Prospects for Improving Food Security through the Targeted Application of Science, Technology and Innovation (STI).

[The contents of this paper are to be distributed across the other contributing sections. This is reflected in the layout of the document, organised to facilitate editing, possibly at the expense of flow and consistency. More attention is given to case studies (possibly for boxes) relevant to key themes of background papers, avoiding the re-introduction of baseline contexts as would be expected in a stand-alone paper. Examples are indicative rather than exhaustive and full referencing and further case studies at different scales can be provided, if need be.]

1 Introduction

Technological advancement has an historical role to play in shifting patterns of food production and consumption. And science, technology and innovation (STI) are central in both tackling the contributing factors to food insecurity, and in developing the social and environmental resilience and adaptability to respond to future socio-environmental challenges. Indeed, the importance of coordinated research into innovative organisational and technological solutions to issues of access, utilisation and use, availability and stability has led to its direct inclusion amongst the SDG's.

As with all technological transitions, potential risks, prohibitive costs, social externalities and political impediments should be effectively evaluated, such that potential challenges and opportunities can be anticipated. With the increased complexity and interconnectivity of the key determinants of food security, an integrated, incremental approach to adopting emerging technological and organisational practices can help significantly enhance the economic and logistical capacities of states and local communities in the timely attainment of food security.

There currently remains considerable scope for targeted technological interventions across the value chain to improve the efficiency and efficacy of food systems in anticipating and bridging the growing regional food gap. To these ends, this paper outlines possible technological and organisational interventions in response to the baseline scenarios and food security vectors outlined in the Background Papers. Considering examples from varying **scales** (*smallholder, sectoral, multi-sectoral etc.*), **directions** (*'grassroots', decentralised, integrated, policy-driven etc*.), and **affordability** (*capital-intensive, managerial etc.*), draws attention to various points of entry for policymakers when mobilising STI in response to regionally variegated food security challenges and capacities.

1.1 STI and Land and Water Management

Effective land and water management better targeted towards achieving more stable food systems can be achieved through reconsidering opportunities for STI interventions. With irrigated agriculture consuming the lion's share of available land and water resources in the region, STI applications which increase their availability, or improve the crop yield efficiency of their use are vital. So too, however, are applications which work to reduce the high rates of food loss and waste, and forward-thinking measures which insulate local populations from social and environmental shocks and transitions. In the following sections, examples of opportunities for technological and strategic interventions are discussed, with examples drawn from different scales: from smallholder adoption, to policy-driven sectoral restructuring, to international cooperation and technology transfers across the food system value chain. The structure of the paper reflects the key themes covered during the background papers. After presenting STI interventions in water availability and use, soil and land degradation and agricultural productivity, STI opportunities for improving food systems through reduced food waste and loss, are discussed. Finally, innovative approaches to finance and investment for secure food systems are touched upon.

2 Water Availability

The growing water scarcity that characterises regions across member states, and the heavy reliance on irrigated agriculture, requires more efficient accounting, monitoring, use and allocation of water among competing users. Water reallocations for land reclamation projcects can have implications for total crop consumptive use (CCU) across existing areas under cultivation. Similarly, appropriately considering the implications of reduced water availability for maintaining ecosystem services across non-cultivated areas can help ensure any such irrigation sustainably contributes to food security whilst maintaining agro-biodiversity and ecosystems.

2.1 Water Harvesting

Several countries across the region experience sporadic and sparse rainfall which, while erratic, offer opportunities if better mobilised for cultivation, also often causing severe soil erosion. Mechanisms for capturing rainwater and its subsequent safe storage and productive allocation for cultivation can be greatly improved through better mapping of the topographical and meteorological characteristics of sub-regions.

Jordanian *Badia* contour ridges planted with fodder plants, before and after (Gammoh & Oweis, 2011; ICARDA)

A contingent factor in more effective implementation of rainwater harvesting systems is the reliability and accuracy of this data. In consideration of biophysical conditions (such as rainfall patterns, soil conditions and so forth) and socioeconomic patterns (including local workforce, employment opportunities, access to markets and existing land rights, use and access), governments have opportunities to support systems of varying scales and locations. Once effective planning and site preparation is complete, low-cost water harvesting systems can be developed relatively quickly, with significant improvements in total crop consumptive use (CCU), and subsequently, optimization of plant growth and yield. In addition to increasing water for food and fodder production, and improving rural livelihoods, micro-catchment water harvesting systems also play a vital role in rehabilitating dry rangelands and combating desertification (Gammoh & Oweis, 2011). With support from the Arab Fund for Economic and Social Development (AFESD), the International Fund for Agricultural Development (IFAD) and the OPEC Fund for International Development (OFIC), ICARDA has successfully demonstrated the capacity of low-cost rainwater harvesting systems to improve and sustain water for crop and livestock production, even in some of the driest regions of member countries. Research sites in Jordanian and Syrian *Badia* used a variety of water harvesting techniques, including contour ridges and furrows, micro-basins (bunds), run-off strips and slopes. Although long-proven to be effective, access to mechanised power (tractor and plough) and accurate GPS- based auto-guiding systems for efficient land-levelling and contour setting have been identified as key factors limiting the large-scale implementation of the system. Manually identifying contour lines for ploughs can cost more than twice the total per hectare cost of ridge construction (ibid 2011, p. 1310). The mechanised *Vallerani* system of water harvesting uses a tractor-pulled plough to create continuous and intermittent contour ridges, allowing between 5,000 and 15,000m^3 of earth to be ploughed per day (in comparison to a meagre 5m^3 per person, per day).[1] ICARDA has been successfully implementing the *Vallerani* system across the *Badia* since 1997, which allows for the opening of contoured furrows at a rate of some 15-20ha per day. By modifying low-cost portable laser-guiding systems (LGS) and a tractor-mounted receiver and guidance controller, the costs and rate of micro-catchment construction was proven to be dramatically improved. Indeed, wind and water erosion of topsoil was also reduced by almost 70%.

3 Water Use Efficiency

The drive for water use efficiency in agriculture is often concentrated on attaining 'more crop per drop' through the cultivation of higher value produce, particularly for export markets. Increasing efficiency in water use and generating higher returns per unit of water used, and from initial investments in irrigation extension can also be attained by supporting irrigation technology and practices that reduce variable costs of water conveyance. However, investment in water infrastructure and new techniques for capture, conveyance, drainage, recycling, irrigation systems and so forth can often place considerable pressure on government budgets. Such investments invariably prove prohibitively costly for many smallholder farmers also.

[1] See www.vallerani.com/wp/wp-content/uploads/2015/06/Meshack-Muga-Paper-25-Final.pdf

3.1 Horizontal Expansion

Horizontal expansion in the region has most commonly entailed the 'reclaiming' arable land from the desert through often costly irrigation and soil preparation. Despite considerable investment in such schemes throughout the past century, and having featured centrally in many regional agricultural water supply improvement plans, the long-term productivity and sustainability remains yet to be proven. And the viability of plans for horizontal expansion have often fallen short in considering the affordability of investments in drip-irrigation or the time necessary to bring reclaimed land up to competitive productivity.

3.1.1 Protected Agriculture

There exist, however, other approaches to bringing marginal lands under cultivation which offer similar opportunities in growing high-value horticultural crops, fruits and vegetables through the development of greenhouse complexes and grow tunnels. More controlled environments of greenhouses present several benefits to cultivators. Fertiliser use can be more targeted, dramatically reduced evaporation of irrigation water, and pests and disease remain far easier to control. In the sunny conditions that invariably characterise more marginal lands in the region, the associated energy costs of heating and cooling greenhouses can also be greatly offset by greater use of solar energy. A more stable, controlled environment offers several advantages over open field cultivation – particularly of high-value horticultural produce. More effective management of the growing environment reduces variable costs of production by reducing the need for chemicals and pesticide use. Increases in water productivity and reuse, off-season cultivation and qualitative and quantitative yield increases. Greenhouse cultivation in marginal lands presents a simple efficient approach to horizontal expansion into marginal lands that can also be promoted at a range of scales, and with varied capital-intensity.

