboration between ICARDA and Public Authority for Agricultural Affair and Fish Resources (PAAFR) and aimed at monitoring the changes in the vegetation cover during several seasons. The system was designed to monitor the changes in the vegetative cover during several seasons using different testing techniques. The techniques, transects, quadrants, and plots, were established for measuring plant cover, species composition, and species density and frequency. The study started in 2015 and has continued for a third year. Four sites were selected to monitor and measure natural vegetation in the study area, using the protocol method of three-way lines.

During the reporting period, the results showed a positive effect on all the scored parameters. The occurrence of rainfall at the beginning of the growing season and the relative abundance of annual species in 2016, as compared to 2015, increased the total plant cover rate to about 11% in some transects, where less than 5% was recorded the prior year. With regards to flora richness, there were 12 annual and four perennial species recorded in the protected area. The fall of 2018 was exceptionally rainy, and a significant impact is expected of the protection on the flora diversity both in the fenced area and in its surroundings.

B.8. Establish feed block manufacturing units

In Yemen, a manual feed block machine was fabricated and used to train some pilot growers in Lahej on feed block production. Different locally available materials, including dry Buffel grass, wheat, date by-products, ETo. were used for the feed blocks.

In Oman, after the feed block units had been installed, different feed formulations were evaluated for the final hardness and compactness of the blocks. Palatability also was tested using animals at the research station.

Finally, two formulas for medium hardness and high compactness were selected to be produced at scale. These formulations comprised 95% local ingredients (see Table 9).

During the field days conducted during 2016, about 400 feed blocks were distributed to animal owners in Al Sharqiya, Al Dhakilya, Al Batinah, and Al Dhahira. The animal's owners' perceptions were very positive towards the new feed and there is good demand for feed blocks to be used as an alternative feed supplement.

Figure 57. Manual feed block machine in Yemen

Table 9. Feed block formulations produced and tested for hardness and compactness

Ingredients	Formula 1 (%)	Formula 2 (%)
Dates not suitable for human consumption	25	25
Dry sardine	8	7
Wheat bran	34	37
Whole barley grains	5	5
Debris	5	5
Urea	4	4
$CaSO_4$ (plaster of Paris/gypsum)	2	5
Bentonite clay	6	7
Quick lime	6	0
Minerals and vitamins premix	0.2	0.2
Salt	4.8	4.8

Table 10. Feed block production using a locally made feed block press, 2015 and 2016

Location	2015	2016
Al Sharqiya, Al Dhakilya, Al Batinah and Al Dhahira	400	400
Jabal Al Akhdar	600	
Total	1,000	400

Figure 58. In Oman 400 feed blocks were produced and distributed among growers during the field days

B.9. Effect of Buffel grass on animal production

In the **UAE**, the effect on goats of a diet of Buffel grass compared with one of Rhodes grass was investigated on a private farm in Fujairah. Two groups of young goats of similar age, size, weight, sex, and species were selected. Each group comprised 10 animals that were treated similarly except that one group was fed Rhodes grass while the second group was provided with Buffel grass. Health and growth indicators were monitored and recorded using a data collection sheet. The quantity of animal feed, concentrate, and water consumed by each group was recorded daily. Health indicators, including the status of the appetite, skin, tail, activity, and feces of each group, were reviewed and marked by the farm veterinarian. The weekly weight (kg) of each animal was recorded as the growth indicator.

The Buffel grass and Rhodes grass were sourced from the same farm. The farm has about 50 ha of Rhodes grass and 1 ha of Buffel grass. The Buffel grass was irrigated by a drip irrigation system while a sprinkler irrigation was used for the Rhodes grass. After eight weeks, the results showed that the total water, grass, and concentrates which were consumed during the study was the same for both groups. The health indicators also did not show any differences between the two groups. Figure 59 also shows the average weight gain for each group per week. As Buffel grass requires less water and fertilizer on the farm, economically and environmentally it appears to be a better food source compared to the Rhodes grass (see Figure 60). A detailed economic cost befit analysis was conducted to finalize the report.

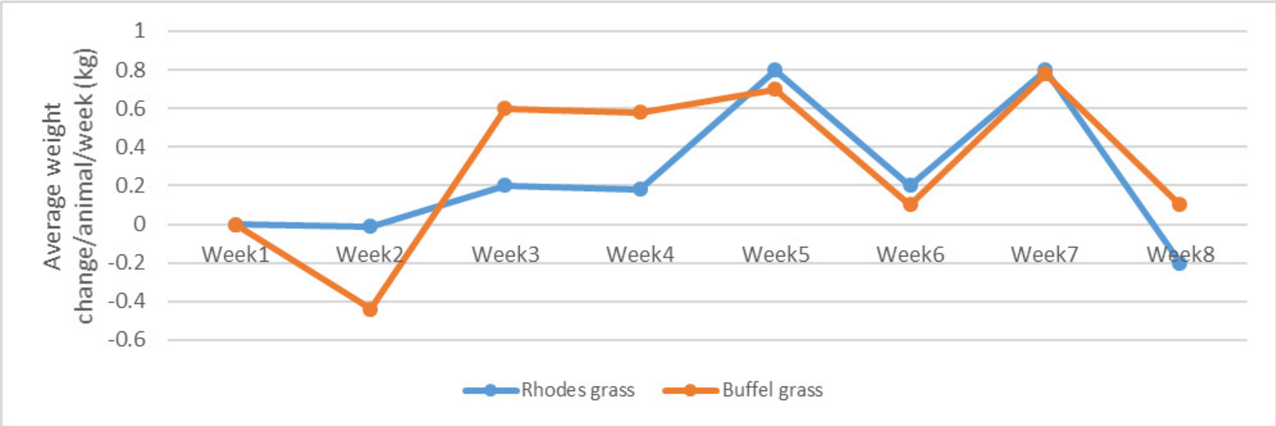


Figure 59. Average weight change/animal/week for two group of goats, one group being fed with Buffel grass and the other with Rhodes grass in the UAE

Figure 60. Comparative study on feeding goats with Rhodes grass and Buffel grass in Fujairah, UAE

B.10. Developing a feed calendar

To understand the best time for using feed blocks to overcome a feed shortage, a study of the feed calendar was necessary. This calendar lists the sources and type of feed used during the months of the year. This kind of information can also be incorporated into general seasonal production calendars. Creating a feed calendar makes it easier to identify the relationship between feeding and the other aspects of production.

In Yemen, a study on feed calendars was conducted where 100 farm animal breeders from four districts of the Lahej and Abyan Governorates were surveyed. The study revealed that there is a deficit in the availability of feed required for farm animals during the winter season. This shortage may extend to some summer seasons when rainfall is low or absent. Furthermore, the study shows that not all farm breeders used concentrated or supplementary feeds during the dry seasons. Feed prices are related to the amounts of precipitation, the flow of floods in valleys, and the amount of feed available for grazing or in the market. Table 11 presents the type and quantity of feed provided per day per animal in the study of a sample of farms in Yemen.

Table 11. Type and quantity of feed provided per day per animal in Yemen

Feed	Winter (October-March) (g/day)			Summer (April-September) (g/day)		
	Camel	Cattle	Small ruminants	Camel	Cattle	Small ruminants
Natural rangeland	500	200	100	2,000	500	300
Maze (green)	2,000	4,000	200	2,000	2,000	200
Maze (dry)	1,000	1,500	100	1,000	1,500	100
Maze (harvested)	2,000	300	50	500	300	50
Syrian maize (green)	2000	1000	100			
Syrian maize (dry)	500	500	50			
Syrian maize (harvested)		200	50			
Sorghum (dry)				3,000	300	50
Sorghum (harvested)				500	200	50
Other crop by-products	500	200	50	500	200	50
Legume crops	300	300	30	300	300	30
Wheat by-products	500	400	100	500	300	100
Buffel grass (green)	300	300	50	500	500	200
Buffel grass (dry)	200	200	50	200	200	50
Acacia leaves	1,000		20	2,000		20
Concentrates	2,000	400	200	1,000	400	200
Animals' average weight				300 kg	15 kg	15 kg

C. Training and capacity building

The human resource development program included the general training of members at ICARDA HQ and specialized training programs developed for different regions or countries. The APRP specialized training program included:

- Regional training courses based on the participating country's needs
- Field days and on-the-job training courses
- Workshops, seminars, and conferences.

Between 2014, and March 2019, APRP conducted 10 specialized training courses, 15 workshops, and 80 field days during which more than 1000 researchers, extension agents, and farmers from seven countries participated.

C.1. In-country short-term training courses organized by ICARDA-APRP

C.1.1. Greenhouse, high-value vegetable crops post-harvest, 27-29 April 2014, UAE

A specialized training workshop entitled 'Greenhouse high-value vegetable crops post-harvest' was organized in Dubai, UAE, and held 27-29 April 2014, in collaboration with the Ministry of Environment and Water, UAE and the World Vegetable Center. The training workshop aimed to enhance the knowledge and capacity of NARES staff on:

- The principles of good post-harvest handling
- Crop maturity and harvesting
- Packing-house operations
- Cooling and storage
- Packaging and transportation
- Pathology and disorders.

The course was conducted in collaboration with the Ministry of Environment and Water, UAE and was attended by about 35 scientists, researchers, and growers from all the Arabian Peninsula countries. The course included practical sessions as well as a field visit to the Mirak company packing house.

C.1.2. Modern techniques for seed production and multiplication of native species, 27-29 October 2014

A training workshop on modern techniques of seed production and multiplication of native species was conducted in Kuwait 27-29 October 2014.

The workshop was organized as a joint effort between the Public Authority for Agricultural Affairs and Fish Resources and ICARDA. The event, which was attended by 10 researchers from the UAE, Kuwait, Qatar, and KSA, covered the following topics during the one-day lecture and two days of practical sessions and field visits:

- Native seed collection, handling, extraction, processing, and storage
- Fundamentals of native seed germination
- Health, safety, and environment for seed collection and propagation
- Database management for seed collection and storage
- Greenhouse and shade house management and mass propagation of native species
- Seed processing techniques
- Seed quality testing (purity, moisture, and germination testing)
- Growth assessment of field grown of native plants.

