Supplemental Irrigation:

A Promising Climate-Smart Practice for Dryland Agriculture

Field trials of supplemental irrigation practice with different levels of deficit to study the yield and water productivity response.

Overview of practice

Supplemental irrigation - *the addition of limited amounts of water to essentially rainfed crops to improve and stabilize yields when rainfall fails to provide sufficient moisture for normal plant growth* - is an effective response to alleviating the adverse effects of soil moisture stress on the yield of rainfed crops during dry spells. Supplemental irrigation, especially during critical crop growth stages, can improve crop yield and water productivity.

GACSA
GLOBAL ALLIANCE FOR CLIMATE-SMART AGRICULTURE

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KEY MESSAGES

1. Supplemental irrigation allows farmers to plant their crops early, increasing yields and preventing exposure to terminal heat and drought stress in hot areas, and frost in cold areas

2. The amount and timing of SI are optimally scheduled not to provide moisture stress-free conditions throughout the growing season, but rather to ensure that a minimum amount of water is available during the critical stages of crop growth that would permit optimal yield.

3. Supplemental irrigation, especially during critical crop growth stages, can improve crop yield and water productivity.

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Overview of practice

About 41% of the Earth's land area is classified as dryland (ISPC 2015), wherein the farming system is characterized by approximately 300–500 mm of annual rainfall, much of which falls in winter and spring (Hyman *et al*. 2008). The low rainfall, which is not only insufficient for production of many crops but irregular, constitutes a major challenge to profitable farming in dry areas. Nevertheless, local populations depend on these lands for producing food. Drylands are inhabited by more than two billion people worldwide.

Since water is the most limiting factor for agricultural production, the primary problem is to identify the most effective means of storing natural precipitation in the soil and how to retain this water until needed by the plants. In drylands, water received as rain or snow can easily be lost before it can be used by a crop (Inanaga *et al*. 2005). Rainfall amounts and distribution during the crop season are suboptimal. Normally, crop evapotranspiration exceeds the 300–500 mm seasonal rainfall and the irregular rainfall results in periods of drought which stress crops and cause substantial yield losses. Mainly for this reason, in the West Asia and North Africa (WANA) region, average wheat yields are less than 2 t ha^{-1}, one-third of its potential (Oweis and Hachum 2012).

Supplemental irrigation (SI) has been a promising practice to overcome the constraints outlined above. SI is defined as the addition of limited amounts of water to essentially rainfed crops to improve and stabilize yields when rainfall fails to provide sufficient moisture for normal plant growth (Oweis and Hachum 2012). SI is the opposite of conventional irrigation. In the latter, the principal source of moisture is fully controlled irrigation water, and highly variable limited precipitation is only supplementary. SI is dependent on the precipitation as a primary source of water for the crop. SI is an effective response to alleviating the adverse effects of soil moisture stress on the yield of rainfed crops during dry spells (Rockström *et al*. 2007). A shortage of soil moisture in rainfed areas often occurs during the most sensitive stages of crop growth (flowering and grain filling). As a result, rainfed crop growth is poor and yield is consequently low. Supplemental irrigation, especially during critical crop growth stages, can improve crop yield and water productivity. Substantial increases in rainfed crop yields, in response to the application of relatively small amounts of water, have been observed (Oweis and Hachum 2003). When rainfall is low, more water is needed, but the response is greater, and yield increases are remarkable even when rainfall is as high as 500 mm (Oweis and Hachum 2012).

Benefits of the practice

- Supplemental irrigation is a simple but highly effective technology that allows farmers to plant and manage crops at the optimal time, without being at the mercy of unpredictable rainfall.
- ICARDA and its partners have developed and optimized supplemental irrigation packages for different crops and cropping systems in Ethiopia, Iran, Jordan, Lebanon, Pakistan, Morocco, Syria, Tunisia and Turkey. Several countries in sub-Saharan Africa, including Burkina Faso and Niger, have launched their own programs based on this model. Supplemental irrigation provides multiple benefits: *higher and more stable yields, lower risk of crop failure, and significantly higher water productivity (the amount of grain or biomass produced per unit of water).*
- Field trials in several countries showed massive increases in wheat and barley yields with small quantities of supplemental irrigation: yields increased from 1.25 to 3 t ha^{-1} in Syria, from 4.6 to 5.8 t ha^{-1} in Morocco, and from 2.2 to 3.4 t ha^{-1} in Iran.
- Supplemental irrigation allows farmers to plant their crops early, increasing yields and preventing exposure to terminal heat and drought stress in hot areas, and frost in cold areas.