Sundrop Farms in Australia is a highly efficient glasshouse grow-operation now supplying 15% of the country's total tomato consumption from its 20-hectare site. Situated in a water-scarce and remote desert coastal zone, the project is organised around a concentrated solar power tower (CPS) which desalinates 1,000,000 litres of seawater daily, and provides for the heating, cooling and energy needs of the glasshouses.[2] The farm also trains crops onto vertical trellising to encourage growth, and grows crops hydroponically, recycling any excess water. Low-cost, locally produced alternatives can have considerable impacts on the productivity of marginal lands also. In Pakistan, a USAID-sponsored project has supported the widespread cultivation in poly-tunnels using inexpensive locally-sourced materials, such as bamboo, steel pipes and supporting steel wires and fishing line. Fishing line is woven together to build and inexpensive mesh to train crops upon, providing a vertical growing plane. Not only does this stimulate plant growth and yield improvements, but it also reduces pre-harvest spoilage and facilitates harvest.[3]

Within the region, ICARDA has supported local craftsmen and farmers in the fabrication, erection and operation of low-cost greenhouses on marginal lands, and with noteworthy outcomes. In Yemen,

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[2] See www.sundropfarms.com

[3] See https://www.usaid.gov/pakistan/news-information/press-releases/usaid-sponsored-farmers-showcase-their-improved-produce

farmers were able to reduce the amount of agrochemicals used by a staggering 80% without impacting yields, while farmers in Oman were able to achieve yield improvements of 60%. Across the Gulf region, ICARDA notes fifteen-fold increases in water productivity through hydroponic greenhouse operations when compared with traditional field crop cultivation. Innovative approaches to the design and manufacture of hydroponic systems as a part of their regional operations has resulted in improved affordability of hydroponic systems. The lower-cost interventions have allowed farmers to more rapidly recover initial greenhouse and hydroponic investment costs, and generate important savings on inputs, supporting both national food security priorities and rural livelihoods promotions.[4]

3.1.2 Irrigation Methods

Diesel- or electric-powered irrigation pumps remain a costly variable in the long-term feasibility of managing reclaimed lands. The costs of diesel are particularly problematic for smallholder farmers, and further embeds often subsidised diesel dependencies and expectations in agricultural practices. The operational costs of irrigation can be reduced through better use of solar-power to lift water from wells or irrigation canals, and powering field irrigation. **KarmSolar**, a start-up founded in Egypt, builds solar-powered and hybrid irrigation pumps for off-grid operation, and with minimal maintenance and infrastructural costs.[5]

Credit: www.karmsolar.com

Many companies are also developing ever-more affordable controllers, which, instead of replacing the irrigation system in its entirety, simply replace the diesel motor with a solar-powered pump-drive controller. Although capital costs are often high, the systems are easily installed, can operate unattended or even remotely.

Reduced dependence on often subsidised diesel for fuel pumps not only helps adapt farmers and the sector to fuel price volatility, and reduce government fuel subsidies, but also provides for cleaner, off-grid, affordable, low-maintenance solutions that can be easily adapted to work with existing irrigation networks. When integrated in regional plans, such systems can also play an important part of reducing the cost of rural electrification, and balance loads on national electricity grids.

4 See www.icarda.org
5 See www.karmsolar.com

3.1.3 Hydroponic Farming

Hydroponic farming is becoming increasingly popular across the globe, boasting several water use efficiency advantages over open field irrigation. Many companies are currently active across the region, with operations of varying proportions, costs and sophistication. System designs are becoming increasingly efficient as more accurate research into the optimal growing conditions for crops becomes more readily available, and as grow systems and monitoring become increasingly automated.

Typically, hydroponic cultivation works by suspending the root system of plants directly into a nutrient solution (water with appropriate amounts of key nutrient mix). Oxygen is made available for root systems by aerating the water, usually via an air-pump and bubbler. Replacing soil with water as the growing medium allows for more efficient use of water and fertilisers, with the more controlled environment also results in faster cultivation periods, fewer pests and more uniform produce. Slightly more advanced systems part-suspend roots into the nutrient solution, which is pumped from a reservoir where nutrients are mixed and water not used by plants is recycled, and residual nutrients replenished.

Egyptian Hydrofarms is a flourishing regional hydroponic farm growing high quality, pesticide-free herbs and salads on deteriorated desert soils outside Cairo. They service high-end supermarkets, hotels and fresh food markets, producing 8 times more produce per *feddan* than traditional field cultivation. With no pesticide- and salt-laden agricultural run-off, and using 80% less water than traditional agriculture, the model represents a low-cost, local adaptation of hydroponic technology to produce pollutant-free fresh produce for local markets, using limited land and water resources.[6]

Credit: www.egyptianhydrofarms.com

3.1.4 Aeroponic Farming

Aeroponic systems achieve the highest rates of water efficiency, using up to 95% less water than field grown crops. Plant roots are suspended in air as the primary growing medium, and are intermittently

[6] See www.egyptianhydrofarms.com

misted with nutrient solution. An automated timer regulates the nutrient mister, which sprays the roots at short intervals, keeping roots moist and supplied with sufficient nutrients.

US-based ***AeroFarms*** are the world's largest indoor aeroponic vertical farm, stacking 12 floors of plant beds in a former steel factory, to grow leafy greens and herbs for national supermarket chains and restaurants. The highly automated production and harvesting facility continually monitors moisture and nutrient levels, and uses optimised LED lighting to produce up to twenty crop cycles each year. Monitoring and data collection allows the company to adapt specific characteristics of crops, such as yield, colour and taste, while the sterile, controlled grow environment precludes the need for pesticides and reduces pre-harvest food and input waste.[7] Although the highly controlled environment and LED lighting represent significant capital investments and ongoing energy costs, adjustments can be made to better suit the resources and constraints in the region. Importantly, it is the innovative delivery of water and nutrients for optimising cultivation and the data-driven monitoring and adjustments to the growing conditions that offer promising ways forward for improving food systems in light of increased water scarcity.

3.1.5 Waste Water Re-use

Improved water use efficiency can also be achieved through the greater management of watershed for multiple uses and functions. Effective treatment and recycling of wastewater itself can provide several opportunities for efficiency improvements and other benefits improving the availability and quality of key agricultural inputs.

An extremely successful example of the many benefits to be found in agricultural by-products and effective wastewater management is found in the Irish dairy industry. Globally, the dairy industry is one of the largest sources of food processing wastewater, with 1.5-3 litres required to produce each litre of milk. Dairy wastewater also has up to 10 times the organic loading than municipal wastewater, with whey – a rich source of protein – proving an energy-intensive by-product to remove.

