Framework for Sustainable Agro-Ecosystems in Support of Gulf Cooperation Council (GCC) Countries' Food Security

Abdirashid Elmi[1*], Husam Alomirah[2] and Sameer Al-Zenki[2]

1 Department of Environmental Technology Management, College of Life Sciences, Kuwait University, P.O. Box 5969, Kuwait, Safat 13060, Kuwait.
2 Kuwait Institute for Scientific Research (KISR), Environment and Life Sciences Research Center, P.O. Box 24885, 13109 Safat, Kuwait

ID #2884
Received: 10/09/2018
In-revised: 11/11/2018
*Corresponding Author:
Abdirashid Elmi
E-mail: a.elmi@ku.edu.kw

KEYWORDS

Arid climate, Food security, Greenhouse, Innovative, Irrigation technology, Resource-conserving.

ABSTRACT

Globally, food security faces unrelenting challenges, including growing population expected to reach 10 billion toward the end of 21st century, shifting diet preferences, diminishing natural resources and a changing planetary climate. This challenge is most acute in arid, hot Arabian Gulf region. Presently, Gulf Cooperation Council (GCC) countries are comfortably food secure, almost entirely through food importation, with all the risks associated with total dependency on food import. Risks related to heavy reliance on food import include i) disturbance to global supplies routes, ii) food price volatility in global markets like 2007-2008, and iii) the unpredicted impact of climate change on global food supplies. To balance risks of food import, two measures seem to be effective: 1) stable grain stock and 2) a boost in domestic production. There are gaps in our knowledge regarding the local production capacity and how much contribution can be expected under prevailing climatic and environmental conditions. The primary objective of this paper is to identify and analyze innovative, resource-conserving, practical and sustainable ways to improve food production under local climatic conditions. In this framework, we considered agro-ecosystem agriculture (AEA) as a farming system that balances production and environmental goals and, most importantly, minimizes the trade-off between the two. We conclude that enhancing local food production would require capital investment in greenhouse structures, irrigation technology, and skilled labor.

إطار النظام الإيكولوجي الزراعي المستدام لدعم الأمن الغذائي لدول مجلس التعاون الخليجي

عبد الراشد العلمي [1] * ، حسام العمررة [2] وسمير الزنكي [2]

1 قسم إدارة تقنية البيئة ، كلية علوم الحياة ، جامعة الكويت ، ص.ب. 5969، الكويت، الصفاة 13060 الكويت.
2 معهد الكويت للأبحاث العلمية (KISR) ، مركز أبحاث البيئة وعلوم الحياة ، ص.ب. 24885، الصفاة 13109 الكويت.

رقم المسودة: (2884)
تاريخ استلام المسودة: 10/09/2018
تاريخ المسودة المُعَدَلة: 11/11/2018
*الباحث المراسل: عبد الراشد العلمي
بريد الكتروني:
a.elmi@ku.edu.kw

الكلمات الدالة

المناخ الجاف ، الأمن الغذائي ، الاحتباس الحراري ، المبتكرة ، الري.