C.1.3. Vegetable quarantine: pest and diseases, 10-12 November 2014

Based on the recommendations of the Ministry of Environment and Water, UAE, ICARDA organized a specialized training workshop on the main pests and diseases of vegetable crops that should be considered for quarantine issues. The course was presented by two invited speakers, Professor Dr. Bouzaid Nasraoui, Plant Mycology, National Agronomic Institute of Tunisia, University of Carthage; and Dr. Ghazi Krida.

C.1.4. Soilless production system for high value crops 8-9 December 2014

A two-day training course was conducted by Dr. Ahmed Moustafa, ICARDA-APRP Protected Agriculture specialist 8-9 December 2014. The course compromised a day of lectures on soilless production techniques and their importance for food security. It was followed by practical sessions on the second day. About 10 research and extension agents from the Ministry of Environment and Water, UAE attended this event.

C.1.5. Integrated crop-livestock rangeland system, Oman, 5-7 October 2015

The ICARDA-APRP, in collaboration with the MAF, organized a training workshop on ‘Integrated crop-rangelands-livestock production systems’ in Oman 5-7 October 2015, when 15 participants from the Arabian Peninsula countries participated. Exploiting well-integrated crop and livestock systems with a close connection to rangeland inputs is one of the powerful entry points to enhance and utilize the capacity of both animal and crop production systems. The integration of crop and livestock production systems increases the diversity and environmental sustainability, of both sectors. At the same time, it provides opportunities for increasing overall production and the economics of farming. This would reduce the preference for specialized livestock production systems, in view of their problems with environmental and economic sustainability.

One of the main focuses of the ICARDA-APRP in the region is to increase the resilience of production systems and livestock under absolute water scarcity and climate change conditions by enhancing rangelands, forage, crop by-products, and livestock integration. This training workshop comprised theoretical and practical sessions on crop-livestock integration concepts with a focus on ICARDA-APRP-targeted technologies, including rangelands, indigenous irrigated forages, spineless cactus, and feed blocks.

C.1.6. Soilless culture and greenhouse management, Qatar, 15-19 November 2015

ICARDA, in collaboration with the Ministry of Environment and Al Sulaiteen Agricultural and Industrial Complex, Qatar, organized a specialized training course on ‘Integrated management of protected agriculture and soilless culture’ in Qatar 15-19 November 2015. A total of 27 participants from seven Arabian Peninsula countries participated in this course.

In dry areas, especially the Arabian Peninsula, agriculture and food production are a challenge given the harsh climatic conditions, scarcity of water, and poor soils. Protected agriculture has shown great potential for producing highly nutritious fruit and vegetable crops that are essential for a healthy and balanced diet. Protected agriculture, with its associated modern techniques, which include soilless cultivation, could increase water productivity substantially with no or minimal quantities of agro-chemicals. Using such techniques would provide considerable savings one water and land.

High quality products require high quality management throughout all production steps. Modern management techniques, such as IPPM and the soilless (hydroponics) production system, would significantly improve water and land productivity of high quality crops under protected agriculture.

C.1.7. Economic assessment, adoption of agricultural technologies, and value chain analysis of agricultural commodities 24-28 April 2016

The ICARDA-APRP, in collaboration with the MAF, Under the patronage of His Excellency, Dr. Ahmed Al Bakri, the Under Secretary of MAF, organized a training workshop on 'Economic assessment, adoption of agricultural technologies, and value chain analysis of agricultural commodities' in Oman 24-28 April 2016.

Optimizing the use of limited resources for technology transfer in agricultural development is one of the biggest challenges facing any decision maker, including end-users and growers. Therefore, economic assessment is a vital tool. It can enumerate the potential costs and value the anticipated benefits of a proposed program targeting group livelihoods. Furthermore, a significant proportion of resources is used to meet the demand for agricultural products through technology improvements. However, little attention has been given to the value chains through which agricultural products reach end-users. The magnitude of opportunity losses caused by this neglect becomes evident if one considers the enormous added value and employment gains that can be generated along agro-value chains from commodity to consumption.

The training workshop aimed to enhance knowledge and capacity of NARES staff on:

- Introduction to cost-benefit analysis
- Partial budget analysis
- Adoption process and factors affecting adoption of agricultural technologies
- Agricultural value chains and supply chain management
- Value chain analysis tools and value chain analysis mapping
- Value chain innovation and upgrading.

The course, presented by Dr. Boubaker Dhehibi, Agricultural Resource Economist, and Dr. Shinan Kassam, Social Scientist; was attended by 23 participants from the seven Arabian Peninsula countries.

C.1.8. Rangeland management and techniques of determining carrying capacity, 8-10 May 2017

The training of researchers and technicians from Kuwait, KSA, and Yemen on the determination of the carrying capacity of the improved rangeland sites was conducted 8-10 May 2017. The training was designed to determine the grazing capacity of the six improved sites to be open for grazing by camel. There were by 13 participants.

C.1.9. Good agricultural practices training course. 30 April-May 2018, Oman.

ICARDA, in collaboration with the MAF, Oman, organized a training workshop on 'GAP for protected agriculture' 30 April-3 May 2018, Oman. H.E. Dr. Ahmed Al Bakri, Under Secretary of MAF, inaugurated the training workshop. Twenty-three researchers and extension agents from seven Arabian Peninsula countries attended. The GAP are a collection of principles to apply to on-farm production and post-production processes that result in safe and healthy food and non-food agricultural products. They take into account economic, social, and environmental sustainability. The GAP protocols were developed in response to the increase in the number of outbreaks of food-borne diseases resulting from contaminated fresh produce, including fruits and vegetables. The GAP provide simple steps that fruit and vegetable growers can implement to greatly reduce the potential for contamination on the farm

C.1.10. Training workshop on use of renewable energy in the management and cooling of a hydroponics nutrient solution, 17-20March 2019

The ICARDA-APRP, in collaboration with MAF, organized a training workshop on the use of renewable energy in the management and cooling of a hydroponics nutrient solution, in Oman 17-20 March 2019. More than 25 participants from seven Arabian Peninsula countries attended this workshop, where they received hands-on training in the new technique for cooling the nutrient solution. Participants also received suitable information on economic calculations and the feasibility of using solar energy for running cooled greenhouses.

The course was based on recent ICARDA-APRP findings from a PhD study supported by the program in Oman. The ideal temperature for nutrient solutions in hydroponics is between 18° and 29° C. If it gets too hot, it loses oxygen and chokes the plants. With that in mind, monitoring the temperature of the nutrient solution throughout the year to determine a baseline value of the solution's normal temperature level is very important. The project supported a PhD study in Oman to develop a locally developed system for controlling and cooling the nutrient solution.

C.2. Seminars, conferences, and workshops

C.2.1. Animal feed resources and their management in the Near East and North Africa region

The regional workshop on 'Animal feed resources and their management in the Near East and North Africa' was held in Muscat, Oman 24-26 March 2014. This event was organized by the MAF in collaboration with the FAO and ICARDA. Altogether, 29 participants from different Near East and North Africa countries and regional and international organizations attended this workshop. During the 3-day workshop, eight scientific papers were presented by international scientists from different regional and international organizations including FAO and ICARDA. These were followed by seven country reports presented by the representatives of the national Ministries of Agriculture.

C.2.2.Joint meeting with MAF Oman, the United States Department of Agriculture Agricultural Research Service (USDA-ARS), and ICARDA

Dr. Azaiez Ouled Belgacem and Dr. Naem Mazahrih attended this meeting on behalf of ICARDA. Dr. Mazahrih presented a brief summary of ICARDA's mission in the dry areas and in the Arabian Peninsula region. A concept note on a new cooperative research project entitled 'Irrigation management information system for efficient water use in Oman' had been prepared by ICARDA, in collaboration with the USDA-ARS, and the NARS in Oman, and was presented at the meeting. This proposal was submitted to the MAF for a funding request by the Agriculture and Fish Development Fund.

C.2.3. Enhance collaboration with Abu Dhabi Food Control Authority

An ICARDA delegation visited ADFCA 7-8 September 2014. The objectives of the visit were to enhance joint research for development activities by the two organizations in areas of mutual interest and activation of a recently signed Memorandum of Understanding between ADFCA and ICARDA. ICARDA's delegation comprised nine scientists, including two program directors, and the ICARDA-APRP regional coordinator. The ICARDA mission during this trip was to become acquainted with current research activities, so they visited the two ADFCA research stations. They also met with His Excellency Rashid Al Shariqi, Director General, ADFCA and Dr. Mohamed Salman Al Hammadi, Director of R&D Division, ADFCA. The visit was concluded by round table discussions between ICARDA scientists and ADFCA research and extension agents in three working groups: 1) Crop production and biotechnology and extension systems; 2) Plant protection; and 3) Livestock and feed resources. The main objective assigned to the work of these groups was to identify potential areas of collaboration between ADFCA and ICARDA

C.2.4. First Regional Technical Coordination Meeting (TCM) and Steering Committee Meeting (SCM), Dubai, 4-7 January 2015.

The ICARDA-APRP organized its First Regional TCM and SCM in Dubai, UAE 4-7 January 2015, when about 40 scientists, researchers, and extension agents from seven Arabian Peninsula countries and ICARDA participated.

The opening session was inaugurated by His Excellency Saif Al Shara, Under Secretary, Ministry of Environment and Water, UAE and Dr. Kamil Shideed, ICARDA Assistant Director General for International Cooperation and Communications (ADG-ICC). It was attended by scientists and researchers from different organizations including, FAO, ADFCA, International Center for Biosaline Agriculture, and UAE University.

H.E. Saif Al Shara, on his own behalf and on behalf of H.E. Dr. Rashid Bin Fahad, the Minister of Environment and Water, welcomed all participants and expressed his best wishes for a successful meeting. On behalf of the Ministry he acknowledged the role of ICARDA, through its regional program APRP, in enhancing agricultural production and food security by introducing and developing adapted technology packages that permit the saving of huge amounts of scarce water.

The ICARDA ADG-ICC, Dr. Kamel Shideed, acknowledged and expressed appreciation for the hospitality of the UAE and the Ministry of Environment and Water, specifically H.E. Dr. Fahd Bin Rashid, the Minister, for hosting and supporting the ICARDA office and meetings. He also welcomed all participants and the heads of the delegations of the seven participating countries. In addition, Dr. Shideed thanked the donors of the project, AFESD and IFAD for their continuous support.