Carbery Milk Products in Ireland have developed an innovative solution to the increased production and waste management costs of surplus whey removal. Often considered a by-product, the company instead sought means of mobilising whey's high lactose content for energy generation. The whey is run through a reverse-osmosis filtration screen to separate the lactose, before sending it to a fermenter to produce 96% ethanol. The company produces enough ethanol to supply the entire Irish biofuel market, also making Ireland the only European country not using Brazilian sugarcane-derived ethanol. The steam generated from the distillation process is used to pre-heat water for milk pasteurisation and other dairy manufacturing processes – greatly reducing energy costs. The waste steam from the fermentation process is then sent to an anaerobic digester that produces methane (biogas) subsequently used by the plant for further heating and power needs. Even the warm wastewater from the digester (around 38^{o}C) is then pumped through a heat-exchange, which both pre-heats incoming milk and lowers the temperature of wastewater helping meet the discharge requirements of the local river. Another discharge requirement is that the high levels of phosphorus evident in dairy wastewater are removed

[7] See www.aerofarms.com

(some 99% average discharge levels) to negate any environmental impacts. The plant also recovers the phosphorus as a sludge which is then applied to agricultural land as a fertiliser (BlueTech Research, 2011).

***As-Samra Waste Water Treatment Plant*,** in Jordan was built to meet the wastewater treatment needs of 3.5 million inhabitants of Greater Amman and surrounding areas. The plant treats more than 70% of the total wastewater treated in Jordan including discharge from numerous septic tankers unloading in the Ain Ghazal pre-treatment plant. The plant generates 230,000kWh of hydropower and biogas on site each day – an energy recovery potential of 80% of its total needs, reducing reliance on the national grid. In addition to the 300,000 tons of CO^2 saved each year, the plant produces reusable treated wastewater for agricultural use, representing approximately 10% of the sector's total water consumption (SUEZ, 2015).

4 Soil and Land Degradation

4.1 Introduction

Soil structure and fertility are central to maintaining, if not improving, sustainable agricultural production. Focus on the importance of soil in agricultural production has waned in recent decades, and accompanied a period of increased land degradation, soil erosion, nutrient imbalance and depletion as a result of intensified cultivation and shifting natural conditions. With the growing need for yield improvement and more sustainable options for agricultural intensification, the importance of integrated soil management has become all the more pressing for farmers in the Arab region. And as active steps are taken towards understanding and improving soil health, agricultural production systems can be developed and promoted in response to more accurate, localised data on the properties, capabilities and limitations of variegated soil qualities.

Several organisations and institutions already operate across the region, specifically mandated to combat desertification and land degradation issues, such as soil erosion, soil salinity, organic carbon change, and soil contamination (FAO and ITPS, 2015).[8] Agricultural activities were reported to be the second most common cause of land degradation in Egypt, Iraq, Syria and UAE. Wind erosion was recognized as the first, dominant and common types of land degradation in 75% of ESCWA countries, located in the arid and semi-arid belt, while water erosion was the most important factor in Lebanon, Syria, Yemen, Jordan and Iraq. Soil salinity is the main type of chemical land degradation in Egypt, Iraq, Syria and UAE (Darwish and Fadel, 2017). The assessment of water erosion risks in the MENA region showed very high vulnerability to water erosion in Comoros Island, Djibouti and Lebanon, with more than 75% of land classified as very high risk. Countries revealing significant risk of soil water erosion are Algeria, Jordan, Morocco, and Palestine, with average erosion risk varying between 25% and 45% of the land in these countries.

[8] http://www.fao.org/3/a-i5199e.pdf

The Arab countries are also highly vulnerable to wind erosion caused by several factors like, the abundance of sandy and weakly aggregated soils, the rarity of vegetation cover, disturbance of surface layer and land use change. Assessment of potential wind erosion risk in the Arab countries, based on soil type and other available information shows prevalence of areas with high and medium risk of wind erosion. Globally, financial losses resulting from salinisation of irrigated land are rising to around US$ 250/ha, constituting about US$ 11 billion in total losses (FAO, 2006). There is no recent assessment of the socio-economic implications of salt-affected soils among Arab countries. However, the development in biosaline agriculture and the use of salinity tolerant genotypes by the International Centre for Biosaline Agriculture (ICBA)[9] provide examples of research demonstrating the economic viability of utilising saline soils to cultivate strategic food and feed crops, such as sorghum, millet, quinoa, salicornia, sesbania and others (ICBA, 2014).

At the national level, the regular collation and generation of scientific data on soil profiles and regional land traits plays a vital role in developing soil capability maps and soil suitability serving the assessment of current land-use and master plans. Improved and shared geo-referenced soil profile data is crucial in supporting experts and policy-makers to develop evidence-based thematic maps and policy options that support preferable crop types. It can also be deployed to ensure more targeted subsidies, and promote better conservation practices. Real-time, location-specific data are also essential in local capacity building efforts, by affording farmers the opportunity to better identify and manage varied soil resources through the timely adoption of innovative, sustainable, tailored methods and practices tailored for local capacities and contexts. Soil management techniques for greater food security can be greatly supported through timely application of data-driven adjustments to agricultural production practices. Supporting sustainable patterns of production that more sensitively correspond with local soil conditions can not only help preserve soil health and increase yields, but also mitigate increasing social demands from growing populations, competing uses and depleting resources. Through improvements and greater harmonisation in data collection, analysis, and dissemination, more effective support for sustainable, nuanced practices can be encouraged that also respond to a number of associated SDGs.

Many supply-side technological responses to food security challenges can be rendered more cost-effective and efficient when dovetailed with localised data on soil nutritional properties, biotic and abiotic stresses, and existing local farming practices and soil management. Ultimately, ensuring the sustainable achievement of food security in the region will be greatly aided by assessing, monitoring, restoring and maintaining soil health, and adapting technologies and practices accordingly.

4.2 Soil Maps

Soil data is vital to both policy-makers and farmers alike. And while national and regional soil maps exist across the Arab region, data are static (if not outdated), of low resolution and the implications of technical categorisations and assessments of land are not readily discernible outside academic audiences. Thus, their utility and decipherability to farmers and policy-makers remains marginal.

[9] http://www.biosaline.org/news/icba-annual-report-2014-now-available

The continual improvement of digital soil maps, together with accompanying interpretation and functionality, renders otherwise obscure data more accessible for supporting responsive food security policies. Such maps spatially present a combination of soil pH, water storage, electrical conductivity and carbon content data, derived from remote sensing, near- and mid-infrared spectroscopy, and field sampling, which are then used to determine the character of distribution across different regions. One such endeavour, GlobalSoilMap.net, is under development by a global consortium of scientists and researchers. The Amman-based Institute of Digital Soil Mapping acts as a regional hub for collating data for the consortium and, once complete, it will offer a fine-resolution web-based mechanism for examining shifting and functional properties of soil health over time. This output can make use of the Global Soil Partnership (GSP) system of International Network for Soil Information Institutes (INSII) to monitor and forecast the condition of the Earth's soil resources,[10] in order to update national and local soil information. When combined with meteorological data, temperature maps, rainfall characteristics, vegetation maps, infrastructural investments, preferential crop types and cultivar decisions can be made with potential for regional scalability in mind.

4.3 Conservation Agriculture

Innovative responses to improving food security need not always entail costly technology transfers. And increased interest in improving soil health for food security is in fact seeing greater interest given to practices that restore and conserve soil health through limiting intervention. 'Conservation agriculture' focuses on maintaining and improving soil health, yields and smallholder profitability through minimising soil disturbance. Locally adapted land races and methods of crop rotation, use of cover crops, mulching and 'zero-tillage' all offer opportunities for sustainable food production, weed management and soil erosion reduction and control, particularly in drylands

4.3.1 Zero-tillage

Seed drills are understood to have been used by the Babylonians from 1500 BCE and so, far from alien to the region. However, the slight modification of their use and design allows for seed planting without the need for prior tilling. 'No-tillage' or 'zero-tillage' farming is an important component of conservation agriculture, and is proving to be a vital component of innovative approaches to tackle desertification, reduce soil erosion, increase the yields obtained from marginal lands, and reduce input costs for smallholder farmers.