المُستلخص

على الصعيد العالمي، يواجه الأمن الغذائي تحديات لا تُضاهى، منها تزايد عدد السكان و المتوقع أن يصل إلى 10 مليارات نسمة في نهاية القرن الحادي والعشرين، وتغير في الأنماط الغذائية للمستهلكين، وتناقص في الموارد الطبيعية المتاحة، وتأثيرات التغير المناخي. وهذه التحديات هي أكثر حدة في منطقة الخليج العربي الحارة. وفي الوقت الراهن، فإن الدول الأعضاء في مجلس التعاون لدول الخليج العربية يتمتعون بالأمن الغذائي بشكل مريح، وذلك بالأعتماد تقريباً على إستيراد الغذاء. هذا الإعتماد الكلي مرتبط بمخاطر شتى تشمل: (1) اضطراب مسارات الإمدادات الغذائية العالمية؛ (2) تقلب أسعار الأغذية في الأسواق العالمية مثلما حدث عام 2008-2007؛ (3) التأثير غير المتوقع لتغير المناخ على الإمدادات الغذائية العالمية. وللتقليل من مخاطر إستيراد الأغذية، هناك تدبيرين فعالين هما، إيجاد مخزون أستراتيجي من الحبوب وزيادة في الإنتاج الزراعي المحلي. وحاليا هناك فجوات في معرفتنا فيما يتعلق بقدرة الإنتاج المحلي و مساهمته الممكنة في ظل الظروف المناخية والبيئية السائدة. لذا، فأن الهدف الرئيسي من هذه الورقة هو تحديد وتحليل الطرق العملية المبتكرة التي تحافظ على الموارد الطبيعية وتحقق الاستدامة في إنتاج الغذاء في ظل الظروف المناخية المحلية. وفي هذا الإطار، اعتبرنا الزراعة في النظام الإيكولوجي الزراعي يوازن بين هدف زيادة الإنتاج والمحافظة على البيئية ويقلل من المقايضة بين الهدفين. وأستنتجت الورقة أن تعزيز الإنتاج المحلي للغذاء يتطلب الإستثمار في تصاميم هياكل البيوت المحمية، وتكنولوجيا الري ، واليد العاملة الماهرة.

Introduction

Achieving food security in the face of growing population, shifting dietary preferences, diminishing natural resources and a changing planetary climate, without degrading the environment, can be described as the most pressing challenge of 21st Century. The most commonly used definition of food security (FS) originates from the 1996 Food Summit at the Food and Agriculture Organization of the United Nations (FAO): Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996). Food security of the Gulf Cooperation Council (GCC) countries rests almost entirely upon imports typically account for up to 90% food consumption (Bailey and Willoughby, 2013). There are genuine concerns that import routes can become vulnerable to disruption or closure in the unlikely event that the current violence in the Middle East and North Africa (MENA) escalates (Fig. 1). Secondly, in the case pirate activities in the horn of Africa off the Gulf of Aden (Somalia) intensifies, it would represent an additional threat to the pathway of food import (Elmi, 2017). Thirdly, near total economic dependence on no-renewable sources of energy exports through which food imports are financed, can expose GCC countries to the volatility of both oil and food prices.

Arid climate, scarcity of arable land, high soil salinity and limited natural water resources are all prevailing limiting factors of food production in the GCC countries to a varying degree. To achieve a satisfactory level of domestic food security, there is a need for radical change in how local food is produced. Objectives of this paper are to i) examine innovative methods for agricultural practices under local conditions, ii) identify ways to optimize the use of natural resources input (energy, soil, water) and iii) design and manage an integrated agricultural production system to make local agricultural practices environmentally, socially and economically viable. To lay the foundation for our analysis, we first reviewed major challenges facing agriculture and agri-food system followed by brief analysis of key individual benchmarks: innovation, integration, and efficiency.

Methodology and Data Collection

In oder to achive the objective of identifying an innovative, resource-conserving, practical and sustainable ways to improve local food production in GCC countries, five key farm practices were selected as benchmarks with defined indicators (Table 2). These benchmarks have been selected as guiding principle, with the goal of developing dynamic solutions. There are a number of data sources used for this analysis. To assess the current level of food production and land use in individual GCC countries, we used Food and Agriculture Organization (FAO) of the United Nations, country profile. The data for research productivity as an innovation index were retrieved from major science and engineering fields published in journals indexed in the web of science database from Thomson Reuters. Publications are assigned to countries according to the address on the publication. The article proceeds as follows: Challenges facing agriculture and agri-food system, followed by rigorous review detailed analysis of the most relevant literature in innovation, integration (systems approach), and efficiency. The article ends with a brief discussion of the results and some concluding remarks.

Analysis and Discussion

Challenges facing agriculture and agri-food system

While the GCC countries currently enjoy a high degree of food security, there are some currents and future risks.