Dr Shideed mentioned that the ICARDA-APRP is an effective and serious contributor to the development of integrated and sustainable production systems under the conditions of the Arabian Peninsula. These are characterized by limited natural resources, especially water and agricultural land. He summarized the objectives of the annual meeting as:

- Discussing and developing the 2015 work plan for the project 'Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula'.
- Discussing the achievements of the project during 2014.
- Presenting and discussing the activities, achievements, and success stories of ICARDA's other projects and works in other dry areas which are applicable to the Arabian Peninsula.
- Implementing the project SCM to review the results achieved and to approve the work plan and budget for the year 2015.

At the end of his speech Dr. Shideed, again thanked the Ministry of Environment and Water for hosting the meeting and congratulated the ADFCA on becoming a member of CGIAR.

C.2.5. Second TCM and SCM, Bahrain, 6-9 December 2015

ICARDA-APRP organized its Second Annual TCM and SCM for the project.

The meetings were held in Manama, Bahrain where the TCM was scheduled 6-8 December 2015 and the SCM was convened 9 December 2015. Meetings were jointly organized by ICARDA-APRP and the Ministry of Municipal Affairs and Urban Planning (MMAUP), Bahrain.

The meeting's opening session was attended by 50 participants from different national and international institutes and was inaugurated by His Excellency Salman Abdul Nabi, Under-Sectary for Agricultural Affaires, MMAUP. In his opening speech. H.E. the Under Secretary welcomed all participants to Bahrain and expressed MMAUP's gratitude for the joint venture with ICARDA. "Adoption of soilless production systems", said H.E. Abdul Nabi, "increased crop production up to five times at pilot sites."

This was followed by Dr. Kamel Shideed, ICARDA ADG-ICC whose presentation was titled, 'Challenges of the 21st Century and the Importance of Investment in Agricultural Research for Development: Implications for the Arabian Peninsula Region'. Dr. Shideed explained ICARDA's activities and achievements in its close partnership with the NARS, with a focus on the Arabian Peninsula region, to tackle the challenges facing Agricultural Research-for-Development. The new Strategy and Result Framework of CGIAR was also explained by Dr. Shideed as being focused on: 1) Reducing poverty; 2) Improving food and nutrition security for health; and 3) Improving natural resource systems and ecosystem services.

The meetings were followed by field visit, with participants visiting pilot project farms and activities in Bahrain.


C.2.6. Seminars on rainwater harvesting techniques in arid region 16 May 2016, KSA

A workshop, 'Rainwater harvesting techniques in arid regions', was presented by Dr. Naem Mazahreh during his visit to KSA on 16 May 2016. More than 25 researchers from the National Center and other government departments, such as the environment and water sectors, attended the seminar.


The workshops highlighted the following topics:

- The concept of water harvesting and its main components
- Types of water harvesting under arid conditions, places, and conditions of use
- Water-harvesting system design at the farm level, methods of calculation of the design rainfall and the ratio of the catchment area to the cultivated area
- Display of ICARDA's experiences in water harvesting in the arid regions focusing on using the Vallerani-type micro-catchments on a large scale
- Discussion of the water-harvesting experiment at Bsita Research Station and the demonstration sites in farmers' fields at Doumet Al Jandal, Al Jouf region, KSA, which are conducted jointly by APRP scientists and the National Agriculture and Animal Resources Research Center staff.

After the lecture the audience raised many questions on this subject that were answered by an ICARDA scientist. Attendees expressed their keen interest in the application of water-harvesting technologies in KSA in collaboration with ICARDA.

C.2.7. Workshop on 'Proven innovative technologies to enhance valorization of agricultural by-products for animal feeding in the United Arab Emirates'

The on-the-job training workshop was designed to demonstrate creative pathways and models for the sustainable use of agricultural by-products and crop waste in animal feeding. Two main formulas were tested for the manufacture of feed blocks. The choice of recipe takes into consideration the availability of the raw materials in the UAE. The formulas also were based on use of the agricultural residues available, particularly palm leaves, roughage, grasses, and waste dates. The formulas are:

Formula 1 (for a quantity of 10 kg of bulk material)

- 50% Chopped palm leaves and grasses (5 kg)
- 5% Urea (500 g)
- 5% Salt (500 g)
- 2% Mineral and vitamins supplement (200 g)
- 20% Barley (2000 g)
- 8% Chopped cactus pads (800 g)
- 10% Lime (1000 g)

Formula 2 (for a quantity of 10 kg of bulk material)

- 48% Chopped roughage material (4.8 kg)
- 20% Waste dates (2 kg)
- 15% Dried sardines (1.5 kg)
- 10% Lime (1 kg)
- 5% Salt (0.5 kg)
- 2% Mineral and vitamin supplement (0.2 kg)

The theoretical part of the training comprised three presentations each with a different focus:

- ***Presentation 1.*** The importance of the feeding gap in dry land areas and potential ways to reduce the feeding gap including the technology of feed blocks
- ***Presentation 2.*** Principles of feed block manufacture and the response of small ruminants when feed blocks are incorporated in their diets (digestibility, growth, milk production, reproduction, ETo.)
- ***Presentation 3.*** Integration of date palm by-products in livestock feeding using mechanical chopping, ensiling, and incorporation into feed blocks as the primary methods for blending these by-products.

At the end of the training session, there was an agreement to carry out on-farm experiments testing different formulas of feed blocks on the performance of sheep and goats. The diets including feed blocks were to be tested against conventional diets during critical physiological stages of the flocks – mating period, end of pregnancy, and lactation period. About 15 participants attended this training program.

C.2.8. On-the-job training on the sustainable management of rangelands and the determination of carrying capacity. 29 February 2016, Al Jouf

Training of researchers and technicians of the Camel and Range Research Center on determining the carrying capacity of the improved rangeland sites was conducted 29 February 2016. The training was designed to help participants determine the grazing potential of the six improved sites to be opened for grazing by camels.

Eight researchers and engineers from the Research Center participated in this training. The techniques for determining the following parameters were presented:

Field data collection:

- Plant cover, point sampling method, three 100 m length lines in each sampling unit
- Species composition and the point sampling method
- Density of perennials in several 25 m^2 quadrants and density of annuals in several 1 m^2 quadrants
- Edible biomass estimation using the semi-destructive method, and dry matter estimation.

Data analysis:

- Establishing Excel templates
- Calculations (conversion and standardization of units)
- Animal's requirements (1 AU needs 12 kg dry matter/day)
- Evaluation of the rangeland vegetation's contribution to the animals' diet.

C.2.9. Workshop on 'Requirements for building a national program for the conservation and sustainable use of plant biodiversity'

ICARDA Deputy Director of the Biodiversity and Crop Improvement Program, Dr. Ahmed Amri, visited KSA 16-23 May 2017. In addition to the workshop 'Requirements for building a national program for the conservation and sustainable use of plant biodiversity' he expressed his thanks for:

- Being shown the working mechanism in the Gene Bank and being provided with views appropriate to the development of the work
- The training of staff in the management of genetic resources
- Being briefed on the draft initiative of the conservation of plant resources, their sustainable use and benefit-sharing, and receiving good feedback to the interests of the initiative.

C.2.10. ICARDA-APRP annual regional meetings 28 November-1 December 2016

The Third Annual regional TCM and SCM of the project 'Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula' were held in Kuwait 28 November-1 December 2016. More than 30 scientists and researchers from ICARDA and Jordan, and growers from seven Arabian Peninsula countries came together to exchange information and ideas on the sustainable development of the Arabian Peninsula. The participants made 20 presentations, in which they discussed and reviewed the project's research-for-development activities and experiences on rangeland rehabilitation, irrigated forages, water use efficiency, and protected agriculture

C.2.11. ICARDA-APRP annual regional meetings, 20-22 November 2017, Amman, Jordan.

The Fourth Regional Annual TCM and SCM of the project 'Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula' were held in Amman 20-22 November 2017.

Dr. Kamel Shideed, ICARDA ADG-ICC, opened the meeting and welcomed all participants. He presented ICARDA's New Strategy, 2017-2026 which focused on science-based solutions for thriving and resilient livelihoods in the dry areas. Dr. Azaiez Ouled Belgacem presented the highlights of the project's activities and achievements during 2017.

More than 30 scientists and researchers, from ICARDA and Jordan, and growers from seven Arabian Peninsula countries came together to exchange information and ideas on the sustainable development of the Arabian Peninsula. The participants also made 20 presentations in which they discussed and reviewed the project's research-for-development activities and experiences on rangeland rehabilitation, irrigated forages, water use efficiency, and protected agriculture. They developed a work plan for 2018 and reviewed the program's new proposals for 2018-2022.

In the SCM participants discussed the overall project progress, financial status, and research activities. The SCM members recommended actions for the next season and approved detailed work plans for the assigned activities for each country participating in the project. The SCM members discussed and approved the new project proposals. They requested ICARDA to approach donors for its funding.

C.2.12. Protected agriculture workshop in Bahrain

A national training workshop on the protected agriculture GAP was organized 4-7 February in Bahrain in collaboration with the Agriculture Incubation Center and the Bahrain International Garden-Show. About 24 farmers and extension agents attended this event.

C.2.13. On-the-job training course and field days on irrigated forage and cactus

Two field days on irrigated forages and cactus were conducted at Dibba, Al Fujairah, UAE. About 25 participants attended these two field days. Different indigene plant species that have potential to be used as irrigated forages were introduced to the participants.

C.2.14. On-the-job training courses on feed block technology UAE and Qatar

ICARDA organized two field days at the Agricultural Innovation Center at Al Dhaid, UAE, 21 November 2018 and before that in Qatar 18 November 2018 for agricultural engineers and extension workers to educate them about fodder blocks. The field days were organized in collaboration with the NARS in the UAE and Qatar. A total of 30 participants attended these two field days; 15 attendees at each session learned about the composition and manufacturing of fodder blocks. In addition to recycling agricultural by-products, such as palm fronds, weeds, dry weeds, and stalks and roots of quinoa and cacti, fodder blocks provide good quality feed comprising essential proteins and minerals for livestock at an affordable price, thereby reducing the dependence on irrigated fodder.