Attention is drawn to the importance of sound management of water resources and integrated planning of climate-smart irrigation interventions at all relevant levels from the field scale to the irrigation scheme, river basin and national scales, considering both irrigation 'hardware' (technology, equipment, etc.) as well as irrigation software (policies, institutions, etc.). The Compendium on Climate-Smart Irrigation (Batchelor and Schnetzer, forthcoming) provides more details on these issues.

Challenges to adoption of supplemental irrigation practice

Biophysical challenges to adoption (Nangia and Oweis, 2016):

i. **Soil texture** is a major deciding factor when introducing SI. Sandy soils have low water holding capacity and high rates of water infiltration compared to soils with higher levels of clay content. The irrigation system capacity and discharge rate should be equal to or less than the infiltration rate of the soil.

ii. The **crop** is another important factor in deciding irrigation depth. Some crops are more water-requiring than others. Knowing how much is growing-season average rainfall, how much is the crop water requirement and how much is the deficit that needs to be met using SI is important information when planning water resources availability for an SI project.

Economic challenges to adoption:

iii. **Landscape of the irrigation site** is another important criterion. If the land is uneven, water cannot flow at a constant rate and cannot reach every corner of the field. In such situations, sprinklers or drips are recommended. Both these methods are relatively expensive and need energy to operate. If the crop is predominantly rainfed and only needs to be irrigated a few times during the growing season, low installation and maintenance costs are a major factor for adoption by the farmer. Solid set or moving sprinkler systems are cheaper to use than drip irrigation systems.

iv. **Capacity of the reservoir** should be such that it can meet the demand of the crop. It is very expensive to excavate, especially in remote locations. When deciding on the capacity, it should be sufficient to meet crop water demands and, in the case of water harvesting, the runoff generated from the upstream catchment area. If the catchment area is insufficient, the reservoir will not get filled and will be unable to meet the crop water demand.

Capacity/knowledge challenge to adoption:

v. **Supplemental irrigation depth and timing** is an important decision. SI is not intended to meet the full crop water demand. It is a critical dose which can increase yields significantly as well as save the crop from failure during a dry year. The depth of SI needs to be fixed when designing the water storage reservoir and the irrigation system. It is better to apply small doses of SI rather than all in 1–2 operations. Smaller doses give the crop an opportunity to use all the water and not let any go waste as deep percolation or runoff. However, there are additional costs involved in applying more doses. So, a balance needs to be achieved between how often and how much water you apply in each dose. But it is not easy to perform such calculations and make decisions without sufficient knowledge of the practice. Capacity building of the farmers is a challenge needed to overcome this obstacle.

Where can supplemental irrigation be practiced?

Supplemental irrigation for early sowing

In the lowlands of the Mediterranean region and rainfed south Asian countries, farmers usually sow/seed their land only when a sufficient amount of rain has fallen. The date by which this amount of rain has fallen is usually called the 'onset rainfall', meaning the beginning of the rainy season.

Here continuous cropping prevails as pure cereal or cereal-legume rotations. Every week's delay after this time results in a yield decrease of between 200 and 250 kg/ha. If the onset of the seasonal rain is delayed, early sowing can be realized with the help of a SI system. With SI it is possible to decide on the sowing date of the basically rain-fed crops without needing to wait for the onset of the seasonal rain. This results in a longer growing season, better yield, and an earlier maturity that helps crops to escape terminal drought.

In the highlands, frost conditions occur between December and March and field crops remain dormant. Usually, the first rainfall, sufficient to germinate the seeds (the onset rain), comes late and results in a small crop stand when the frost occurs. As a result, rainfed yields are much lower than when the crop stand, pre-frost, is good. Ensuring a good crop stand before frost can be achieved by early sowing and applying from 50 to 70 mm of SI. Supplemental irrigation, given at early sowing, dramatically increases wheat yield and water productivity. In the highlands of Turkey, applying 50 mm of SI to wheat sown early has increased grain yield by more than 60%, adding more than 2 t/ha to the average rain-fed yield of 3.2 t/ha (Ilbeyi *et al*. 2006). Water productivity (WP) reached 4.4 kg/m^3 of consumed water compared to WP values for wheat from 1 to 2 kg/m^3 under traditional practices. Similar results were found in the Iran highlands for wheat and barley (Tavakoli *et al.* 2010).