Figure 1. Entry points through which 75-80% of food imports from North America, South America, Europe, and black Sea are shipped to the GCC (Source: www.chathamhouse.org)

These risks include i) disturbance to global supplies routes (Fig. 1), ii) food price volatility in global markets,

and iii) the unpredicted impact of climate change on global food supplies. It is worth emphasizing here that if food price shock occurs concurrently with oil price hikes as they did in 2007-2008, oil-producing nations like the GCC were not affected. (Use scientific words rather non-scientifc). Consequently, the main concern for the GCC Countries during 2007/2008 food crises was not so much with food prices increases as much as it was with the food availability in the market. Exporters like India, Argentine, and Russia, for example, hinted to restrict or completely ban food export out of fear for their domestic food security. For net food importing dependent countries like the GCC (Table 1), such episodes represent an existential threat to national food security.

One obvious option to mitigate these threats can be establishing sustainable local production strategy. However, agri-food production capacity of GCC region is limited for hydrological, pedagogical and climatic factors. Annual rainfall is averaging typically less than 100 mm/year, is well below that required for rain-fed crop production (reference). Renewable water resources are among the lowest in the world (Qadir et al., 2007; Amer, 2006. Elevated temperatures during summer extend for well over eight months when the weather conditions are harsh, with heats occasionally reaching or even exceeding 50 °C. Additionally, climate change, which can potentially cause significant reductions in global food production, is an emerging challenge for food security (Lobell et al. 2008).

Table 1: Weather conditions, land area under cereal production, cereal imports, and cereal import dependency ration (%)

GCC States	Weather (2015)		Area under cereal production (000 ha)		Cereal imports ¥ (million tons)		Cereal import dependency ratio (%) ¥
	Rain (mm)	Temp. (°C)	2000	2015	2015	2020	2015
Bahrain	83	26.6	N/A	N/A	1.1	1.6	N/A
Kuwait	121	25.7	1.9	2.8	3.6	5.3	97.8
Oman	125	28.8	3.8	4.3	3.3	4.8	93.4
Qatar	74	26.7	1.1	1.1	2.1	3.3	N/A
Saudi Arabia	59	26.5	704.8	236.1	24.5	35.2	88.1
UAE	59	27.5	0	1.9	5.5	8.4	94.7

Source: Compiled from WDI (World Development Indicators) 2015. Arable land per capita in all GCC countries is less than 100 m2, except Saudi Arabia where it is about 1000 m2. http://wdi.worldbank.org/table/3.1; ¥ Cereal imports and cereal import dependency ratio (%) are extracted from food security indicators, FAO (2015). Food-Security-Statistics@FAO.org; N/A = Not applicable

Despite this, on average, the four countries big enough to be covered by the FAO database meet more than half (50%) of their needs in poultry meat, milk and other food products (Fig. 2).

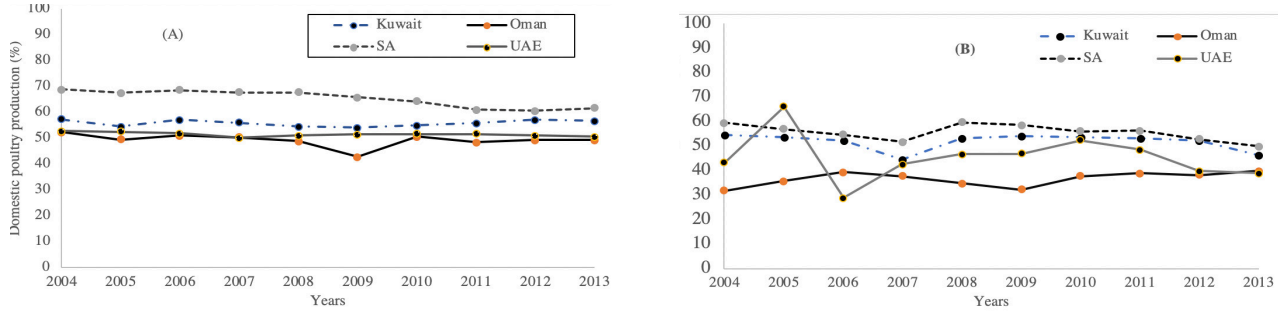

Fig. 2: Self-sufficiency ration of (A) domestic poultry production (%) and (B) milk in the four Gulf Cooperation Council (GCC) countries covered by the FAO database.
Source: http://faostat3.fao.org/home/index.html (Accessed 10/4/ 2018).