C.2.15. ICARDA-APRP annual regional meetings 10-12 December 2018

The Fifth Regional Annual TCM and SCM of the project 'Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula' were held in Oman 10-12 December 2018. More than 40 scientists, researchers, and extension agents from ICARDA and seven Arabian Peninsula countries came together to exchange information and ideas on the sustainable development of the Arabian Peninsula. The participants made 25 presentations in which they discussed and reviewed the project's research-for-development activities and experiences on rangeland rehabilitation, irrigated forages, water use efficiency, and protected agriculture.

Implementation arrangements

ICARDA was responsible for the overall coordination and the technical and financial management of the project, including technical and financial reporting through its APRP office in Dubai.

ICARDA's Regional Coordinator in Dubai was responsible for all logistical and administrative support and for liaising with the national programs. ICARDA experts in the UAE office ensured the follow-up of the project implementation. The activities under their respective disciplines included rangeland and irrigated forages, protection of agriculture, and on-farm water management. ICARDA scientists were in direct contact with the project implementation teams and researchers in all seven Arabian Peninsula countries.

Each country had a designated National Coordinator, as well as a Technical Coordinator and a project implementation team, who followed the day-to-day activities of the project in each country. The project's progress was monitored by a Regional Steering Committee (RSC), which met once a year to review the project's progress and approve new annual work plans and budgets. The RSC consisted of donors and ICARDA representatives, the ICARDA ADG-ICC, the Regional Coordinator, scientists, and National representatives (National Coordinators) of the participating NARS.

Once a year the project held a Regional Technical and Coordination Meeting (RTCM) in one of the participating countries at which scientists (including those from ICARDA), extension agents, and farmers analysed the results of the previous year and finalized the work plan for the next. During the implementation period, the project organized six Regional Steering Committee Meetings (RSCM) and six RTCM.

The project carried out an external evaluation 2014-2017. An ICARDA-commissioned mission was fielded from 12 August 2017 to 5 September 2017, to carry out an external completion review mission of the ICARDA implemented 2014-2017 APRP. Its final report is entitled 'Improving food security and sustainable natural resources management through enhancing integrated agriculture production systems in the Arabian Peninsula'. The executive summary of the mission report is attached.

Innovation

The project conducted the following problem-solving research activities which are considered innovative in the region:

- Safe use and improved efficiency of TWW for irrigated forages,
- Participatory rehabilitation of degraded rangelands through reseeding seedlings in rainwater harvesting micro-catchments,
- The introduction of new techniques for monitoring and assessment the dynamics of rangelands vegetative cover,
- Development of water-saving greenhouse cooling systems combining the use of renewable energy,
- Introduction of feed lock technology in the region, especially to the resource-poor farmers in Yemen with a high level of rural women participation.

Also, the institutional partnership with the American University of Ras Al- Khaimah is an innovative first-time arrangement in UAE for pooling resources to undertake valuable research work on water use efficiency.

The Program component on the introduction and adoption of technology in a large number of pilot farm sites is designed as an up-scaling initiative during the five years implementation and beyond. Based on the excellent level of productivity and associated income increases per unit of water and land achieved at pilot farm sits, the up-scaling of open field irrigated Buffelgrass production technologies and high-value vegetables hydroponic production systems is likely to continue in all countries.

Knowledge management

During the reporting period, the ICARDA-APRP published:

- 14 peer-reviewed journal articles and a book chapter
- 12 technical reports and advisory notes
- 10 posters and roll-ups
- 4 Annual Reports
- More than 60 reports by the NARS to the RTCM.

A. The scientific publications are below listed:

1. Mazahrih N. Th., Al Sayari A. S., Al-Hamoodi A., Nejatian A. & Ouled Belgacem A. 2018. Impacts of irrigation with reclaimed wastewater on forages production, nutrients, and heavy metals content. Journal of Agricultural Science; 10(2): 206 - 216.
2. Atroosh K.B, Al-Khader Ahmed G., Lardi O.S., Eissa A.A., Ouled Belgacem A. 2018. Yield and Irrigation Water Productivity of

Three Varieties of Buffel Grass (Cenchrus ciliaris L.) in the Southern Coastal Plains of Yemen. Journal of Agricultural Science; 10(1): 114-121.

3. Ouled Belgacem A., Nejatian A., Ben Salah M., Moustafa A. (2017). Water and food security in the Arabian Peninsula: struggling for more actions. *Journal of Experimental Biology and Agricultural Sciences*, 5: 50-62.

4. Al Wawi, H.M.; Al Yafei, M.S; Al Marri M.; Ouled Belgacem, A. (2017). Evaluation of some morphological and chemical characteristics of 38 accessions of spineless cactus under Qatar environmental conditions. *Acta Horticulturae* (In press).

5. Awawdeh, F., Nejatian, A. (2016). Water resources and agriculture in Arab countries. Pages 245-266 *in* The Arab World and Latin America; Economic and Political Relations in the 21 Century. I.B. Tauris, London.

6. Awawdeh, F., Ouled Belgacem, A., Nejatian, A., Mazahrih, N., Moussa, M., Al Bakri, A., Atroosh, K. (2014). Improving the livelihood of small farmers in the Arabian Peninsula through increasing land and water productivity: a transition towards green economy. 2014 Green Economy in the Gulf Region workshop 25-28 August 2014, University of Cambridge, UK.

7. Dhehibi, B.; Nejatian, A., Al-Wahaibi, H., Atroosh, K., Al Yafei, M., Al Otaibi, A., Al Hendi, M., Ouled Belgacem, A. (2017). Adoption and factors affecting farmer's adoption of technologies in farming system: a case study of improved technologies in ICARDA's Arabian Peninsula Regional Program. *Journal of Sustainable Development* 10(6): 1-13.

8. Louhaichi M., Ouled Belgacem, A. (2014). Understanding the vulnerability of rangeland ecosystems to global climate change in the dryland areas of MENA region. Proceeding of 3rd Scientific Conference of the United Nations Conference to Combat Desertification (UNCCD), 9-12 March 2015, Cancun, Mexico.

9. Mazahrih, N., Al-Wahaibi, H., Al Farsi, S., Ouled Belgacem, A. (2016). Yield and water productivity of Buffel and Rhodes grasses under different irrigation water regimes using the sprinkler line-source system. *Grassland Science* 62(2): 112-118.

10. Nejatian A., Naqbi, S.A.M.T., Ibrahim, H.Y.H., Ono, E. (2017). An agro-economic comparison between dwarf and long green beans production with soilless production system under greenhouse conditions in UAE. *International Journal of Agriculture Innovations and Research* 6(1): 176-182.

11. Mazahreh, N., Nejatian, A., Mousa, M. (2015). Effect of different growing medias on cucumber production and water productivity in soilless culture under UAE conditions. *Merit Research Journal of Agricultural Science and Soil Sciences* 3(9): 131-138. Available online at http://meritresearchjournals.org/asss/index.htm

12. Nejatian, A., Ganan, A., Ouled Belgacem, A. (2016). Factors affecting the adoption of soilless production system in UAE. *International Journal of Agriculture Extension*, 4(2): 119-131.

13. Nejatian, A.; Ouled Belgacem, A. (2014). Technical, environmental and economic review of ICARDA-targeted technology packages for adoption in the present Arabian Peninsula farming systems: the case of UAE. Proceeding of 3rd Scientific Conference of the United Nations Conference to Combat Desertification (UNCCD), 9-12 March 2015, Cancun, Mexico.

14. Ouled Belgacem, A., Nejatian A., Al Farsi, S., Al Wawi, H.M., Al-Sharari, M., Al-Hamoodi, A., Louhaichi, M. (2017). Spineless cactus in the Arabian Peninsula: adaptive behaviors and production performances. *Acta Horticulturae* (In press).

B. technical reports and advisory notes

1. ICARDA-APRP. (2015), Improving food security and sustainable natural resources management through enhancing integrated agricultural production systems in the Arabian Peninsula. ICARDA-APRP Annual Report 2014. ICARDA, Dubai, UAE.

2. Mazahrieh, N., Nejatian, A., Gartley, M., George, B., Ouled Belgacem. A. (2015). Use of Reclaimed Wastewater in Agriculture, A Literature review. ICARDA, Dubai, UAE.

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Scaling-up and sustainability

In an attempt to scale-up the adoption rates of the targeted technologies, the project promoted a farmer-to-farmer extension system by developing pilot demonstration sites at private farms. Several participatory technology development approaches, such as introductory workshops and farmers' field schools, were implemented to select and introduce the innovative technologies to the pilot farmers in all seven Arabian Peninsula countries. As a result, the adoption rate of the project objectives was higher than anticipated. For example, in the UAE the number of greenhouses equipped with soilless production techniques increased from five units in 2009 to 75 greenhouses in 2009, there was a further increase to 600 units by the end of 2013. By 2018, based on ministry figures, this number surpassed 1100 greenhouses. Similarly, in Oman, the number of hydroponics greenhouses was more than 420 by the end of 2018. The number of pilot farmers who adopted Buffel grass as an irrigated forage also increased significantly in December 2013; in total there were 130 of pilot farmers in all the Arabian Peninsula countries.

The project directly benefited about 1600 rural households. Moreover, it is estimated that about 5500 rural households also profited indirectly through the project's impact.

The success of the pilot farmers encouraged the NARES to further support the sector through focused subsidies and the development of new policies. For example, in Bahrain, Oman, and the UAE, the NARS are financially supporting growers who adopt the hydroponics system. Similarly, in Oman and Abu Dhabi those growing Buffel grass instead of Rhodes grass are supported by the government.

As mentioned earlier, the technologies targeted by the project are receiving good support from the policy makers in participating countries, which positively enhances the sustainability of the project outputs and achievements. Following are some examples of the NARS' support:

- The Oman Government supports farmers who adopt a soilless production system by providing infrastructure, credit, technical advice, and financial assistance
- The UAE's Ministry of Water and Environment covers 50% of the cost of the greenhouse structure and soilless production system
- Bahrain's government allocated a large grant to support growers who adopted greenhouse and soilless production systems
- Abu Dhabi Farmers' Services Center has determined that Buffel grass is a more sensible alternative to Rhodes grass, and the organization has begun educating farmers about proper cultivation methods
- Oman's MAF supports growers to replace Rhodes grass with Buffel grass by providing technical backstopping and some financial incentives.