Supplemental irrigation to alleviate moisture stress

Unlike for full irrigation, the timing for SI cannot be determined in advance. This is because the basic source of water to rainfed crops is rainfall which, being variable in amount and distribution, is difficult to predict. Since SI water is best given when the soil moisture drops to a critical level, the time for irrigation can be best determined by measuring the soil moisture on a regular basis. Supplemental irrigation is even referred to as life-saving irrigation in some south Asian countries. Usually, however, one to three supplemental irrigation applications of not more than 100 mm each annually appear sufficient, depending on the rainfall amount and distribution.

Contribution to CSA pillars:

How does supplemental irrigation practice increase productivity, farm livelihoods and food security?

The area of wheat under SI in northern and western Syria (where annual rainfall is greater than 300 mm) increased from 74,000 ha (in 1980) to 418,000 (in 2000), an increase of 470%. Estimated mean annual income in production cost due to SI (including fixed and variable costs) as compared with rainfed equals USD 150 per hectare. Estimated mean increase in net profit between rainfed and SI for wheat equals USD 300 per hectare. The ratio of increase in estimated annual net profit per hectare to estimated difference in annual costs between rainfed and SI is 200%, which is high (Oweis and Hachum, 2006).

But increase in crop production per unit of land or per unit of water does not necessarily increase farm profit, just because of the nonlinearity of crop yield with production inputs, particularly with water and its interaction with other input factors (such as fertilizer, sowing date, choice of cultivar, irrigation system, etc.). Therefore, a water management strategy that maximizes yield or water productivity is not necessarily the most desirable one, especially in water-scarce areas. Often such a strategy is not the most economical in terms of net return. Actually, the most desirable strategy is somewhere in between these two (Oweis and Hachum, 2009).

How does supplemental irrigation help adapt to and increase resilience to climate change impacts?

Climate change adaptation strategies can only be effective if done in an integrated manner. For rainfed agriculture, the strategies may need to encompass water management, crop improvement, cultural practices, policies, and socioeconomic and other issues. Supplemental irrigation, however, can play an important role in the adaptation efforts to climate change in rainfed agroecosystems. Following are some of the potential responses that SI can make to adapt to climate change:

- ICARDA is currently investigating climate change effects using biophysical crop models (Sommer *et al*., 2011). First scenario simulation results highlight the positive effect of SI in alleviating the negative impact of climate change, especially on the year-to-year variability in crop yields which are predicted as consequences of climate change in the near future (2011–2050). Supplemental irrigation management resulted in an application of irrigation water of between 0 and 330 mm (average, 122 mm), usually, between one and three (maximum, six) irrigation events per season. No supplemental irrigation was necessary in six of the 49 years. Thus, on average, yields were 2.6 times higher with SI than without. The corresponding water-use efficiency (precipitation plus irrigation) increased from 0.50 kg/m^3 under rainfed-only conditions to 0.99 kg/m^3 under SI (applied to meet 100% of crop water requirement).

  Therefore, in conclusion, it can be noted that SI can be used to overcome the changes in soil-water-plant relations, especially in alleviating soil water stress resulting from changes in crop ET and crop patterns. As rainfall is unpredictable, SI becomes the most viable practice to alleviate the moisture stress caused by increased temperature. Another adaptation option is the possibility of changing planting dates. With SI, this can also help adaptation to global warming. With the help of SI, early planting is possible and the growing season can start relatively early.

- Less and more erratic precipitation is expected in the dry areas as a result of global warming. Lower precipitation will cause a further moisture stress on already stressed rainfed crops and some areas on the peripheries of the rainfed zones may drop out of dryland agriculture as a result. It is also expected that rainfall will be more erratic and intensive, and the season will have prolonged drought spells. Crop yields and WP losses are mainly associated with soil moisture stress during such drought spells. Prolonged drought spells during the rainy seasons resulting from global warming will make the crop situation even worse and further drops in yields are expected as a result. Supplemental irrigation, by definition, deals with two situations. It adds some water to compensate for lower rainfall and less moisture storage and it alleviates soil water stress during dry spells. It is however, important to quantify the changes in rainfall characteristics and the durations of potential drought spells in order to design SI schedules to adapt the system to climate change.