The growing prominence of zero-tillage farming – particularly in degraded agricultural lands – reflects an increased awareness of the effects of tillage on the soil profile. These can include the loss of organic matter, soil compaction, depletion of soil aggregates, the disruption of important soil flora and fauna, and greater top soil vulnerability to erosion. Tillage also greatly increases the rate of evaporation from topsoil which, whilst possibly suited for climates receiving more rainfall, presents a significant challenge to farm yields in drylands. Zero-tillage seed drills plant and fertilise directly into unploughed soil. Stubble from previous crops is maintained, providing erosion control whilst the variegated flora and fauna it helps accommodate in the soil profile improves biological fertility and resilience. Indeed, zero-tillage farming can help reduce soil erosion rates into line with rates of soil production, whilst untilled topsoil is

[10] http://www.fao.org/global-soil-partnership/resources/events/detail/en/c/296249/

considerably less vulnerable to extreme temperatures, water and wind erosion than that of tilled topsoil (Montgomery, 2007). Leaving post-harvest crop residue and stubble *in situ* further helps improve the structure of degraded or marginal soils with the organic matter helping structure the soil profile. This helps both maintain the moisture content of farmland and increase the rates of rainfall absorption, and thus, reducing the rate of erosive runoff. By leaving farmland untilled between harvests, soil moisture is also maintained. The higher water infiltration and reduced soil erosion can improve yields and overall productivity. It also allows farmers to shorten fallow periods between harvests in favour of crop rotation, usually with cover crops.

Zero-tillage farming also offers considerable reductions in the costs associated with labour, irrigation, fuel and machinery. As well as eliminating the need for extensive ploughing, zero-tillage seeding reduces the power requirements needed from tractors, such that less powerful, lighter, more affordable tractors can be used, further reducing soil compacting. The costs of imported zero-tillage seed drills are invariably prohibitively expensive for smallholder farmers in the region, with prices typically exceeding US$30,000. The servicing and maintenance of imported machinery provides additional costs and liabilities that impede the uptake of zero-tillage. However, low-cost zero-tillage seed drills have been developed across the developing world, and adapted to local needs and conditions, with costs ranging from US$1,000-2,000. Across South-East Asia, zero-tillage seed drills are being developed for a fraction of the cost of imported drills, also allowing for their timely maintenance and affordable sourcing of replacement parts. A recent project in the region delivered by ICARDA and the Australian government, worked in partnership with local farmers and craftsmen in developing procedures and prototypes for successfully adapting existing seed drills already in use by local smallholder farmers in Syria and Iraq. By 2013, almost 200 seeders were converted for zero-tillage and in use across Syria, Iraq, Lebanon, Jordan, Algeria, Tunisia and Morocco.[11]

4.3.2 Crop Management

Strategic crop rotations can increase soil fertility and also – when coupled with prudent pesticide use – control weed, disease and pest problems, by interrupting the build-up of disease and pest colonies and food sources. Crop rotation also avoids many of the longer term issues associated with monoculture such as nutrient mining, imbalanced nutrient content and the destruction of soil structure. Although farmers may benefit from economies of scale in the short term, the associated soil degradation undermines self-regulating mechanisms associated with biodiversity, and increases dependency on chemical inputs with implications for soil, water and food safety, and energy consumption.

Another method for controlling weed growth during zero-tillage cultivation is the targeted use of cover crops, which help both interrupt pest and weed populations, and fix nutrients in the topsoil for future cultivation. Better soil data will support choices between, for instance, longer-rooted cover crops that help draw nutrients up towards the topsoil, and leguminous cover crops that fix nitrogen sufficient to reduce synthetic applications (Badgley et al., 2007). Mulching, either with organic ground cover, paper or polythene sheet, is another approach which can dramatically curtail weed growth and soil nutrient waste, and helps further reduce the rate of evaporation from topsoil. Seeds are then planted in evenly-

[11] See www.icarda.org/conservation-agriculture/zero-tillage-seeders

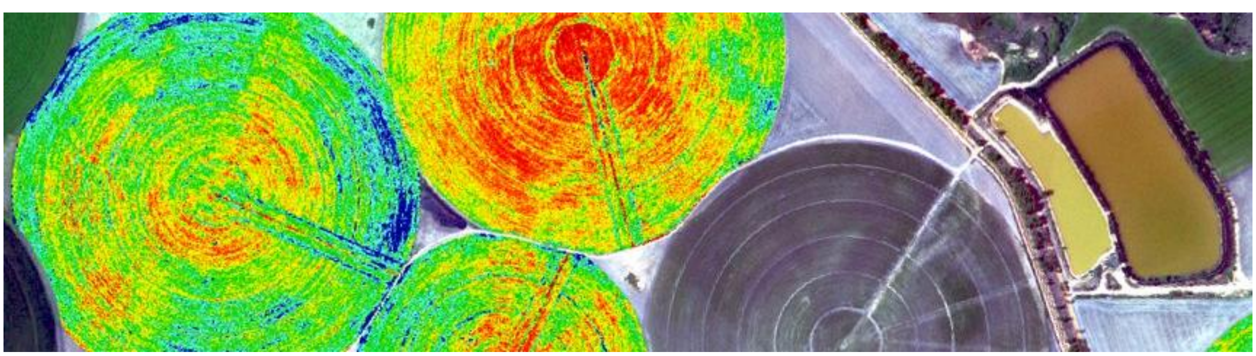
space openings in this ground cover, allowing for more targeted application of fertiliser and water, more efficient weeding where needed, and reducing run-off.

Scientific research and technology which allow for more accurate real-time mapping and classification of land and water resources are crucial variables in ensuring more effective deployment of increasingly scarce resources for cultivation. As well as informing and aiding in policies targeting expanding available resources – either through reclamation, reuse or extraction – better classification also supports the timely restoration and bioremediation of depleted and contaminated soils, and improvement of regionally scarce water supplies.

5 Agricultural Productivity and Production

5.1 Precision Agriculture

Precision agriculture could be understood as a catch-all phrase for describing the more automated, localised, time-sensitive management of the cultivation process. It focuses on mobilising real-time data and the increased automation of agricultural processes to increase the overall efficiencies of food cultivation. Digital farming is becoming one of the leading growth industries with considerable interest and investment from technology, chemical and private equity firms keen to capitalise on the urgency of reducing margins of error and increasing productivity. Such advances are evident in, for instance, the continual development and increased use of remote sensing and satellite-guided farm machinery. On larger commercial farm operations, autonomous-driving tractors cover extensive plots, differentially dispensing fertilisers and pesticides according to historic yield data, real-time soil and plant tissue data, and weather forecasts. The combination of these data are allowing the developers of these 'AgTech' products to make increasingly accurate yield predictions and suggest more targeted, data-driven in-field input application adjustments. Soil yield and biomass maps provide site-specific data which allow for more precise farming decisions to be made, reducing input use, agricultural run-off, waste, and increasing yields. It also allows for crop yields to be estimated, aiding farmers in the pre-harvest marketing of their products – again reducing the likelihood of food waste and price fluctuations that can often affect wholesale food markets during harvest periods. Synthesising and interpreting data is key in informing yield-improving decisions, but such technologies are often prohibitively expensive.



SpecTerra **digital multi-spectral biomas and yield maps: high yield areas are shown by blue, whilst red areas represent low yield forecasts. (Credit: www.SpecTerra.com.au)**

5.1.1 The '*Internet of Things*' (IoT)

Mounting increasingly specialised and affordable sensors and receivers across different stages of the production processes allows for the greater automation of routine cultivation processes in response to feedback from a range of sensors, monitoring pH levels, moisture levels and sunlight for example. This field-level data can be combined with real-time weather forecasts and other data to significantly improve the efficiency of water, fertiliser and other input use, and pre-empt drought events or impacts on yield reductions.