Nevertheless, although the technology packages successfully increased production efficiency and improved the pilot farmers' livelihoods, more efforts are needed to improve their sustainability. A study, conducted by the Ministry of Environment and Water, UAE and ICARDA in 2012, shows that about 30% of growers who had adopted hydroponics, rejected it and reverted to soil-based conventional production systems after the first or second year. Based on feedback from the farmers, it appears that the main factor affecting the expansion of hydroponics production systems in the UAE is a lack of know-how and sufficient information among farmers because of an absence of active technical backstopping and extension systems. A similar situation exists for the adoption of indigenous irrigated forage and spineless cactus.

Furthermore, in addition to the challenges related to high aridity and severe water scarcity, the region is affected by some international challenges, such as the effects of climate change and food security, which are reflected in NARES' policies as new priorities and research objectives. These new priorities are focusing on using TWW, integrated animal production systems, exploiting renewable energy sources in agricultural production, and alternative animal feed resources. Therefore, to increase the sustainability of APRP achievements there is a need to:

- Continue the capacity building program for the NARES and increase the number of growers using the technologies targeted by the project
- Improve the existing technology packages so they are better adapted to the regional environment and local farming systems
- Transfer the technology to a larger number of pilot growers
- Enhance the economic feasibility of the technology packages by using locally-available production materials and resources.

Monitoring and evaluation

The ICARDA-APRP was responsible for the implementation and monitoring of the on-going activities and reporting to donors and the SCM. Monitoring was based on approved and documented progress indicators and SCM recommendations. Annual reports covered the program activities and achievements during the reporting periods as well as the NARS' and NAES' activities in each Arabian Peninsula country. A socio-economic study was implemented in all Arabian Peninsula countries to monitor and study the effects of the targeted technologies on the target groups. The executive summary of the report follows in A.

The project carried out an external evaluation for 2014-2017. An ICARDA-commissioned mission was fielded 12 August-5 September 2017, to carry out an external completion review mission of the ICARDA-APRP as implemented during the period 2014-2017. The executive summary of the mission report follows in B.

A. Adoption and Economic Assessment of Improved Technologies in ICARDA's Arabian Peninsula Regional Program

The objective of this report is threefold. First, to investigate costs and benefits associated with ICARDA-APRP technologies adopted by Arabian Peninsula farmers and identify the most effective and economic indicators based on general information and the responses of the Arabian Peninsula countries' farmers and the cost-benefit analysis framework. The second objective is based on the fact that there is much existing knowledge about the factors that influence adoption of new technologies and practices in agriculture, but few attempts have been made to construct predictive quantitative models of adoption for use by those planning agricultural research, development, extension services, and policy makers. Within this framework, is a sub-objective purpose to estimate the expected rates of adoption of these innovations and identify the main constraints that limit the adoption process in the Arabian Peninsula region by using ADOPT (Adoption and Diffusion Outcome Prediction Tool). The application of ADOPT is the result of such an attempt, providing predictions of the likely rate and peak level of adoption of the improved practices, as well as estimating the importance of various factors influencing adoption. It employs a conceptual framework that incorporates a range of variables, including ones related to economics, risk, environmental outcomes, farmer networks, characteristics of the farm and the farmer, and the ease and convenience of the new practices. A focus group discussion (FGD) methodology was used to apply ADOPT with a panel of farmers in each country and for each technology introduced. In the FGDs we streamlined 22 discussion questions around four categories of influences on adoption – the characteristics of the innovation, the characteristics of the target population, the relative advantage of using the innovation, and learning of the relative benefit of the change. The third objective was to assess the Arabian Peninsula researchers' and extension agents' perceptions of the technology-specific characteristics significantly conditioning technology adoption decisions. The omission of the researchers' and extensionists' evaluations of the technology-specific attributes may bias the results of factors conditioning adoption choices. A Likert-type scale was used, having a sample of seven research and extension centers in the Arabian Peninsula region.

Empirical findings indicate clear evidence of the economic profitability of the evaluated technologies (native forages, IPPM, ETo.). The results of the cost-benefit analysis for the technologies implemented in Yemen's case revealed a clear profitability of the improved forage *Clitoria* (perennial legume forage) in comparison to sorghum (seasonal grass forage). On average, the adoption of *Clitoria*, a protein rich forage, implies a reduction of about 39% in the total costs when it is compared with sorghum and an increase of about 207% on the revenue and 479% on the net return. These findings are confirmed by the high cost-benefit ratio when adopting *Clitoria* (7.97) in comparison with the farming of sorghum (1.86). In addition to reducing the total costs and increasing the total revenue, the major perceptible benefit is the amount of water saved when adopting this technology, which constitutes a reduction of about 48% per hectare.

Moreover, the economic valuation between the local variety of Buffel grass (*Cenchrus ciliaris*), locally called *libid,* and an introduced variety called gayanda reveals a high BCR for farmers who adopted gayanda (around 22.32) against 18.35 among farmers who continued with the local *libid* forage. Findings indicate that, although we noted a slight increase in total costs for the adopters of such technology, the net return is increasing large – about 126%. The major benefit to adopting this technology is the high level of revenue resulting from the increase in yield. Therefore, the tangible benefit from this technology is the high amount of forage produced per hectare multiplied by its unit price during the period of analysis.

The third technology evaluated was the soilless production system (hydroponics) against the soil production system in protected agriculture. This technology was introduced to the farmers to enhance the sustainability of their farming systems through an efficient use of resources, mainly water. The empirical findings indicate that the BCR for the adopters of this technology for the cucumber crop is an average 2.91 whereas the ratio is almost 1.4 for those farmers holding to the soil production system. The tangible benefit from the adoption of this technology is, in addition to the high level of productivity and production, the conserved amount of water (around a 200% saving in comparison with the soil production system). By applying this technology, the net return per hectare is increased by around 260%.

The interventions introduced by the project in using IPPM were also subjected to economic analysis using partial budgeting analysis. This compares the adoption of the IPPM package with the common practices of chemical pesticides or no pest control. The analysis showed that using IPPM increased yield by 15% per ha compared to that using chemical pest control and gave a reduction per hectare in total costs of about 11%. Economic analysis showed that the net benefit to cucumber growers by applying IPPM technology was US$1903. The BCR was around 1.72 among farmers who practiced IPPM against 1.53 among farmers who did not.

The economic valuation of the ICARDA-APRP's improved technologies highlighted the following:

I) There is a clear evidence of the economic profitability (reducing production costs and increasing net return) if these improved technologies are applied appropriately.

II) The adoption of such technologies offers an opportunity for arresting and reversing the downward spiral of resource degradation, protecting the environment (less chemical use) decreasing cultivation costs, and making agriculture more resource-use-efficient (irrigated water) and sustainable for the cucumber growers in Yemen.

III) A sustainable increase in the productivity of crops and forages can be achieved, the environment is better protected, and an important quantity of water can be saved if farmers/growers are encouraged to adopt the improved technology packages.

IV) The benefits of these technologies must be clearly perceived by farmers, given their own socio-economic conditions.

The results from the ADOPT exercise confirmed the extent to which the tool has a potentially important role in providing information on the peak adoption level and the time to peak adoption for the improved technologies implemented by the ICARDA-APRP project. The quantitative predictions about the adoption outcomes for the APRP improved farming practices showed that the predicted peak of adoption and the time to reach it vary between technologies, countries, and within the same country.

The results from the focus group with farmers in Bahrain, KSA, Qatar, and Yemen, with respect to the adoption of a soilless production system, showed that the peak adoption rate for this technology is predicted to be 95% after 17.5 years, 91% after 18.3 years, and 86% 18.5 years. In Oman, the findings reveal a slight difference between the regions on the predicted level of adoption of a soilless production system. This difference arises mainly because of the socio-demographic and socio-economic conditions of the growers and because of the farming system practiced in each region.

Results from the sensitivity analysis indicate that the trialability of the technology and its complexity, where the effects of its use cannot be easily seen when it is used, are considered the main factors constraining the widespread adoption of the technology. These factors also affect both the peak of adoption and the time taken to reach it. In Bahrain, adoption of the soilless system is affected negatively by the fact that it is not observable by the farmers who are yet to adopt it when it is used in their area. In addition to the factors mentioned above, there are three other factors specific to Yemeni growers that affect the adoption of the considered technology. These are the risk, the investment cost, and the technology's profitability in the years that is used. In Qatar there is an additional factor – the need to develop substantial new skills and knowledge to use the innovation. This factor influences also the time to peak adoption of a soilless system in Oman.

The quantitative predictions of the IPPM technology suggest that the peak adoption rate for Bahrain, KSA, and Yemen for this technology will be 95% after 11.2 years, 94% after 21.6 years, and 85% after 13.8 years. Five years from the start, the predicted adoption level is quite acceptable in Bahrain and Qatar, but for KSA it is very low. Furthermore, this level remains low 10 years after the start of the adoption process. This could be explained by the existence of many constraints that prohibit adoption and affect mainly the time to peak adoption level. Such constraints could be summarized as: short-term financial constraints of the farmers, the trialability of the technology, its complexity, lack of an effective advisory service, and lack of know-how on use of the IPPM technology.

Predictions of the likely rate and peak level of adoption of the improved practices for irrigated forages as well as estimates of the importance of various factors in influencing their adoption are similar to the years to peak adoption in KSA, Qatar and Yemen (for *Clitoria* forage). In KSA a peak level of adoption of (95%) is expected occur after 13.5 years. In Qatar the time taken increases to 14.6 years while in Yemen it is slightly shorter at 13.2 years. In the case of Yemen, this peak for Buffel grass is predicted to be after 17.3 years. In Oman, we note that this peak can be reached in a shorter time in comparison with the rest of the Arabian Peninsula countries. It is expected to be around 5 years for the northern region and between 6 and 8 years for the southern region. This variability arises because the natural environment of the northern region of Oman is characterized by important water and animal resources, which enhance adoption of this technology. We identified four key drivers as the primary factors influencing the adoption process. These are the characteristics or attributes of the technology, financial factors, the change agent (extension system, professionals, ETo.), and the socio-economic and physical environments in which the technology takes place.