Similar trends are observed for fruit and vegetable crops (FAO, 2015). For example, Saudi Arabia has achieved self-sufficiency for most of the demands vegetables and become an important exporter of dates and eggs. However, the challenge to contemplate domestic cereal production is greater; most cereal crops, for example, require around 600–650 mm per year in hot climates (Laaboudi and Mouhouche, 2012). Saudi Arabia, for example, tried to achieve self-sufficiency of cereal production in the late 1980s and early 1990s through the expansion of irrigation by extracting non-renewable fossil groundwater (Yang et al., 2003). However, soon it became evident that this intensified agriculture is exerting a huge toll on groundwater resources and, therefore, ecosystem functioning. An important lesson from this experience is that renewed efforts for increasing domestic food production must be innovative and integrated with environmentally sustainable practices that are designed to minimize resource depletion and adverse environmental impacts. Here we are proposing a simple and practicable framework, which consists of innovative, efficient and integrated approach.

Table 2. Framework Benchmarks for Sustainable Agroecosystem and Brief Descriptions of Potential Indicators

Benchmarks	Indicators/Descriptions
Innovation	Exploring innovative methods for agricultural practices, to formulate solutions to local food production challenges
Integration (Systems approach)	Combination of practices and principles to optimize interactions between crops (plants), animals (livestock), resources input (energy, soil/land, water, technology) and environment (waste as a resource).
Efficiency	Resource conserving by maximizing output/production (crops, forage, milk, meat, etc.) per unit of resource input (materials, energy, labor, water), avoiding wasting resources.
Sustainability	Identifying best management practices that maintain a healthy balance between production activity and environmental integrity.
Economically competitive (affordable	Greater production with fewer resources input and better quality of the produce with competitive market advantage

Innovation

Often when innovation is mentioned, technological innovation emerges as the first thing. However, innovation can also be non-technological, including, for example, changes in thinking, social behavior and/or novel research approach. As shown in Fig. 3, food production system is directly affected by a substantial number of physical environment, technological and economic factors, each one requiring a certain level of innovation. To find a transformative solution to food challenges, the ability to innovate is critical. The critical role of innovation in agricultural practices, including promoting conventional crops, greenhouse farming, research in bio-salinity and importance of extension services to keep farmers aware of innovative technologies necessary for improving productivity are discussed in great details in Fiaz et al. (2018). The region's present and future needs to expand domestic production are severely limited by lack of arable land (Table 1) and water scarcity. In our research, the emphasis is on improving water resource efficiency and enhancing soil health in an integrated fashion in order to lessen the high degree of import dependence shown in Table 1.

Irrigation technology is a prime example of agricultural innovation for water savings such as sub-irrigation; a system that applies only enough water to meet crop needs and minimize water use between 40-80% compared to another less efficient irrigation system in temperate wet regions (Skaggs et al., 1999). In Arid and hot climate regions like the GCC, water savings can be expected to be much

higher. This state-of-the-art irrigation technology is especially relevant because agriculture sector, which does not contribute much to the economy, consumes enormous quantities of freshwater in the Gulf region, sometimes close to 90% of the water uses (Brown et al., 2018; International Fund for Agricultural Development [IFAD], 2009; Qadir et al., 2007). Additionally, there is a potential saving in fertilizer with sub-irrigation since the solution is recirculated and not lost by leaching or runoff. Leached inputs represent an economic loss to the farmer and degrade the environment such as surface and groundwater. Acceptance of modern technologies by farmers largely depends on their impact on crop yields. Sub-irrigation has a proven track record of significant yield increase during dry seasons (Cooper et al., 1999).