- Higher intensity rainstorms are also predicted, not only in the dry area, but also in SSA and globally (Karrou and Oweis 2008). This naturally will cause more runoff and soil erosion in rainfed areas, especially on sloping lands. The portion of the precipitation that normally infiltrates the soil to support plants growth will be less as more runoff will go downstream. In addition, it is predicted that the process of land degradation will be accelerated. Supplemental irrigation combined with water harvesting can provide workable solutions to this problem. Macro- and micro-catchment water harvesting are effective strategies for intercepting runoff and storing water either in the soil profile or in surface and groundwater aquifers. Water stored in the soil may support plants directly or it can be used for SI during dry spells if stored in small reservoirs or ground water aquifers. This model is being researched and tested in many places and should provide a good platform for overcoming the effects of climate change on runoff.

How does supplemental irrigation mitigate GHG emission?

Supplemental irrigation can help mitigate greenhouse gas (GHG) emissions in two ways: (1) Increased yields achieved with SI (compared to rainfed production) result in higher carbon sequestration rates in plant biomass and for the build-up of soil organic carbon (SOC), especially if crop residues are returned to the soil or if cover cropping practices keep the soil protected as much as possible (Lal, 2004). This increase in SOC, in turn, has a synergistic effect on adaptation through improved soil fertility as well as reduced nutrient leaching and soil erosion. If this soil fertility improvement results in a decrease of mineral fertilizer use, additional mitigation benefits can be obtained through a reduction of GHG emissions linked to fertilizer manufacturing and use.
(2) When substantial yield gains are achieved through SI compared to a relatively low increase in farming inputs, the GHG emission intensity per unit of produce decreases. Although this may imply higher GHG emissions per area, the yield gains can prevent conversion of additional areas to crop land and associated release of carbon from soils. The GHG emission intensity can be further reduced by the use of renewable energies instead of fossil fuels for SI, e.g. through solar-powered irrigation systems that lower the carbon dioxide emissions associated to the delivery of irrigation water (McGill, 2014; IWMI, 2017; Schnetzer and Pluschke, 2017). Also the production of biofuel crops using SI that displaces the use of fossil fuels on farm or in the wider economy can contribute to mitigate GHG emissions. Biofuel crops should be considered only in contexts and at scales that do not negatively affect the food security of the local population through competition with food crops.

Costs and funding for supplemental irrigation

Risk weighs on the daily lives of poor rainfed farmers, and investment packages have to help reduce that risk. Risks include not only climatic and limited access to reliable technology and water, but also unstable land tenure and poorly functioning product and credit markets. Investing in SI can have a significant impact on justified returns from dry farming systems. Biophysical returns on water with SI are higher than those under conventional irrigation, and are highest with deficit applications. An integrated investment package including water-harnessing and irrigation technology, irrigation scheduling, training, and cropping and fertilizing guidance is probably the best. Combined soil and water management investments can also have a high return. The key requirements for successful investment in SI include:

- Determining the most appropriate scheduling, crops and cropping patterns, and socioeconomic feasibility.
- Strong water-user associations with incentives for local communities to use water efficiently.

- Managing the economic and environmental consequences of using water in SI.
- Developing policies that foster an enabling environment for the adoption of water-efficient technologies.

Metrics for CSA performance of supplemental irrigation

The effect of supplemental irrigation goes beyond yield increases to substantially improving the water productivity. Both the productivity of irrigation water and that of rainwater are improved when they are used conjunctively. Water productivity in supplemental irrigation is a function of the amount of irrigation water applied. It has been found that maximum water productivity is attained when from one- to two-thirds of the full irrigation water is applied.

Interaction with other CSA practices

Supplemental irrigation alone, although it alleviates moisture stress, cannot ensure the best performance of the rain-fed agricultural system. It has to be combined with other farm management practices and inputs such as land preparation, fertility and pest management, and choice of right crop varieties for the location and climate. According to Rockström *et al*. (2007), supplemental irrigation is a key strategy, still underused, for unlocking rainfed yield potential and water productivity.

Supplemental irrigation in the Ghanaian farming system

Rainfed agriculture provides about 95 percent of Ghanaian food and feed, and it is the main source of livelihood for more than 70 percent of the population. Therefore, any inadequate rainfall (intensity or timing) at key periods during the crop growth cycle (seeding, growing, flowering and grain filling) affects crop yields and farmers income which in turn may pull framers into poverty trap. Rainfall is the most variable climatic parameter and as such shows wide variability differences over ecological regions. In Ghana, based on 1961 to 2000 climate statistics, annual rainfall amounts are expected to decrease by 1.1 to 3.1 percent across all ecological regions by the year 2020 and by 13.0 to 21.0 percent by 2080 (EPA, 2012). SI is an effective response to alleviating these adverse effects of rainfall shortage or dry spells on the yield of rainfed crops. It consists of supplying crops with water during key stages of crop growth cycle when rainfall fails to provide sufficient water.