Also, we tested the ability of ADOPT to predict adoption levels and factors affecting the adoption of spineless cactus technology in Qatar. The likely adoption rate for this technology is predicted to be 95% after a period of 9.4 years. The predicted adoption level after 5 years is predicted to be 80% and in 10 years from start up, 90%. According to factors such as farmers' profits, the environment, and risk, the number of farmers expected to benefit from the innovations, the environmental and profit advantages, the ease and convenience of implementation and use, and, therefore, the level of peak adoption of the innovations, is quite high.

Finally, we predicted the adoption levels and factors affecting the adoption of rangeland rehabilitation technology in both KSA and Qatar. The empirical findings for this technology indicate a substantial difference between KSA and Qatar for the predicted peak level of adoption of this technology. Although, the predicted years to the peak level of adoption are around 18 years, the peak of adoption is expected to be 92% for KSA and 11% for Qatar. This predicted peak remains very low even during the first 5 and 10 years for Qatar. The sensitivity analysis suggests that many factors are contributing to/constraining this peak level of adoption, mainly for Qatar. These factors are the complexity of the innovation, its trialability, and the need for farmers/communities to develop substantial new skill sets and knowledge to use the innovation. In addition, the problem is linked also to the up-front cost of the investment relative to the potential annual benefits from adopting this technology.

The quantitative prediction results provide a valuable alternative and comprehensive empirical basis for improving our understanding of individual users' acceptance of innovation and the adoption outcomes for these new farming practices introduced by the project. Such results suggest:

1. Although some technologies are complex (for example the rangeland management system), there is a willingness by farmers/growers to adopt them.
2. The predicted level of peak adoption for these technologies is different both between the Arabian Peninsula countries and within the same country (for example, Oman).
3. The characteristics of the technology are a determinant of its peak level of adoption and for the time to reach that peak. Thus, we see a low predicted level of adoption for the irrigated forages and a high predicted level of adoption for the IPPM and rangeland rehabilitation.
4. Technical assistance, substantial new skills and knowledge, up-front cost of investment, financial resources, and effective extension advisory services are considered the main factors influencing the adoption of these technologies.
5. The action on these factors will affect only the time to the peak adoption levels of the technologies.
6. Technological characteristics proved to be important in farmers' decision-making. This allows decision makers and planners in research and extension to determine and target which characteristics of the new technologies should lead to their easy transfer and diffusion among the Arabian Peninsula's small-holding farmers.
7. Farmers are encouraged to adopt these proven and promising technologies. In the Arabian Peninsula countries, increasing farmers' knowledge and perceptions of the merits of such proven technologies through better access to technical information, extension, and training will help them to develop a positive economic and environmental assessment of them.

With respect to the third objective, the findings from the questionnaire show the assessment of researcher's and extension agents' perceptions of the ICARDA-APRP technology-specific characteristics/attributes. These include:

- The technology's necessary skills and know-how
- The technology's complexity and affordability
- The extent to which the technology reduces farming costs and increases profits
- The extent to which the technology reduces risk in farming operations
- The environmental benefits
- The ease of implementing, monitoring, assessing, and following up the technology
- The communicability and compatibility of the technology
- The technology's divisibility.

These are the key factors in determining adoption and driving adoption decisions in the Arabian Peninsula countries. The results show a clear convergence of the perceptions of researchers and extension agents in the Arabian Peninsula countries regarding soilless production, IPPM, and rangeland rehabilitation technologies. The analysis between countries suggests that in Kuwait the irrigated forages and spineless cactus technology assessment are getting low scores. This is an indicator that these technologies are not well diffused and, therefore, an additional effort is needed to spread them wider. The cooled greenhouse technology is given a low score in Yemen. This could be explained by the adoption of this innovation being very low; it is mainly constrained by the high level of up-front cost for this technology, so it is not affordable by small-scale farmers.

Having this information and knowing which technology characteristics proved to be important for farmers' decision-making should certainly allow managers and planners in research and extension to determine and target which characteristics of the new technologies led to their easy transfer and diffusion among the Arabian Peninsula's small-holding farmers.

A.1. Policy recommendations and practical implications

A number of recommendations arise from the findings and conclusions of this research study:

- First, since these technologies meet the technical, economic, and socio-economic requirements, there is a need for a greater political and institutional input into them. It is necessary to design and develop alternative policy instruments (other than subsidies) and institutions for a well-developed agricultural extension system that will facilitate adoption of APRP technologies. There is a need also to create a new price policy that gives higher prices for IPPM products (or organic products). Furthermore, raising awareness of farmers and decision makers on the environmental benefits by applying these technologies is necessary to gain their support and confidence.
- Second, the benefits (economic and environmental) of these technologies must be clearly perceived by farmers, given their own socio-economic, cultural, and economic conditions. In the Arabian Peninsula areas, increasing farmers' knowledge and perceptions of the merits of these technologies through better access to technical information, know-how, effective extension delivery system, credit services, and training will help them to develop a positive assessment of them. This will ensure their scaling-up and widespread use.
- Third, to accelerate the adoption of these technologies, it is imperative to create favorable conditions so that a greater

number of farmers can take advantage from the benefits of such technologies. Creating a strong networking among different institutions related to applying ICARDA-APRP technologies and involving public and private financial institutions and support services could be examples of mechanisms to enhance adoption. More specifically, linking mechanisms between research and extension and extension education on ICARDA-APRP technologies would further promote the adoption of such resource-saving technologies at farm level.

- Fourth, it is necessary to promote collective action by farmers practicing these technologies in order to stimulate their demand and adoption countywide. Through these groups, farmers will be able to access credit and the logistics involved in training and providing access to markets for their outputs will be facilitated.
- Finally, there is a clear disparity at the regional scale on the level of adoption and on the factors affecting and encouraging the adoption of a specified technology (i. e. case of soilless production systems and irrigated forages in Oman and Yemen). Thus, scaling-up and disseminating the knowledge to other regions within the same country could be facilitated using interactive similarity maps. Such maps would identify areas having similar socio-economic and environmental contexts. Hence, only technologies with a high financial feasibility should be promoted and farmers should be encouraged to join established and strengthened associations through which training, technical assistance and help with access to extension information can be provided. The policy implication that emerges from this finding is that action can only be achieved through planned and designed programs in partnerships with all concerned organizations and targeting the right beneficiaries.

A.2. Highlights

- We evaluated the economic profitability of the improved technologies implemented in the frame of the ICARDA-APRP.
- We estimated the expected adoption levels and times to the peak level of adoption of these improved technologies.
- We identified the main constraints affecting adoption levels and the widespread use of each one of the innovations implemented.
- We assessed the Arabian Peninsula researchers' and extension agents' perceptions of technology-specific characteristics and attributes that significantly influence technology adoption decisions.

We have provided key practical recommendations to ensure the successful adoption/diffusion and widespread transfer of these technologies.

B. Project external evaluation

An ICARDA-commissioned mission was fielded from 12 August 2017, to 5 September 2017, to carry out an external completion review mission of the ICARDA implemented 2014-2017 Arabian Peninsula Regional Program (APRP) entitled "Improving food security and sustainable natural resources management through enhancing integrated agriculture production systems in the Arab Peninsula". The following is an executive summary of the mission report.

The review approach based on field visits and assessments, interactions with farmers, research and extension staff and review of annual overall and country progress reports, work plans and budgets, and publications focused on: (i) output achievements; (ii) impact of the technologies generated; (iii) relevance, sustainability and scaling-up of technologies; (iv) lessons learned and recommendations for the Program continuation to consolidate the achieved results and their scaling-up.

Covering Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, the UAE, and Yemen, and designed to build on the results of the previous three APRP phases (1995-2013), the goal of the Program under review is to contribute to improving: food security, livelihoods, and sustainable management of natural resources. The first component of the Program is on the introduction and adoption of technology packages, the second on problem-solving research and impact assessment, and the third on capacity building and institutional strengthening. The total original Program cost over its 5 years' implementation amounted to USD 11.626 million of which 16% was financed by a grant from AFESD (USD 1.896 million), 13% by an IFAD grant (USD 1.5 million), 3% by a cash contribution from United Arab Emirates (USD 0.380 million, and 68% by the benefitting countries for their national programs in the form of research staff, facilities, and operating costs (USD 7.850 million).

B.1. Overall assessment

The Program implementation context in the region had been marked by a high frequency of extreme seasonal droughts in all countries in particular in Saudi Arabia, Yemen, and Kuwait where rangelands are in advanced stage of degradation; and (ii) difficult security conditions and reduced national budget for agriculture research in Yemen. Bearing in mind the above regional context, the overall performance of the Program has been in line with the targets set in annual programs and budgets. The performance per component are:

For component 1 on introduction and adoption of technologies, the establishment of new pilot farmers' sites included a total of 109 pilot demonstrations, 118% against target, on irrigated indigenous forage grasses and 21 accessions of spineless cactus; 4 pilot demonstrations, 100 % of target, on feed block production using crop residues and agro-industrial by-products; a total of 106 pilot demonstrations, 101% against target, on soilless and IPPM production technology packages.

For component 2 on problem-solving research, the Program made a significant progress in addressing its six core long-term thematic research areas of regional relevance namely, the safe use and improved efficiency of treated wastewater (TWW) for irrigated forages; the development of animal feed calendars based on the use of indigenous forage species, spineless cactus and alterative feed resources; the introduction of participatory rehabilitation of degraded rangelands including testing new techniques for monitoring and assessment of species composition dynamics; the assessment of different media in soilless production systems; the development of enhanced water use efficiency soilless production systems; and the development of enhanced water saving greenhouse-cooling systems combining the use of renewable energy. The achievements in the above core thematic areas are valuable results to build on in future research work.

For component 3 on capacity building and institutional strengthening, the output achievements are in line with Program targets and beyond. They included: (i) regional level short-term group training of 144 national research and technology transfer staff and pilot farmers; (ii) short-term country level group and individual training of 74 participants; (iii) on-the-job training of over 100 participants through technical implementation support by ICARDA scientists; (iv) strengthening of research facilities with the rehabilitation of two meteorological stations; and (v) institutional partnership development with two universities to conduct joint research.