Modern hardware and proprietary software involved in such systems, together with accessing the collated data, can often be prohibitively expensive. There already exist, however, a host of open-source programmes and inexpensive devises that can be assembled for greater automation of irrigation and other cultivation processes. Vitally, the affordability of increased monitoring and automation offers prospects of more efficient use of inputs, and labour-hours, allowing for greater yields, and reduced wastage. Installing cheap sensors into grow operations can provide farmers with real-time updates on changes in grow conditions, such as soil moisture changes with changes in relative humidity and air temperature, or sunlight with soil temperature. Certain parameters can be set that, for example, automatically activate irrigation pumps, based on readings from soil moisture and temperature sensors; activate heat pumps to regulate night time glasshouse temperatures; or control ventilation based on optimal relative humidity and air temperature data. Nutrients can also be mixed and delivered automatically, and the pH of hydroponic reservoirs or fish tanks in aquaponics systems monitored and regulated. Individual zones can be set up, depending on the optimal watering patterns or nutrient needs of different crops. The processes and data collected by such sensors can be monitored and controlled from mobile phones using free, open-source software. These operations are ideal for smaller grow operations, particularly in greenhouses. The affordability of such hardware also allows smallholders to reduce the risks of crop failure and harness real-time farm conditions for optimised cultivation.

5.1.2 Hyperspectral Imaging

Hyperspectral imaging – or spectroscopy – enables remote measurement of field data about the health of crops and soils. The varying physiology and traits of different crops means that they reflect light differently. The greater differentiation hyperspectral images offer, when combined with specific crop variety data and yield traits, and historical weather and climatic records, offers targeted, crop-specific guidance for optimal management of pesticide and fertiliser use, and even the possible advantages of developing sources of supplemental irrigation. This imaging type allows for the detection of nitrogen, potassium, phosphorus levels, weeds, crop diseases, and crop health, maturity and yield prediction. One such company, *Gamaya*, offers precision farming services based on remote-sensing, hyperspectral imaging and weather records.[12] Through combining a variety of crop, region and weather data and modelling, the company produces detailed maps that visualise different agronomic issues, such as weed infestations, crop infections, and nutrient deficiencies. The company combines this crop performance data with information on yield potential and crop models, to make crop management suggestions. Such

[12] See www.gamaya.com

services, again, can be costly which may undermine potential yield improvements. However, the costs and sizes of hyperspectral cameras themselves have dropped considerably over the past two decades, providing opportunities for regional agricultural research centres, universities and local entrepreneurs – with adequate funding – to develop more affordable drone-mounted alternatives for surveying crops and developing yield and bird's-eye crop health field maps. Locally, this can help optimise harvesting timing and crop quality. On a national level, more accurate advanced predictions and monitoring of yield and crop growth could allow for alternative supplies from global commodity markets to be tendered ahead of season. In addition, the national Centres for Remote Sensing based in Arab countries received due capacity building through several World Bank-, GEF- and EU-funded projects, and are also capable of producing national and local crop distribution maps, ET maps and make crop yield estimation using open access satellite images and modules.

5.2 Yield

5.2.1 Seeds – Strength through Diversity

Successive interventions in the history of cultivation in many countries in the region has resulted in some plant varieties being abandoned for commercial cultivation, possibly due to once-less desirable traits, genetic flaws or susceptibilities to disease. This historic 'narrowing' and homogenisation of the landrace of strategic crops has also contributed to increased vulnerability of crops to climatic and ecological shifts. Overcoming the corresponding challenge in expanding yield capacity and shrinking pre-harvest waste, and reliance on pesticides and fertilisers has a significant role to play in ensuring food security and rural livelihoods.

With the growing prevalence of nutritional imbalances among local populations and the increasing vulnerability to climatic shifts, greater research into seed and plant varieties best suited to deteriorating environmental conditions, and their subsequent deployment, offers great potential to improving food systems. Agricultural and scientific communities in the region have played an historic role in the preservation and selective breeding of seed varieties, suited to local environmental conditions and local nutritional preferences. The local management of regionally-unique seed varieties has already proved vital in reducing the impacts of conflict and instability on local cultivation and, thus, food security.[13] Further coordinating these long-standing regional practices of breeding and storing plant varieties provides further scope for reducing the socio-economic drivers of conflict and facilitating the arduous process of post-conflict reconstruction – often in increasingly challenged ecological conditions and population growth.

ICARDA's recent development of an agricultural gene bank database search tool is a significant improvement to research into specific 'target' plant traits. The regional development supports identifying and further enhancing the genetic properties of 'heirloom' crops. The selective breeding of more stress- and pest-resistant plants can help attain higher yields and crop predictability in accordance with the increasingly uncertain, challenging agro-ecological characteristics affecting many countries within the region.

[13] See (REF article on ICARDA and Seed Bank)

Elsewhere, many research communities continue to develop and promote seeds modified with genetic traits drawn from different organisms, specifically targeting the challenging climatic contexts in the region. The selective modification of the traits, capabilities and characteristics of different plant varieties also has a role to play in generating yield improvements, tolerance and resistance to droughts, pests and changing soil profiles. Many concerns remain around the affordability, ethical considerations and potential market vulnerabilities implicated in the introduction of genetically modified crops in the region. Nonetheless, increasing amounts of research and product development by private sector companies and philanthropic organisations are generating a plethora of products tailored to the climatic and nutritional needs of food insecure communities across the region. Greater focus on research-based evaluations, risk assessments and developing bio-safety regulations is one way to potentially engage with transgenic crops whilst safeguarding the capacity, durability and security of agricultural communities.

5.2.2 Fertilisers

Fertilisers play an important role in plant production and better-targeted, more judicial application of macro-nutrients in soils (or other growth media) is key to increasing yields, reducing run-off pollution and stabilising food systems. Nitrogen plays a key role in formulating key proteins in plants, while phosphorus is a vital nutrient in plant photosynthesis, and seed and root growth. Sufficient amounts of Potassium are required to ensure effective stem strength and rate of growth. The historically intensified cultivation of cash crops has depleted their levels in traditional sites of cultivation, mostly due to their not having been restored at the same rates of extraction. The production of chemically-derived inputs is invariably energy-intensive, and price fluctuations can significantly impact the profitability of production. Although fertiliser use in most countries in the region has remained comparatively low, many inputs or local manufacturers still receive state-subsidies, adding additional strain to government budgets. As demonstrated in the Carbery Dairy wastewater and phosphate recovery system (above), considerable scope exists for reclaiming vital nutrients and inputs, such as phosphorus and biofuel, from food systems waste and by-products.

Aquaponic farms are also becoming increasingly prevalent in the region, demonstrating the effectiveness of holistic, innovative approaches to integrated food systems management in responding to many of the supply-side constraints of food systems in drylands. Aquaponic cultivation combines aquaculture fish farming and hydroponic cultivation in a closed, self-sustaining system. A particularly interesting aspect to these systems is the approach to sourcing sustainable supplies of key agricultural inputs, and fertilisers in particular. In the absence of naturally occurring key nutrients in the soil profile, hydroponic systems require the addition of key nutrients to water for effective plant growth. By farming fish onsite and in unison with fruit and vegetable crops, the ammonia-rich waste water from the fish farming operation is used as the growth medium for hydroponic crop cultivation. Rather than rely on chemical fertilisers for cultivation, aquaponic systems locally generate important nitrates for plant growth, and purify otherwise toxic ammonia-laden water which is then cycled back into fish ponds. Not only does such a closed system provide vital nutrients for plant growth, and efficiently process and recycle water for fish farming, but it also increases the economic viability of providing a healthy, toxin-free source of protein for local markets. Several aquaponic businesses have begun trading across the region in the last decade, demonstrating the viability of more integrated farming business models, and holding potential for growth and efficiency improvements.

