Improvement of Irrigation Water Efficiency and Productivity Using Supplementary Irrigation: A review

Saif Hameed Abed Al-Katb

Design Department, Center of Studies and Engineering Designs, Ministry of Water Resources, Baghdad-Iraq.

*Corresponding author's email: sha_alkatb@yahoo.com

Abstract

Supplementary irrigation (SI) is an effective response to mitigate the negative effects caused by soil moisture stress on the yield of rainfed crops during dry periods. Soil moisture deficit often occurs in dry rainfed areas during the most sensitive growth stages of the plant (flowering and grain filling) as a result, the growth of the rain-fed crop becomes weak, which leads to lower yields. As for (SI), which provides limited amounts of water, especially during critical periods of crop growth, it leads to a significant improvement in yield and water productivity. This article presents review methodologies used for significant increases in the yield of rainfed crops in response to the use of relatively small amounts of water and the state of the art of (SI) in the dry lands, which (SI) should be appropriately integrated with other production inputs including crop and soil management options, climate change, and other options necessary to achieve the required results. The main contribution of this work lies in farms using water supply system on demand and small farms that use wells or nearby surface water sources. This study will help the farmers to understand the technology transferred to them and how to properly employ and manage it. Here, agricultural extension and human capacity building must play a key role in this field. Long-term training and advisory programs must be designed and implemented at various levels.

Key words: Supplementary irrigation, rainfed, climate change, Yield, Crops

تحسين كفاءة استخدام مياه الري وانتاجيته بأستخدام الري التكميلي : اعادة عرض

سيف حميد عبد الكاتب

رئيس مهندسين, قسم التصاميم, مركز الدراسات والتصاميم الهندسية,وزارة الموارد المائية

*المؤلف المراسل: sha_alkatb@yahoo.com

الخلاصة

يعتبر الري التكميلي ذي استجابة فعالة للتخفيف من التأثيرات السلبية التي يحدثها اجهاد الرطوبة في التربة في غلة المحاصيل البعلية خلال فترات الجفاف. يحدث نقص في رطوبة التربة في المناطق البعلية الجافة خلال مراحل النمو الاكثر حساسية (الازهار و امتلاء الحبوب). نتيجة لذلك, يكون نمو المحصول البعلي ضعيفا مما يؤدي الى انخفاض الغلة. اما الري التكميلي الذي يوفر كميات محدودة من المياه وبخاصة خلال فترات حرجة من نمو المحصول فيؤدي الى تحسين كبير في الغلة والانتاجية المائية. تقوم المقالة بعرض المنهجية المستخدمة للزيادة العالية الحاصلة في الغلة للمحاصيل البعلية باستخدام كميات مياه قليلة نسبيا بالاضافة الى فن استخدام الري التكميلي في الاراضي الجافة, حيث يجب ان يتم ادماج الري التكميلي بشكل مناسب مع مدخلات انتاج اخرى تشتمل على خيارات ادارة المحصول والتربة , تغير المناخ , وخيارات اخرى ضرورية لتحقيق النتائج المطلوبة. ان المساهمة الرئيسية في هذا العمل يقع في استخدام الاراضي الزراعية للمياه عند الحاجة و للاراضي الزراعية الصغيرة المستخدمة للابار ومصادر المياه السطحية القريبة, تقوم هذه الدراسة بمساعدة الفلاحين لفهم التكنولوجيا المنقولة اليهم وكيفية توظيفها وادارتها بشكل صحيح. وهنا يجب على الارشاد الزراعي وبناء القدرات البشرية ان تلعب دورا اساسيا في هذا المجال.ويجب تصميم وتنفيذ برامج تدريبية واستشارية طويلة الامد وعلى مستويات مختلفة.

الكلمات المفتاحية: الري التكميلي , بعلية , تغير المناخ , العائد , المحاصيل

Introduction

Rainfed agriculture (dry farming) occupies about 80% of the agricultural land around the world and contributes to two-thirds of the global production of food. In the sub-Saharan Africa region, rain-fed lands constitute more than 95% of the total cultivated lands; Latin America 90%; in South Asia 60%; East Asia 65%; West Asia and North Africa 75% (Rcckstrom , et al., 2017). We find that rainfed production can play a significant role in meeting the future demand for food, Thus yield variations lead to instability in farmers' incomes. In semi-arid tropics, the yields of rain-fed agriculture are often low, around 1 ton/ha (Rcckstrom , et al., 2021).