B.2. Program Relevance

The objectives, components, activities and the generated outputs of the Program implemented to address shared agriculture production constraints, are highly relevant and in line with benefitting countries' priorities for research, technology transfer, capacity building, and sustainable management of their limited water and rangelands resources. In the case of Yemen, which is a priority country for AFESD and IFAD support and lending, the progress made by the Program in the adoption by pilot farmers of Buffel grass forage, IPPM, and soilless production technologies is a strong technical base for scaling-up in future agriculture and rural development investment projects. The significant levels of productivity increases achieved at the pilot farmers' sites confirmed the relevance and impact on incomes and sustainable use of scare natural resources of the production technologies introduced and adopted for irrigated indigenous forages and high value vegetables in soilless greenhouse conditions.

B.3. Program Efficiency

The frequency and country rotation of RTC and RSC meetings on annual basis, the timely approval of well-coordinated work programs and budgets and well prepared regular country and regional annual progress reports are a reflection of the high management and coordination efficiency of the well-established ICARDA Regional Coordination core team based in Dubai and of the performance of ICARDA scientists that have been assigned for technical backstopping of national implementation teams.

B.4. Program Effectiveness

The Program demonstrated a good effectiveness in (i) the adoption of improved technology packages for open field production of water saving indigenous forages and drought tolerant spineless cactus; the production of low cost feed blocks using on-farm crop residues and available agro-industrial by-products; soilless and IPPM technologies for the production of high value vegetables in cooled and not cooled greenhouses and; (ii) conducting problem-solving research on the safe use of TWW in irrigated forage; the assessment of different media in soilless production systems; participatory rehabilitation of degraded rangeland including testing new techniques for monitoring and assessment of the vegetation dynamics; and (iii) capacity building through skill enhancement, access to improved research facilities and institutional partnerships to undertake joint research work.

B.5. Assessment of Impact

The Impact on human assets and social capital has been positive on research and extension staff and pilot farmers in the forms of skill enhancement and access to knowledge through short training, hands-on-experience, and confidence building while conducting research with regular technical back stopping provided by

ICARDA. This helped to conduct quality research.

The Impact on productivity and income increases has been encouraging. For Buffel grass, the average productivity at the pilot farmer sites is quite profitable, ranging from 19.5 t/ha dry mater in Oman, 20 t/ha dry matter in the UAE, 75 t/ha green matter in Qatar, and 7.8 kg green matter per m^3 of water. For cucumber, the average water productivity ranged from 82kg/m^3 to a high of 133kg/m^3 for the closed soilless production systems in Oman. For tomatoes, the average water productivity reached 44kg/m^3 in Qatar for the closed soilless system with gravel as media. However, while the average yields per ha achieved by pilot farmers are significant, there are potential gains, 20% to 40%, through continuous improvement of crop management.

The Impact on the efficient management of scare resources is evident and happening. Both the Buffel grass and the soilless production technologies introduced for adoption at pilot farmers' sites have been designed to achieve optimum water use efficiency. Two new promising technologies in an advanced stage of development and validation under the 'Problem-Solving Research' component are designed to further enhance and sustain the impact on efficient management of water resources. The first technology relates to the safe use and improved efficiency of TWW for irrigated forage and the second relates to innovative water saving greenhouse-cooling system combined with the use of solar energy.

Regarding the impact on policy influence, the results of the technologies generated by the Program offered a convincing rationale to influence decision makers in the development and approval of enabling policies for the efficient use of underground water. On the basis of the proven superiority of Buffel grass as a high water-saving forage crop, Abu Dhabi Emirate adopted a policy measure banning the cultivation of Rhodes grass and promoted its replacement by Buffel grass. This policy had been coupled with incentives in the form of favorable loans to farmers with a built-in matching grant to speed-up the adoption of the Buffel grass. Oman also adopted policy incentives for replacing Rhodes grass by Buffel grass.

B.6. Program sustainability

The Review Mission approached the post program sustainability of results through two indicators namely the capacity to generate a continuous flow of improved technologies and the capacity for effective technology transfer to farmers. On the basis of this completion mission and direct interactions with research and extension staff, pilot farmers in UAE, Oman, and Saudi Arabia, and with some of ICARDA backstopping research staff for Qatar, Bahrain, Kuwait, and Yemen, the likelihood of securing adequate research and extension facilities and operating budgets varies between countries. For the capacity to deliver research outputs, the overall rating is adequate for funding research and moderate for the mobilization of qualified national research staff. Regarding the capacity delivery of efficient technology transfer services, the overall rating is moderate.

B.7. Program Innovation and Scaling-up

In the context of the Arabian Peninsula, the following problem solving research themes are innovative: (i) safe use and improved efficiency of TWW for irrigated forages; (ii) feed block technology using crop residues; (iii) participatory rehabilitation of degraded rangeland based on reseeding and seedlings through rainwater harvesting micro-catchments; (iv) introduction of new techniques for monitoring and assessing the density and composition of the rangelands' vegetative cover; and (v) development of water saving greenhouse-cooling systems combined with the use of solar energy, and the introduction of feed block technology. In addition, the institutional partnership with the American University of Ras Al-Khaimeh is a first-time innovation in the UAE for pooling resources to undertake valuable research work. The Program component on the introduction and adoption of technology in a large number of pilot farm sites is designed as an upscaling initiative during the 5-years implementation period and beyond.

B.8. Performance of Partners

All countries ensured through their counterpart ministries, national research, and extension institutions, active participation in the implementation and the coordination of the Program and demonstrated a strong commitment to its objectives. The RTCMs and RSCMs chaired by ICARDA met regularly on an annual basis and efficiently fulfilled their respective functions of preparation and review/approval of annual work plans and budget, guidance, and regional coordination. The RSC members played a critical advocacy role in maintaining a high profile for the Program both at national and donor level. ICARDA, through its Regional Coordination Office in Dubai, composed of a lean structure, one Regional Coordinator, one coordinator officer, and one executive secretary, collaborated efficiently with all in-country institutional partners, prepared on a timely basis comprehensive consolidated annual progress reports for donors, and contributed significantly to knowledge distillation and sharing. The co-financing partners performed smoothly their respective roles, IFAD and AFESD in disbursing the proceeds of their respective financing grants, and the UAE in hosting the Dubai based Program Regional Coordination office. IFAD and AFESD participated occasionally in the RTC and RSC meetings.

B.9. Lessons Learned

The previous three phases of APRP have been a continuum of a long-term regional research agenda of global relevance implemented in a network mode by national research institutions coordinated and technically supported by ICARDA through catalytic co-financing primarily from two multilateral donors, IFAD and AFESD. The Program phase under review is an integrated part of this continuum. The need to avoid financing gaps between phases of the continuum has been fundamental to mitigate disruption. During the Program implementation period, 2014-17, available funding of national research programs tended to be low to moderate in most countries. Maintaining adequate funding and highly qualified scientists on a continuous basis to generate a constant flow of improved production technologies is the imperative. The need to invest by national governments in performing and quality public sector extension services and to promote results-based private agricultural advisory services to disseminate at a large scale the technologies largely proved at pilot farmers' sites and to narrow prevailing productivity gaps is a persistent third lesson applicable to the Program under review. The need to strengthen national research teams with social scientists and economists to assess the financial and economic returns of the technologies and to formulate enabling policies for their upscaling by farmers is paramount to the successful future of APRP.

B.10. Recommendations

The introduction and adoption of technology package activities under component 1 and the problem solving research work under component 2 and associated capacity building under component 3 are to be considered as a pilot phase for the implementation of a long-term Arabian Peninsula strategy for technology generation and transfer to farmers. The number of pilot lead farmers' sites established by the program in few communities is a valuable base to build on for scaling up across the many potential communities to be impacted. New demonstration sites are required in new communities. Given the complexity and specificity in the Arabian

Peninsula's agricultural production environment, the research themes on problem solving put in place are still a work-in-progress and require consolidation. On the basis of the above, ***the mission recommends a continuum follow-up phase (2018-2023) preferably starting in early 2018 with bridge funding from at least one donor to maintain the momentum and avoid disruption of the on-going research work in the Arabian Peninsula.***

The goal of the follow-up phase would be, within a climate change context, to contribute further toward an improved and sustainable food security in the Arabian Peninsula with emphasis on the commodities for which the region has a comparative advantage while preserving the limited water and rangeland resources.

B.11. Next Step after 2017, Conclusions, and lessons learned

The ICARDA-APRP targeted technologies can significantly improve yield and water productivity and consequently increase farmers' incomes and improve their livelihoods. However, although the systems are simplified by ICARDA and NARES, growers need more and continuous technical backstopping for the adoption of the technology packages. To enhance and secure the project achievements there is a need to:

- Increase the number of pilot farmers
- Enhance the technical capacity and technology transfer skills of NARES personnel.

Transferring the project-targeted technology to the end-users necessitates good and strong links between the NARS and the NAES in the Arabian Peninsula countries. Regional coordination and understanding are necessary to avoid duplication of efforts and to optimize use of limited resources. Developing and strengthening a regional mechanism for coordination and integration of activities related to technology transfer and raising the ability levels of National Agricultural Extension Systems (NAES) of the Arabian Peninsula countries will further enhance and speed up the technology transfer process.

ICARDA-APRP managed to establish successfully a regional network for NARS. This happened through several regional meetings, expert consultation sessions, and the use of modern communication systems. The same mechanism should be implemented to establish a link with the extension systems. This would establish a suitable regional mechanism for technology transfer and feedback of the on-farm activities to the research centers and expedite the problem-solving process. This Network would also help in introducing NARES staff to and training them on the latest agricultural extension approaches and methodologies suitable for transferring the technologies targeted by the project.

Although the project has scored higher than its original goals as a result of the NARES policy and in-kind support, it seems there is need for further efforts to enhance the sustainability of the achievements and tackle the new emerging issues. ICARDA, in partnership with donors and NARES, will continue to seek new horizons to support agricultural development and natural resource management in the Arabian Peninsula, through scientifically sound R&D activities.