Bustan – an Egyptian-based aquaponic farm successfully farming fish and fresh produce along the desert peripheries of Cairo is a regionally successful example of zero-waste farming systems. Fish are farmed without the need for antibiotics or hormones, and crops are cultivated without the use of pesticides and In addition to the daily operation of the farm, the owner regularly hosts research centres and academic institutions and even other entrepreneurs keen to learn more about the practicalities of efficiently managing sustainable aquaponic farming operations on marginal lands. While there exists considerable scope of innovation, technological improvement, automation and capital cost reductions, the farm's produce are well-marketed and increasingly sought after locally, as consumers become more conscious of safety and sustainability issues in fish and fresh produce production.[14]

Agrimatic is another Egypt-based aquaponic cultivator yielding up to ten times more produce per *feddan* when compared to traditional agricultural methods, with no pesticides, fertilisers, chemicals, hormones or antibiotics. The pre-seeded plants floating in the nutrient-rich solution also grow more than twice as fast. The highly-collaborative business model allows the company to respond to customer feedback and preferences, and improve farming conditions according to advice and support from commercial tilapia breeding stations and academic researchers. The company also reports that patent-pending technological developments allow their operations to save up to 99% water and 94% energy, when compared with traditional field cultivation.[15]

5.2.3 Plant and Soil Treatments

Other scientific developments offer examples of the value of issue-driven research and innovation, in increasing yields and supply-side food security.

T6P: UK scientists have developed a synthetic precursor molecule of the naturally occurring sugar signal, *trehalose 6-phospate* (T6P), which regulates and allocates sucrose use. By influencing how plants use sucrose – the main fuel source for photosynthesis – both yield and crop-stress resilience can be increased. When applied directly to wheat crops, the chemical molecule increases both the size and starch content by up to 20%, and also enabled plants to recover from sporadic drought. The T6P 'precursor' is added to a solution and sprayed on either the ears or the whole plant, causing a sudden release of T6P and starch production in the grain, and enhance plant recovery and resurrection performance after drought periods (Griffiths et al., 2016). As T6P performs the same function in all plants, the approach offers potential to improve yields across a wide range of crop types in the region.

Friendly Fungi: Another innovative approach for improving yields and drought resilience among certain wheat cultivars may involve the introduction of 'useful' fungi to plant roots – the *Arbuscular Mycorrhizal* fungi group (AM fungi). Research from Aarhus University widens understanding of the important role certain fungi play in nutrient and water absorption, as well as resilience to biotic stresses, such as pests and diseases. The symbiotic relationship between fungi and plant roots also play an important role

[14] See www.bustanaquaponics.com
[15] See www.agrimaticfarms.com

during drought periods, providing phosphorus and regulating nitrogen, resulting in improved rates of photosynthesis and biomass production (Zhou, Ravnskov, Jiang, & Wollenweber, 2015).

Cool Terra is an 'engineered biocarbon' made from renewable biomass demonstrated as positively impacting the biological, physical and chemical properties of soils, in turn increasing yields and productivity.[16] Its introduction to soil profiles reduces water consumption, improves soil health, retains soil water, encourages beneficial microbe growth in the soil and helps optimise fertiliser use by keeping nutrients in the root zone for longer periods. Greater efficiency of fertiliser use also reduces the associated issues of agricultural runoff and fertiliser leaching.

Thymox – a non-toxic, biodegradable agricultural disinfectant derived from thyme oil – has anti-viral, anti-bacterial and anti-fungal properties with applications in crop protection and livestock health. Botanically derived, it is understood to be highly effective without damaging the environment or living tissue.

5.3 Vertical Expansion

5.3.1 Urban and Peri-Urban Farming

The loss of arable land to urbanisation is a problematic trend affecting many countries in the region, and likely to be exacerbated by population growth and increased rates of rural-urban migration. Indeed, by 2050, some 75% of the world's anticipated 9 billion-strong population will be urbanised, making laying the groundwork for durable supply chains all the more pressing. As rural populations and livelihoods decline, the areas so urgently needed to produce food for these urban populations are becoming increasingly abandoned. There are, however, developments in the spatial organisation of cultivation that can help mitigate this loss of arable land mass and increased urbanisation, whist also shortening food chain length and reducing food waste and prices.

The assessment of urban spatial distribution in the Arab region using Landsat images in 1990 and 2015 revealed a general increase of the area of human settlements (Darwish and Fadel, 2017). Changes in urban area coverage shows an increase in 0.4 % of the total land area of the Arab countries. Urban sprawl occurred mainly on the coastal area and river banks. The main increase of urban expansion for the last twenty five years was observed on highly and moderately productive soils. It occurred in Jordan (91.5%), Sudan (76.8%), Iraq (54%), Algeria (41%), Egypt (36%), Syria (25.2%), 17% (Libya), and Morocco (13%) No urban expansion in Palestine occurred on highly productive soils compared to average values ranging between 9% (Algeria), 8% (Somalia), 4% (Lebanon, Syria and Iraq) and 1.3% (Yemen).

In developing more locally targeted responses to observed challenges, understanding the importance of supply chain length is vital. Issues of food waste, nutrient deterioration, alternative food sources, access, and market dynamics affecting urban food supply may emerge from closer examination of the role of supply-chain length in local food supply stability. Again, by tracking, monitoring, and collating data on prices, local yields, input availability and so forth, organisational 'bottlenecks' may be identified that warrant non-conventional infrastructural investment or support.

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[16] See www.coolplanet.com/cool-terra/

Short-chain systems see fewer transactions between producer and end consumer, evident in urban farmer's markets, or among rural subsistence farmers. 'Long-chain' systems, where particular foods are imported considerable distances and through several intermediaries are more likely vulnerable to food contamination, nutrient deterioration, spoilage, spillage and price increases – all impacting urban food security. Shortening supply chains will likely result in improved productivity, evident in fresher, cheaper supplies of food, available faster and in greater quantities. There is considerable momentum forming behind 'urban farming' movements across the globe, with systems becoming increasingly efficient, automated and also integrated into even high-end urban supply chains.

Growing Underground: Beneath the bustling streets of London, crowd-funded urban farmers, *Growing Underground*, use LED lighting and hydroponics to cultivate gourmet herbs and salads that serve local farmer's markets, restaurants and even deliver. Located in disused London underground air raid shelter, the project boasts 'zero-air mile' products, and the freshest packed produce from farm to fork within 4 hours.[17] The project also offers a host of other social benefits, such as product price stability, generating inner-city employment opportunities, the productive utilisation of redundant spaces, pesticide-free cultivation, longer product shelf-life helping to reduce food waste, 70% less water use than conventional cultivation methods, no polluting agricultural run-off, and lower energy consumption than traditional glasshouse cultivation. Importantly, by constructing an innovative business model that specifically targets food waste, environmental damage, and urban social challenges, the company has generated a significant support base, been able to crowd-fund initial capital costs, and develop key partnerships with top celebrity chefs, Transport for London, and local governments.