SI is an old practice in Ghana. It started with the involvement of the Ghanaian government in agriculture in the 80s through construction of runoff reservoirs that were then used by farmers for both wet and dry seasons farming. SI in Ghana represents 0.8 percent of the country entire irrigation land use mostly based in the Northern Savannah agro-ecological zone (Northern, Upper East and Upper West) which is the largest agriculture zone in Ghana.

Through a three years USAID project on drought risk management in Northern Savannah agro-ecological zone, which one key objective was to access supplemental irrigation use and demand, it was found that nowadays many farmers in drought prone area through their association or community based organization are able to dug micro ponds to collect and store runoff water from neighbouring farm micro-watersheds. The pond is man-made and is dug in an upstream location from the irrigated plot to collect runoff. Adjustments are made in the ground to facilitate runoff pouring into the pond. The pond water is then applied to rainfed crops using watering cans and in some areas moto pumps using hose to apply to the crops. Some farmers own seasonal shallow wells which range in depth from 1 to 5 meters (FIGURE 1). A well can be dug by one person in approximately 6 hours at a cost of around USD 5/hour and it can serve plots within a 50 to 60 meters radius.

FIGURE 1: Seasonal shallow well located at Kupulima community, Ghana.

Water is collected from the wells using ropes and buckets. Seasonal shallow wells are commonly used in low-lying areas with high water tables and they are for wet season farming as they are mostly dried in dry season.

- Farmers under the government irrigation facilities pay a user fee of GHS 20 (USD 5) per acre of land to have access to water during wet season. While under the community-based irrigation facilities farmers are to pay a maintenance fees of GHS 4 (USD 1). However, through a contingent valuation assessment, it was found that the average Willingness-to-Pay (WTP) for SI per acre of land is GHS 26 (USD 6.5) in the Northern Savannah agro-ecological zone of Ghana.
- The benefits of the SI system, however, are more evident in the Northern Savannah agro-ecological zone of Ghana which is characterized by unimodal rainfall of short duration compared to the rest of the country which is characterized by two rainy seasons. Farmers mostly apply SI in their rice and maize farms. SI provides multiple benefits to farmers: it provides higher and more stable yields, reduces the risk of crop failure, significantly increases water productivity, and has a positive spill-over effect in modern technologies adoption (seed and fertilizer). The gain in maize yield due to SI in the scheme is 2.22 times higher than the average rainfed yield in the Northern Savannah agro-ecological zone (cf. FIGURE 2). Farmers under SI invest 20 percent more in farm inputs per hectare compared to the average per hectare farm inputs investment in Northern Savannah agro-ecological zone. Through this investment farmers under SI are able to increase their per hectare income by 35 up to 50 percent.

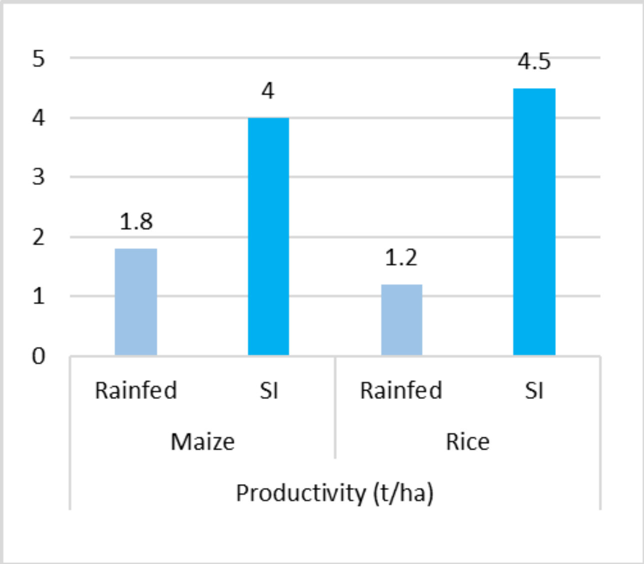

FIGURE 2: Maize and rice productivity under supplemental irrigation (SI) and rainfed production in Northern Savannah agro-ecological zone of Ghana (Year 2015).