Besides water, the second most important earth's resource upon which food and feed production rely on is soil. Sustainable soil use and management is an important frontier to improve productive capacity and enhance the quality of degraded soils in desert ecosystems. The concept of soil quality has gained prominence with respect to the sustainability of agriculture. Soil organic content (SOC) present is considered as the most important measure of soil quality because of the pivotal role soil organic matter plays in soil physical, chemical and biological processes (Wilson et al., 2008). Therefore, practices that enhance SOC should be viewed as a key component to sustainability. Strategies to improve SOC, and therefore soil health, have included conservation agriculture practices such as maintaining high levels of crop residue between plantings and integrating livestock into cropping systems (Fig. 4). For the sake of brevity, we limit our discussion on the potential for water and soil (the two most limiting factors in the GCC region) innovative practices and potential synergies between the two.

Science and technology provide sustainable means to feed people and improve their health. The biggest challenge in achieving food security will be, among other things, deployment of technologies, and varieties that will sustainably increase the production of food per unit area while minimizing the use of water and other agricultural inputs such as energy. Consequently, we included scientific output analysis in our framework using research publications as indicators of innovation capacity building in the region. In the long run, as no region or nation can remain a simple user of new knowledge permanently, there is a need also to become a creator of new knowledge, which will necessitate new investment in research and development. Furthermore, the extent to which innovative thinking can help farmers to boost productivity largely depends on concomitant design of effective extension program. The core function of agricultural extension is to disseminate information with the intention promoting newly generated knowledge and promote skills (Fiaz et al. 2018). These innovative water saving and land use technologies, discussed above, have great potential to boost agricultural productive capacity from the limited (Table 1) crop land currently under cultivation in coordination with efficient extension.

Table 3: Scientific and technical journal articles, research and development (R & D) expenditure as in the GCC countries.

Selected Arab states	**Scientific and technical articles***				**R & D§**
	2000	2008	2011	2017	2014
Bahrain	40	49	98	133 (107)¥	0.04
Kuwait	202	469	607	429 (338)	0.30
Oman	144	185	315	731 (638)	0.17
Qatar	111	38	195	408 (338)	0.47
Saudi Arabia	1491	1321	1745	2,883 (2,631)	0.07
United Arab Emirates	324	270	660	643 (545)	0.49
Total	2312	2332	3620	5227 (4627)	---

Source: 2000 and 2008 scientific articles are extracted from UNESCO 2010, whereas 2011 data was obtained from WDI (World Development Indicators, World Bank): Science and technology. ¥ Values between parenthesis represent sum of articles marked as science and technology from web of science of all databases option, * § Research and Development (R & D) as expenditure as a percentage of GDP (2005 – 2014)

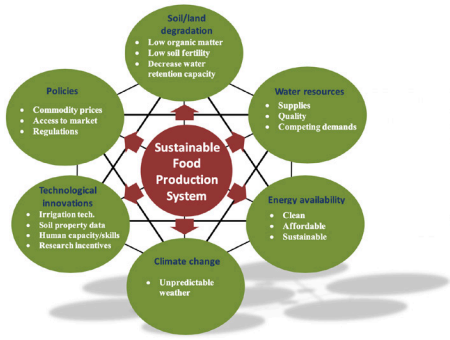

Fig.3: Interconnectedness of food production system with resource inputs, policies, natural factors and farm level technology.

The number of papers in science and technology (engineering) fields published in journals indexed in the web of science database from Thomson Reuters between 2000 and 2017 is shown in Table 3. Publications are assigned to countries according to the author's address on the publication. The 2017 data show total sum of articles, with the values between parenthesis representing articles marked as science and technology from web of science of all databases option. This level of scientific output appears to be disproportionate to the region's human and economic capacity. Although these estimates should be viewed with caution as these are derived from scarce data, they nonetheless indicate an overall poor research output performance of GCC countries. Consequent to the preceding highlights, there is an exigent need to improve agricultural research capabilities in the region if food security challenges were to be tackled, making sustainable future possible. However, an important note of caution is that these publications do not represent total research output; papers published in journals not indexed in JCR and publications in the fields of arts and social sciences are not included in the data reported.