Across Cairo and Amman, rooftops are being transformed into self-sustaining oases of sustainability and food security. Amman-based food security start-up ***Meezan*** responds to Jordan's growing food and water crises by helping urban populations develop low-tech, integrated organic, aquaponics and hydroponic urban farming projects that mitigate the growing resource dependences that characterise the region.[18] One of their urban projects has seen 9 of their 'freedom machines' installed on rooftops across Jordan, Palestine and even Switzerland. The system combines five different technologies, including aquaponics farming, rainwater harvesting, and rooftop insulation to mitigate many of the resource-demanding conditions of the Amman cityscape. The company also successfully developed a model ecological farm that has employed permaculture farming techniques for local rainwater harvesting and desert land reclamation, using organic pesticides, solar power and rotating sun shading grow houses, that have rehabilitated an otherwise barren, arid mountainous landscape without the use of irrigation.

[17] See www.growing-underground.com
[18] See www.meezan.cc

Credit: Schaduf

Similarly, Cairo-based ***Schaduf*** have transformed what was initially a series of rooftop farming projects into a vibrant technology hub for innovative, low-cost irrigation and farming solutions to local income and food security, using locally available materials. The company regularly hosts researchers, schools and other urban entrepreneurs. Their business model allows for their community farming and outreach projects that target Cairo's sprawling informal housing districts to be subsidised by installing high-end vertical growing walls and roof gardens for corporate clients and residents of gated communities. Striving to develop ever-more affordable hydroponic systems, they now set up $20m^2$ roof farms for around $360, enabling residents to supplement their incomes by up to 40% per month from produce sales. Importantly for the company, the rooftop gardens also create 'micro-climates' where children can play and learn, and the city's high carbon emissions and temperatures can be absorbed.[19]

6 Food Loss and Waste

6.1 Introduction

If any increases in production and yield are to be captured, it is important to ensure a capacity to handle increased production benefits, not least through minimising existing post-harvest crop and grain spoilage. Each stage of the dynamic processes forming food systems – including production, storage, transportation, processing, trade and retail – provide potential points of entry for systemic improvements and waste reduction. Evaluating the requirements, constraints and liabilities at each interval is vital to building more integrated, efficient and stable food systems.

6.2 Post-Harvest Storage

Poor post-harvest storage can contribute significantly to food insecurity. Post-harvest losses reduce overall market supply contributing to increased food prices. Such losses also represent a waste of the natural resources, inputs and labour-hours used for produce, process, handle and transport food.

The persistent levels of food loss across the region provide an important point of intervention for improving food availability and utilisation. Improving post-harvest produce management can reduce breakage, infestation, spillage, contamination and nutrient degradation. More effective storage facilities

[19] See www.schaduf.com

promise not only to reduce crop spoilage, but also provide important buffer stocks for safeguarding against price fluctuations or local food shortages. In addition to national storage and processing facilities which often require significant investments, there are also important options available for local province- or village-level (decentralised) storage and processing facilities.

Local storage conditions are often impacted by the late preparation of storage structures, late harvesting and storage bags with a low shelf-life, that soon deteriorate. Shortages of time and finance are limiting factors that make low-cost, local and simple solutions all the more necessary. Simple post-harvest interventions such as increased solar-powered dryer use and better designed silos offers many advantages in providing local food security, reducing food waste and spoilage during transportation and storage, and also stabilising crop market prices.

In preparing harvested crops such as grains for storage, adequate drying is needed, usually below 14%, in order to reduce the moisture levels to those conducive to preventing bacterial and fungal proliferation. Lowering temperatures also help preserve grain nutrients and is important in insects and mite prevention. With an abundance of sunlight across the region, solar-powered crop driers provide affordable and sustainable ways of ensuring quicker drying, sorting and packaging of crops for storage. Timely drying and transition to storage has additional impacts on nutrient profiles of stored grains. The initial costs can be minimal, whilst maintenance is easily supported locally. Solar installations offer opportunities for other off-grid rural electrification and other household industry applications.

The **GrainPro** solar bubble dryer is one example of a low-cost approach to solar-drying for smallholder farmers. Farmers spread out the crops in the solar dryer, as air is cycled through using a solar-powered fan attached at one end. The transparent covering traps solar heat which heats the commodities, with the resulting vapour released from the rear vent.

Larger grain dryers may consider retrofitting replacing energy intensive propane and electricity grain drying systems with solar-powered dryers with significant energy-, cost- and waste-reducing advantages.

Hermetic silo bags: having been used extensively across different countries for some time, with individual bags ranging in storage capacity, from 50kg to 200 tonnes. The hermetic sealing allows for the naturally 'respiring' grains and other organisms to consume remaining oxygen and emitting CO_2, helping conserve the grains. Larger hermetic 'cocoons' made from robust PVC storage can be set up indoors or in fields, and are designed to contain smaller storage sacks. Valves allow oxygen to be removed and carbon dioxide to be cycled through the grain stock, acting to preserve contained grains and prevent insect populations from taking hold. No fumigation is required and the more durable cocoons can be reused in following seasons.

Horizontal silage field bags are a lower-cost, flexible storage solution for *in situ* processing and storage, offer a rapidly deployable response to regional storage issues. Suffering from up to 25% grain storage waste, and keen to reduce dependency on international grain markets, Egypt successfully tested their effectiveness in storing some 2,000 tonnes of wheat in *Daqahliyya* province. The costs were found to be significantly lower to both burlap, and metal silo storage systems (El-Kholy, 2015). Changes in CO_2 levels inside the silo bags, grain moisture content, fungal and total microbial load count, percentage of aflatoxins, insect count, and physical, mechanical and other qualitative changes to the grain were monitored over one season, with minimal losses in grain quality and quantity reported. Long distances between production areas, ports and processing facilities also make horizontal wheat silo bags an important instrument for expanding national and regional storage capacity and efficacy. It also has considerable potential for reducing storage losses affecting other grains and legumes (ibid).

Simply designed, locally produced tin **metal silos** have also been developed affordably, offering more durable silage solutions for smallholder grain producers. In addition to their effectiveness in reducing storage losses and stabilising household food supplies, the fabrication and sale of the silos is also an opportunity for generating new rural livelihoods.

6.3 Retail and Consumer Waste

Another innovative response mobilising food waste for food security is evident in the ***Aponic*** aeroponic circular production system, that takes food waste reuse and aquaponic cultivation to new heights. Departing from the other systems described above, the cycle starts with supermarket food waste, used to breed black soldier fly larvae, which are subsequently fed to the fish. Water is siphoned from the fish tank and pumped through tubes with friendly bacteria which bio-digest the ammonia from the fish waste, turning it into nitrate for the irrigated plants. Chia plants (high in Omega 3 oils) are grown, some of which is also fed to the black soldier fly larvae, producing an Omega 3-rich fish food, and the cycle repeats. Only iron needs adding to the solution, not otherwise present in the fish waste. Such a system is an interesting example of possible opportunities that lay even in supermarket food waste, for producing much-needed sources of protein.

Tagaddod, a renewable energy and waste management company operating in the region, produces biodiesel and food grade glycerol from a growing number of restaurants, hotels and factories.[20] Not only does the operation help reduce the increasingly problematic disposal of waste oil, but also mitigates local reliance on fossil fuels, the regional sensitivity to diesel price fluctuations and the budgetary burden of diesel subsidies. Fuel price fluctuations have presented a stubborn stumbling block to the long-term viability of some desert land reclamation projects promoting smallholder farms. These farmers often come to rely on diesel powered pumps for irrigation and are thus disproportionately affected by price fluctuations. Low-cost, decentralised technological developments such as biodiesel production from used cooking oil are also an alternative to crop-derived biofuels which compete for increasingly limited water and land resources.