Conclusions and lessons learned

The ICARDA-APRP targeted technologies can significantly improve yields and water productivity and consequently increase farmers' incomes and improve their livelihoods. However, although the systems have been simplified by ICARDA and the NARES, growers need more and continuous technical backstopping to ensure adoption of the technology packages. To enhance and secure the project achievements there is a need to:

- Increase the number of pilot farmers
- Enhance the technical capacity and technology transfer skills of NARES personnel.

Transferring the project-targeted technologies to the end-users necessitates good, strong links between the National Agricultural Research Systems (NARS) and the National Agricultural Extension Systems (NAES) in the Arabian Peninsula countries. Regional coordination and understanding are necessary to avoid duplication of efforts and to optimize the use of limited resources. Developing and strengthening a regional mechanism for the coordination and integration of activities related to technology transfer and raising the ability levels of National Agricultural Extension Systems (NAES) of the Arabian Peninsula countries will further enhance and speed up the technology transfer process.

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Annexes

A. Composition of Research and Development Teams

Name	Discipline	Research themes	Agency
ICARDA Regional Team			
Azaiez O. Belgacem (RC)	Rangeland	Rangeland and forage	ICARDA
Arash Nejatian	Technology transfer	Protected agriculture	ICARDA
Naem Mazahrih, Consultant	Irrigation	Forage ad protected agri.	Consultant
Ahmed Mustafa, Consultant	Protected agriculture	Soilless and IPPM	Consultant
ICARDA HQ Tech. support			
Mounir Louhaichi	Range ecology	Forage and rangelands	ICARDA
Boubaker Dhehibi	Socio-economy	Forage and vegetable	CARDA
Muhi El-Dine Hilali	Animal production	Forage	ICARDA
Mourad Rekik	Animal production	Forage	ICARDA
Biju George	Irrigation	Forage and vegetables	CARDA
Bahrain			
Hussein Jawad Allaith (NC 2017)	Crop production	Overall Coordination	MMAUP
Essam Abdul Razak (NC 2014-2016)	Crop production	Overall Coordination	MMAUP
Khalifa Al Ameen (TC)	Agriculture extension	Technology transfer	MMAUP
Jassim Kuwaid	Agriculture extension	Technology Transfer	MMAUP
Emirates			
Mohamed Al Dhanhani (NC 2018-19)	Crop production	Overall Coordination	MOCCE
Alia Al Muhairi (NC 2017)	Crop production	Overall Coordination	MOCCE
Salah Abdullah (NC 2016)	Crop production	Overall Coordination	MOCCE
Mohamed Mussa (NC 2014-15)	Crop production	Overall Coordination	MOCCE
Shamma Al Shamsi (TC)	Crop production	Overall Coordination	MOCCE
Tahra Saeed A.M Naqbi	Crop production	Soilless and IPPM	MOCCE
Halima Y.H Ibrahim	Crop production	Soilless and IPPM	MOCCE
Echii Ono	Crop production	Soilless and IPPM	MOCCE
Abdulla Salem A.J Al Seiri	Crop production	Forages	MOCCE
Ahmed M.S Ali Al Hamoudi	Rangeland and forages	Forages	MOCCE
Kuwait			
Mohammed Jamal (NC 2014-2018)*	Research management	Overall coordination	PAAFR

Amal A.A. Redha (TC 2014-2018)* & NC(2018-2019)	Plant protection	IPPM	PAAFR
Sarah Al-Ateeqi	Agriculture research	Rangeland rehabilitation	PAAFR
Nouf Al- Hashash	Agriculture research	Rangeland rehabilitation	PAAFR
Fatma Al-Qalaf	Agriculture research	Rangeland rehabilitation	PAAFR
Dana al Ali	Agriculture research	Soilless and IPPM	PAAFR
Zainab al jazzaf	Agriculture research	Soilless and IPPM	PAAFR
Karam Abdul Shafi	Agriculture research	Soilless and IPPM	PAAFR
Shaikha dhaif ullah	Agriculture research	Soilless and IPPM	PAAFR
Hassah al Rees	Agriculture research	Soilless and IPPM	PAAFR
Mariam Mahmoud	Agriculture research	Soilless and IPPM	PAAFR
Abrar Dahrab	Agriculture research	Soilless and IPPM	PAAFR
Muhammad Riaz, Consultant	Agriculture research	Soilless and IPPM	PAAFR
Sanjeev Krup, Consultant	Agriculture research	Soilless and IPPM	PAAFR
Rawan alKhalidi	Agriculture research	Soilless and IPPM	PAAFR
Omar Qasri	Agriculture research	Soilless and IPPM	PAAFR
Oman			
Hamoud D. Al hasani (NC)	Research management	National coordination	MAF
Hamdan S. -Wahaibi (TC)	Soil and water	Technical coordination	MAF
Safaa Mohamed Al-Farsi	Genetic resources	Seeds and forages	MAF
Salah Ali S.Al-Hinai	Genetic resources	Seeds and forages	MAF
Badria Saif Al Hosni	Irrigation	Irrigation systems	MAF
Nadia Al Jabri	Field crop	Forages and vegetables	MAF
Zaher Saif Al Salmani	Crop water requirement	Irrigated crops	MAF
Muthir S. Al Rawahy	Vegetable crops	Protected agriculture	MAF
Rashid K. Al Shikaili	Vegetable crops	Protected agriculture	MAF
Saif K. Al Qutati	Vegetable crops	Protected agriculture	MAF
Waleed Salim Salah Al Abri	Vegetable crops	Protected agriculture	MAF
Saud A. Al Rasbi	Vegetable crops	Protected agriculture	MAF
Said M. Al Adawi	Extension	Extension - Batinah G.	MAF
Salem Z. Al Hinai	Extension	Extension- Al Dhahira G.	MAF
Khald Al Mughairi	Extension	Extension	MAF
Said S.Al Wardi	Extension	Extension- Al Dhakila G.	MAF
Qatar			
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Masoud Al Marri (NC 2014-2017)*	Research management	Overall coordination	MME
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Hasan I. Al Asmakh	Crop production	Vegetables	MME
Hail Mohamed Al Wawi	Crop production	Forage, protected agri.	MME

Saudi Arabia			
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Abdulrahman Al Habeeb (NC 2016-2017)	Research management	Overall coordination	MEWA
Bandar Al Odiani (NC 2014-2015)	Research management	Overall coordination	MEWA
Bander Al Mahari (NC)*	Research management	Overall coordination	MEWA
Saud A. Al-Eyyed (TC)*	Crop production	Protected agriculture	MEWA
Hamed Ben Hamoud	Crop production	Protected agriculture	MEWA
Sanad Nunif Al Qahtani	Vegetable production	Protected agriculture	MEWA
Murlee Lubu	Vegetable production	Protected agriculture	MEWA
Melahi Awadh Al Sharari	Forage and rangeland	Rangeland rehabilitation	MEWA
Mubarak Naji Al Sharari	Rangeland	Rangeland rehabilitation	MEWA
Ibrahim Ali Al Batayen	Rangeland	Rangeland rehabilitation	MEWA
Saud Salem Al Sharari	Forage crops	Spineless Cactus	MEWA
Faisal M. K. Al-Anzi	Crop laboratory	Rangeland rehabilitation	MEWA
Yemen			
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Khadher B. Atroosh (TC)	Water and irrigation	Irrigated forages	MAI
Gamhoryah A. Al Khader	Crop production	Forage	MAI
Wajeh Al-Mutawakel	Protected agriculture	IPPM (S. Highlands)	MAI
Mohamed A. Gamil	Forage	Spineless cactus	MAI
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Hashem A. Moqbil	Rangeland	Rangeland rehabilitation	MAI
Abdullah Q. Magram	Forage	Spineless cactus	MAI
Suad Ali Mohamed	Forage	Feed blocks	MAI
Zahra Ahmed Essa	Forage	Feed blocks	MAI
Mohamed A. Al Khadher	forage	Rangeland rehabilitation	MAI

RC: Regional Coordinator NC: National Coordinator TC: Technical Coordinator

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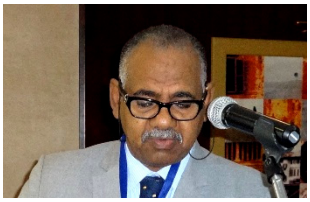

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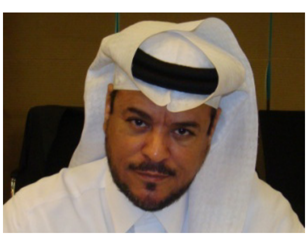

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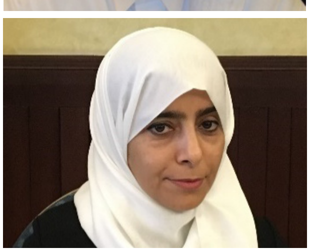

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The Arabian Peninsula Regional Program (APRP) of ICARDA serves the seven countries of the Arabian Peninsula, namely, Bahrain, Kuwait, Qatar, Saudi Arabia, Oman, United Arab Emirates, and Yemen. The program addresses three priority themes: (i) Rangelands, forage and livestock; (ii) Protected agriculture; and (iii) Water resources management. These themes are supported by research on agroecological characterization and stress physiology. Emphasis is also placed on institutional strengthening and capacity building, human resource development, and promotion of the use of information technology.

The International Center for Agricultural Research in the Dry Areas (ICARDA) is an international organization undertaking research for development. We provide innovative, science based solutions for communities across the non tropical dry areas. In partnership with research institutions, NGOs, governments, and the private sector, our work advances scientific knowledge, shapes practices, and informs policy.

Since its establishment in 1977, ICARDA has implemented research-for-development programs in 50 countries across the world's dry areas - from Morocco in North Africa to Bangladesh in South Asia

The Consultative Group on International Agricultural Research (CGIAR) is the world's largest global agricultural innovation network. The 15 CGIAR Research Centers are independent, non-profit research organizations, conducting innovative research. Home to more than 8,000 scientists, researchers, technicians, and staff, CGIAR research works to create a better future for the world's poor. Each Center has its own charter, board of trustees, director general, and staff. CGIAR Research Centers are responsible for hands-on research programs and operations guided by policies and research directions set by the System Management Board

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وزارة الأشغال وشئون البلديات والتخطيط العمراني

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Ministry of Agriculture and Fisheries, Oman

Ministry of Municipality and Environment, Qatar

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Ministry of Environment, Water & Agriculture
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