Integration: System's perspective

Food security challenges in the Arabian Gulf region have heightened interest in a search for solutions. We argue that integration of various components in food/feed production system would help address this complex challenge. A framework of integrated pathway in sustainable farming system is depicted in Fig. 4. While components of food and feed production systems can be managed individually, it usually comes at the expense of efficiency and sustainability. Integrating all components of the production system provides an opportunity to close resource loops across the system. There is potential for resource-conserving synergies between components and can rely on one another. The key concept is that outputs from one component are utilized as inputs into other components and/or sectors. For example, manure from livestock component can be used as soil amendment for crop production as well as a source of energy (Fig. 4). Similarly, water used in one sector can be recycled and made available to other sectors. Therefore, this integrated system approach is designed to preserve natural resources. Integrated methodologies for achieving sustainable farming systems in GCC Countries will include innovative protected environment agriculture and aquaculture, renewable energy, water reuse/recycle and innovative irrigation methods, improving soil quality, alterative forage production, enhanced animal production, and finally address the need for agricultural restructuring strategies and farmer skill development.

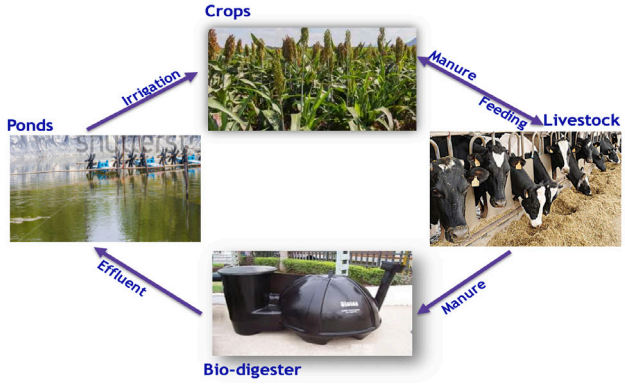

Fig. 4: Integration Pathway in Sustainable Farming System=

Efficiency as a Resource-Conserving Approach

Productivity relies heavily on two of the earth's primary resources: soil and water, both of which are severely scarce in the GCC countries. The total suitable land for vegetation and agriculture activities is less than 1% of total area of GCC countries, except Saudi Arabia where potentially arable land is estimated to be about 2% of the total land area (FAO, 2013). Consequently, increasing production on existing agricultural land by managing available resources more efficiently can be postulated as a key part of a solution and should be high on the Gulf food security policy agenda, given limited land and water resources. This means efforts to boost crop production locally to become less reliant on food imports will require significant improvement in productivity per unit area of currently cultivated lands. Efficiency in relation to agricultural production system can be viewed as a model of agriculture associated with lower consumption of resources such as energy, water, and resources inputs and, therefore, reduced pollution level in comparison to conventional agricultural practices. In other words, efficiency is the quest to eliminate wasteful practices.

Farming in the greenhouse, where environmental factors can be controlled can be a promising approach in regions with harsh environmental conditions. This practice has recently become increasingly popular for growing food in many parts of the world. Land degradation will not be a problem because the food will be grown hydroponically and that only a fraction of the amount of water and nutrients will be needed compared with conventional farming (The Economist, 2010). Protected environment agriculture (PEA) is the only viable option for year-round food production. The PEA system increases crop yield, improve product quality, decrease proliferation of soil borne pathogens and prevent groundwater pollution (Raviv et al., 2008a, b). Also, the nutrient availability to plant roots can be manipulated and controlled more precisely than in most arable soils. However, currently, producers use outdated PEA structures, rely on imported production inputs and use inefficient production systems. This has led to excessive use of natural resources and wasteful practices in food production, low crop productivity, poor product quality and safety and, low farm efficiency. Therefore, the present PEA food production system in Kuwait is grossly unsustainable with negligible contribution to the national food security. We hypothesize that as time progresses with the implementation of the framework proposed in this analysis, farmers and researcher's ability to come up with new, different and innovative ideas to food security problems will increase and generate new possibilities.