- Though SI is an old practice in Ghana, few farmers have adopted it. The main challenges of its adoption include: lack of water resources, lack of knowledge transfer, landownership, high-lying lands, and poor farmers often cannot afford the construction, maintenance and operational costs given their limited resources. There is a need for the government and other development agencies to provide incentives and facilities through which farmers may be able to adopt supplemental irrigation. Construction of large and small scale runoff reservoirs, farmers' capacity building on the use and maintenance of water resources are some key incentives. Farmers are also to operate in cooperative or farmers based organization to gain economy of scale as natural resources, particularly water, are more efficiently utilized on a collective basis than individually.

Further reading

Batchelor C. and Schnetzer J. (Eds.). Forthcoming. *Compendium on Climate-Smart Agriculture*. Global Alliance for Climate-Smart Agriculture (GACSA). Rome, Italy. To be published at: http://www.fao.org/gacsa/en/

EPA. (2012). Climate Change Impact: Why Must Ghana Worry? Environmental Protection Agency (EPA), Policy Advise Series.

Hyman G., Fujisaka S., Jones P., Wood S., Carmen de Vicente M., Dixon J. (2008) Strategic approaches to targeting technology generation: Assessing the coincidence of poverty and drought-prone production. Agricultural Systems 98:50–61.

Ilbeyi A., Ustun H., Oweis T., Pala M., Benli B. (2006) Wheat water productivity and yield in a cool highland environment: effect of early sowing with supplemental irrigation. Agricultural Water Management 82: 399–410.

Independent Science and Partnership Council (ISPC). 2015. (Visited on March 17, 2017).

International Water Management Institute (IWMI). 2017. Solar-powered irrigation: Adding value through a business model approach. R4D Capabilities. Colombo, Sri Lanka.

Karrou, M. and T. Oweis. 2008. Climate change and water: the challenges for dry areas. Pages 17–20 in Caravan, No. 25 Review of Agriculture in the Dry Areas International Center for Agricultural Research in the Dry Areas (ICARDA). Aleppo, Syria.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science 304: 1623–1627.

McGill University. 2014. *Advances in sustainable agriculture: Solar-powered irrigation systems in Pakistan*. Montreal, Canada. (Accessed January 24, 2018)

Nangia, V., and Oweis, T. 2016. Supplemental irrigation – a promising climate-resilience practice for sustainable dryland agriculture. In M. Farooq, and K.H.M. Siddique (eds) Innovations in dryland agriculture, 549-564 pp., Springer, Heidelberg.

Oweis, T., and Hachum, A. 2003. Improving water productivity in the dry areas of west Asia and North Africa. In: Kijne, W.J., Barker, R., and Molden, D. (eds) *Water productivity in agriculture: Limits and opportunities for improvement*. CABI, Wallingford, UK, pp. 179-197.

Oweis, T., and Hachum, A. 2006. Water management in rainfed agriculture – investing in supplemental irrigation. In: *Agricultural Water Sourcebook: Shaping the Future of Water for Agriculture*. The World Bank, Washington, DC, USA, pp. 206-213.

Oweis, T. and Hachum, A. 2009. Water harvesting for improved rainfed agriculture in the dry environments. In: Wani, S.P., Rockstrom, J., and Oweis, T. (eds), *Rainfed agriculture: unlocking the potential*, CABI, Oxford.

Oweis, T. and Hachum, A. 2012. Supplemental irrigation, a highly efficient water-use practice. ICARDA, Aleppo, Syria. iv + 28 pp.

Rockström, J., N. Hatibu, T. Y. Oweis, S. Wani, J. Barron, A. Bruggeman, J. Farahani, L. Karlberg, and Z. Qiang. 2007. Managing water in rainfed agriculture, In: *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*, edited by D. Molden, pp. 315–352, Earthscan, London.

Schnetzer, J. and Pluschke, L. 2017. *Solar-powered irrigation systems: A clean-energy, low-emission option for irrigation development and modernization*. CSA Practice Brief. Rome, GACSA.

Sommer, R., Oweis, T. and L. Hussein. 2011. Can Supplemental Irrigation Alleviate the Effect of Climate Change On Wheat Production In Mediterranean Environments? Oral presentation at the ASA, CSSA, SSSA Annual Meetings - Fundamental for Life: Soil, Crop, & Environmental Sciences, 16 to 19 October 2011, San Antonio, Texas, USA.

Somé, L., and Ouattara, K. 2005. Irrigation de complément pour améliorer la culture du sorgho au Burkina Faso. Agronomie Africaine, 17(3), 201–209.

Tavakoli A, Oweis T, Farahani H, Ashrafi S, Hormoz A, Siadat H, Liaghat A (2010) Improving rainwater productivity with supplemental irrigation in upper Karkheh River Basin of Iran. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

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