The ***Bashaier Foundation***, in partnership with Orange Egypt, launched a digital network for agricultural marketing in September 2016. The mobile service is designed to provide smallholder farmers with key information, and the opportunity to interact directly with all parties in the agricultural marketing system to market, sell and buy their products. Along with the accompanying mobile app, farmers and service users obtain updated price information on commodities, such as vegetables, fruits, medicinal and aromatic plants, both via the mobile app and text messages. Price updates and text message alerts for

[20] See www.tagaddod.com

specified commodities are periodically sent to farmers' mobile phones. Farmers also receive localised weather forecasts and agricultural news.

7 Financing Food Security

7.1 Introduction

Government approaches to ensuring food security are often centrally managed, capital-intensive, involving significant up-front capital expenditure. Historically, the sites of these investments – such as reclaimed desert land, storage facilities, processing centres, logistics hubs or research centres – rarely generate the revenues necessary to cover ongoing costs of operation, maintenance and periodic modernisation. As a result, such facilities either represent a significant strain on government budgets or fall into disrepair. The opportunity-costs for such investments and the deteriorating long-term efficiencies of some such operations epitomise a central challenge inherent in many responses to achieving food security that focus solely on increasing supply. Greater coordination of investment and the financing of agricultural production, technology transfers, and institutional capacity building within broader strategies of food systems optimisation, overall efficiency and stability of the food supply value chain can be attained.

By also focussing on demand-side dynamics and targeting food loss and waste, new revenue streams can be developed that mobilise agricultural by-products as inputs into new business models. Responding to food insecurity represents an opportunity, not only to attract private investment into infrastructural cost recovery and waste reduction, but also to steer private investment towards engendering more sustainable business models.

Investments in value chain efficiency – through food system waste reuse, loss reduction and so forth – most often represent comparably lower extra costs than infrastructural investments for largescale land reclamation projects, hydraulic infrastructure construction, or overseas farm operations for instance. Incentivising food systems waste and loss reuse and reduction can also target the recovery of key agricultural production inputs, such as energy and fertilisers, also further reducing waste.

Growing populations, rapid urbanisation and limited natural resources inform challenging new environments for ensuring affordable, timely access to affordable, nutritious food supplies. They also, however, provide impetus for improving the efficiency and profitability of rapidly expanding consumer markets, with considerable growth potential.

7.2 Investment

Food and agricultural technology start-ups are attracting increasing amounts of investment and attention from large corporations and financial institutions, recognising the revolutionary potential of greater mobilisation of disparate databases to driven increasingly precise, automated farming operations. In addition, innovative approaches to financing and marketing technological improvements that respond to key drivers of food insecurity are already evident in the rapidly increasing number of start-up labs, ag-tech incubators and accelerators, and crowd-sourced seed funding platforms operating in the region. These new financial institutions play a crucial role in supporting and scaling affordable, environmentally sound technologies and innovations that respond to technological performance gaps across several sectors. Not only do these platforms help introduce inventors, entrepreneurs and innovators to much-needed seed funding, but they also facilitate the marketing of new technological solutions, whilst generating social support for products, even before launch. Facilitating the founding of funds targeting food security concerns can help local entrepreneurs access the resources, support and collaboration necessary for developing regionally-tailored, lower-cost technological solutions to constantly evolving vectors of food insecurity.

The *I:GROW* entrepreneurship initiative in Morocco for instance, promotes entrepreneurial responses to challenges to the agricultural sector by offering financial, technical and mentoring support to young Moroccans from rural communities. *Flat6Labs* is another start-up accelerator operating out of Cairo, Jeddah, Abu Dhabi, Beirut and Tunis that continues to support innovative technological solutions to persistent regional challenges. Several successful projects are being developed through timely access to support and funding, such as the ***Bustan*** aquaponics project, mentioned above.

Another seed funding platform based in Jordan, *Oasis500*, that offers funding and support to develop from tech start-ups into scalable businesses. One such venture, ***Revofarm***, supports small-holder farmers in making agricultural intelligence-driven field-level decisions which help increase yields and mitigate the growing uncertainty of climatic shifts. The accompanying SMS to Web app allows farmers to directly market their goods with a wider network of potential buyers whilst reducing logistics costs. ***Meezan***, discussed above, also received seed funding from *Oasis500*.

Greater institutional promotion and support for potential applicants would help ensure more equitable, successful access to such resources, whilst further cultivating an enabling environment for local, sustainable, issue-based innovation.

7.3 Incentives and Subsidies

Farmers, food processors, wholesale traders and retailers have a significant role to play in generating more stable food systems. Incentivising food producers and retailers to prioritise food safety and nutrition, possibly through industry targets, awards and regulations, could help mobilise the private sector more firmly in successfully marketing healthy diets. Yet government incentives and subsidies can generate a host of negative externalities not immediately captured in initial cost-benefit analyses. In addition to the more apparent budgetary distortions and possible loss of government revenue, markets continue to view waste loss and systemic failures as rent-seeking opportunities, rather than market opportunities.

More effective management of food subsidies can also ensure timely access to basic food stuffs for those in need of support. The improvement of the subsidy smart card in Egypt, in partnership with Visa, not only facilitates access to food, but also provides anonymised data on consumption patterns, which could better inform future nutrition policies, and effective import substitution policies. The high number of Syrian refugees dispersed across Lebanon, Egypt, Jordan, Turkey and Iraq has posed a challenge for aid agencies in wanting to ensure the food security and welfare. In response, aid agencies and charities are increasingly registering beneficiaries using biometric verification and using smartcards to distribute assistance that can then be used in partner retail outlets. Indeed, it is estimated some 1.6 million Syrian refugees are already using iris scanning technology to access a wide variety of different financial, social and food services.

There is a tendency for investment incentives – particularly when in response to a public crisis or challenge – to function as subsidies, thus distorting performance metrics, state budgets and possibly even functioning as political rents. By Instead viewing food systems' waste as *resources*, and gaps as opportunities, both small entrepreneurs and larger investors can begin to be deployed in innovating, improving and developing business models that support self-sustaining, stable food systems.

The greater capture and mobilisation of food production by-products represents a significant source of inputs for agricultural production. This entails developing systems that not only reduce the amount of food waste and loss through improved storage, transportation and processing facilities, but also through the recapture and reuse of by-products, not least for energy and nutrient retrieval. Decentralising these processes by encouraging private sector food system stakeholders to locally modify behaviour and practice will also help offset financial burdens, providing opportunities for smaller scale innovation, investments and operation. 'Harnessing the capacity of the private sector' could be usefully reimagined to include the strategically planned, data-driven, effectively monitored and crowd-funded mobilisation of social actors of varying capacities in generating innovative, integrated localised solutions to evolving constraints of food systems.

8 Tech Vectors for Food Security

This paper has introduced insights into technological and organisational interventions at a range of scales currently in use or under development that can contribute to building more adaptive, stable food systems that are able to efficiently respond to shifting social and ecological conditions. Observable in these examples is a general trend across the private sector towards innovations and technological improvements that primarily tackle or mobilise food system waste. Such a trend has not formed in the absence of government intervention. Instead, data-driven strategic planning, incentives and investment from governments have created an enabling environment for innovation. In this environment, innovation and technological advancements for greater productivity are shifting focus away from increases in total outputs through greater use of land, water and inputs, towards decreasing total inputs needed to satisfy demand. The examples above, share a common theme in mobilising opportunities that reside both in the 'externalities' of production, and the intersections between different links in the value chain. The deployment of technology and organisational innovation in such a way targets food systems efficiency, and loss and waste reduction and reuse, as a parallel path to yield increases, towards tangible improvements in food security.

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