Efforts to produce more food locally require both a vertical and a horizontal expansion of agriculture that will increase productivity per hectare and the total area of cultivated lands. This effort will require massive investments in modern technologies and knowledge transfer. However, we recognize that there are agronomic and engineering challenges that need to be overcome, requiring heavy investment in research technology. Fortunately, oil-rich GCC nations have the financial ability to adopt efficient technologies, skills, and resources needed to carry out such an expansion. Despite some technical challenges requiring heavy investment in technology, PEA allows vertical expansion of food and feed production. Vertical farming is a practice of growing plants greenhouse, where all environmental factors can be controlled. This practice has recently become increasing popular for growing food in many parts of the world. Land degradation will not be a problem because the food will be grown hydroponically and that only a fraction of the amount of water and nutrients will be needed compared with conventional farming (Fiaz etal., 2018).

Summary and Conclusions

Meeting food security involves multiple managerial and technical aspects: sustainable land use, water saving irrigation technology, and integrated nutrient management. There is a need for radical change not only in how local food is produced but also how it

is consumed. A conceptual framework for meeting food security in the GCC that can form the basis for achieving low input and high output farming is outlined in this paper. The GCC countries are not expected to perform uniformly when it comes to their capacity to meet food security. The innovative approach outlined in this paper should serve a guiding model. Qatar, for example, has identified food security as a matter of national strategic issue and aimed to produce 70% of its food needs locally by 2020 (Qatar National Food Security Program, 2011). Although this policy represents the most comprehensive measure, it is not clear whether it was put into action (Brown et al., 2018) and constraints faced to achieve desired results. Clearly, this goal can only be accomplished through the development of a local, integrated agricultural ecosystem that utilizes all available technologies more efficiently. This integrated ecosystem (Fig. 4) should preserve natural resources while providing practical and sustainable ways to improve local food production. Integrated methodologies for achieving sustainable farming systems will include innovative protected environment agriculture and aquaculture, renewable energy, water reuse/ recycle and creative irrigation methods, improving soil quality, alterative forage production, enhanced animal production, and finally address the need for agricultural restructuring strategies and farmer skill development.

No country in the entire world has ever achieved complete self-sufficiency and prosperity without import. However, under the world's oil price decline and food price fluctuations, relying entirely on importing food may not be sustainable in the long term. Consequently, there is an urgent need to achieve, partially at least, self-sufficiency of food production to minimize risks of total dependency on imports. The GCC regions' advantage of having abundant energy resources is a strength that can be used to mitigate consequences of land and water scarcity while transitioning to a more suitable path to food security.

Local agriculture has the potential to produce sustainable food production system with the help of modern technology that enhances water resources availability and use, as well as soil quality improvement. This goal is attainable with elaborate efforts of scientific research to identify things that work optimally. Several ways to ensure self-sufficiency of food supply for the current and future human population have been suggested, none of which alone can solve the acute food security challenge, but each can form the basis towards a sustainable solution. From the economy perspective, however, energy, food, and water subsidies in many Gulf countries are on paths that may be unsustainable in the long term. Finally, a key aspect of sustainability is the ability to adapt to future challenges. We argue that sustainable agriculture system can best be achieved by implementing the framework proposed in this paper.

REFERENCES

Amer, KM. (2006). Policy perspectives for ecosystem and water management in the
Arabian Peninsula. United Nations University International Network on Water, Environment, and Health (Canada). http://unesdoc.unesco.org (accessed 28.1.2018.

Bailey, R, and Willoughby, R (2013). Edible Oil: Food Security in the Gulf Energy:
Environment and Resources | November 2013 | EER BP 2013/03.

Brown, JJ, Das, P, and Al-Saidi, M (2018). Sustainable Agriculture in the Arabian/Persian Gulf Region Utilizing Marginal Water Resources: Making the Best of a Bad Situation. Sustainability 10: 1364; doi:10.3390/su10051364

Cooper, RL, Fausey, NR, and Johnson, JW (1999). Yield response of corn to a subirrigation/ drainage management system in northern Ohio. Journal of Production Agriculture 12: 74-77.

Cosgrove, WJ, and Rijsberman, FR (2000). World Water Vision: Making Water
Everybody's Business. World Water Vision: The World Water Council, Earthscan Publication Ltd.: London. pp 33-40.

Elmi, A. (2017). Food Security in the Arab Gulf Cooperation Council States. Sustainable Agriculture Reviews 25: 89-114.

FAO. (2013). FAOSTAT - FAO database for food and agriculture, Rome Food Agric.
Organ. U. N. FAO. http://faostat3.fao.org/home/index.html (Accessed 10/3/ 2018).

FAO. (2015). food security indicators. Food-Security-Statistics@FAO.org (Accessed on 27/10/ 2018).

Fiaz, S, Noor, MA, and Aldosri, OF (2018). Achieving food security in the Kingdom of Saudi Arabia through innovation: Potential role of agricultural extension. Journal of the Saudi Society of Agricultural Sciences 17: 365–375

IFAD. (2009). "Fighting water scarcity in the Arab countries." Rome: IFAD. Available http://www.ifad.org/operations/projects/regions/pn/factsheets/WWF_factsheet.pdf

Laaboudi, A, and Mouhouche, B (2012). Water Requirement Modelling for Wheat under Arid Climatic Conditions. Hydrological Current Research 3: 130-134.

Lobell, DB, Burke, MB, Tebaldi, C, Mastrandrea, MD, Falcon, WP, and Naylor, RL (2008). Prioritizing Climate Change Adaptation Needs for Food Security in 2030. Science 319: 607-610.

Qadir, M., Sharma, B.R., Bruggeman, A., Choukr-Allah R., and Karajan, F. (2007). Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agricultural Water Management, 87, 2-22. http://dx.doi.org/10.1016/j.agwat.2006.03.018

Qatar National Food Security Program (2011). Expanding Domestic Agricultural
Production to Increase Qatar's Food Self-Sufficiency: www.qnfsp.gov.qa

Raviv, M, and Lieth, JH (2008a). Soilless culture in agriculture – Theory and Practice. Elsevier ISBN-13: 978-0-444-52975-6.

Raviv, M, Lieth, JH, Bar-Tal, A, and Silber, A (2008b). Growing crops in soilless culture. Operational Conclusions. In: Soilless culture in agriculture – Theory and Practice ISBN-13: 978-0-444-52975-6.

Rosegrant, MW, Cal, X, and Cline, SA (2002). Global water outlook to 2025: Averting an impending crisis. International Food Policy Research Institute. <http://www.ifpri.org> (accessed on Jan. 5, 2018).

Skaggs, RW, Reynolds, WR, and Chescheir, GM (1999). Effects of subsurface drain
depth on nitrogen losses from drained lands. ASAE. paper No. 99-2086, ASAE, St. Joseph, MI.

The Economist. (2010). Technology **Quarterly: Q4 2010.** Vertical farming. Does it
really stack up? December 9, 2010.

UNESCO Science Report (2015). Towards 2030. Available at
http://unesdoc.unesco.org/
images/0023/002354/235406e.pdf (accessed 15.1. 2018).

World Bank. (2015). World Development Indicators.
https://data.worldbank.org/indicator/IP.JRN.
ARTC.SC (accessed 15.1. 2018).

Wilson, BR, Growns, I, and Lemon, J (2008). Land-use effects on soil properties on
the north-western slopes of New South Wales: implications for soil condition assessment. Soil Res 46:359–367.

World Food Summit. 1996. Rome Declaration on World Food Security and World
Food Summit Plan of Action. World Food **Summit 13-17 November 1996.** Rome

Yang, H., Reichert P., Abbaspour K.C., Zehnder A. J.B., (2003). A Water Resources
Threshold and Its Implications for Food Security. Environ Sci. Technol. 37: 3048–3054.