Supplementary irrigation (SI) combined with water harvesting can provide practical solutions to this problem, as water harvesting in large and small water reservoirs is effective strategies for intercepting runoff and storing water either in the soil itself or in surface or underground aquifers. The water stored in the plant soil may be directly supported or may be used for (SI) during dry periods. This is being researched and tested in many regions and should provide a good platform for overcoming the effects of climate change on runoff.

When considering current conditions and the potential for (SI) technology, experience has shown that the most effective approach to introducing new technology or improving existing practices is through integrated and participatory research programmers. The farmers need to understand the technology transferred to them and how to properly employ and manage it. Here, agricultural extension and human capacity building must play a key role in this field. Long-term training and advisory programs must be designed and implemented at various levels.

Dry Farming: High Risk and Indiscernible

Rainfed agriculture in the tropics with scarce water and large parts of dry areas is concerned not only with the total amount of rainfall, but also with its fluctuations over time and space. The main challenges lie in how to reduce the dry periods during the season in order to improve the yield and stability of the rain-fed crop. As a result of the characteristics of fluctuating rainfall, the moisture in the root zone of the crop does not meet the needs of the crop throughout the season. For example, with regard to the wheat crop in northern Syria the stored rains in the humid months (December-

February) are abundant, the crops planted at the beginning of the season (November) are in their early growth state, and the rate of water depletion from the root area due to evaporation is very low (Singh , et al., 2009). (See Figure (1)).

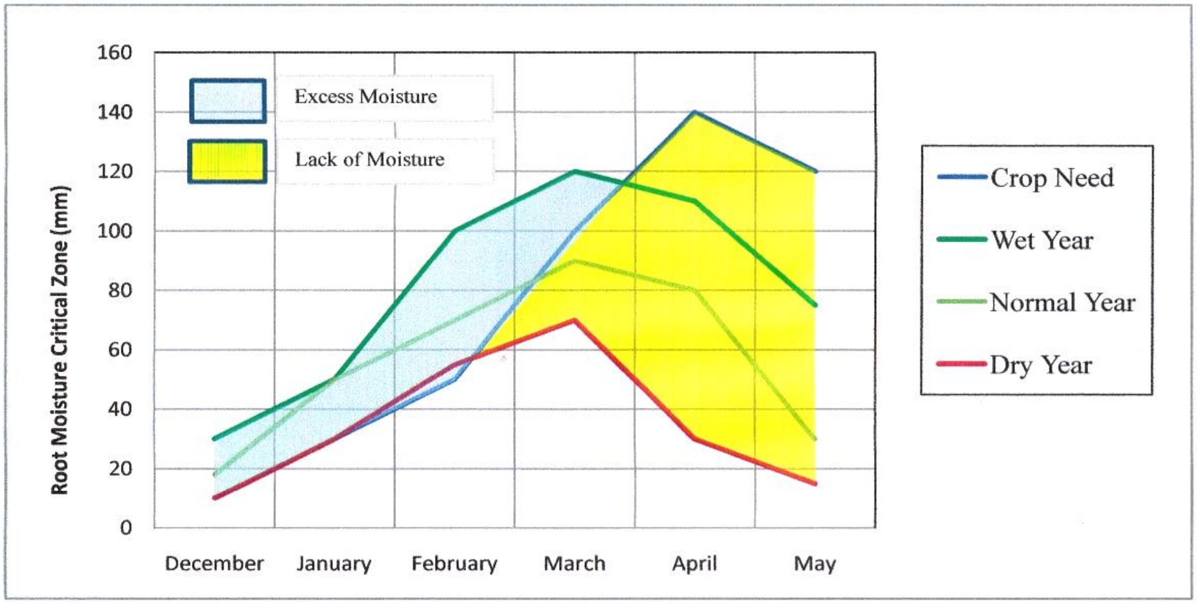

Figure 1: Wheat growing season

So, rainfed yields are very low in relation to the potential that can be reached in the absence of moisture stress. The distribution of rainfall during the season may be inappropriate, which also exposes crops to moisture stress at the end of the season or during sensitive stages of growth and thus reduces production.(llbeyi , et al., 2006)

In addition to water stress in rainfed systems, many other factors work to widen the gap between potential yields in rainfed areas and the actual yields produced by farmers like (Agricultural policies, increasing soil fertility by adding chemical fertilizers, using improved varieties of seeds, etc.). (Oweis , 2011). (See Figure(2)).

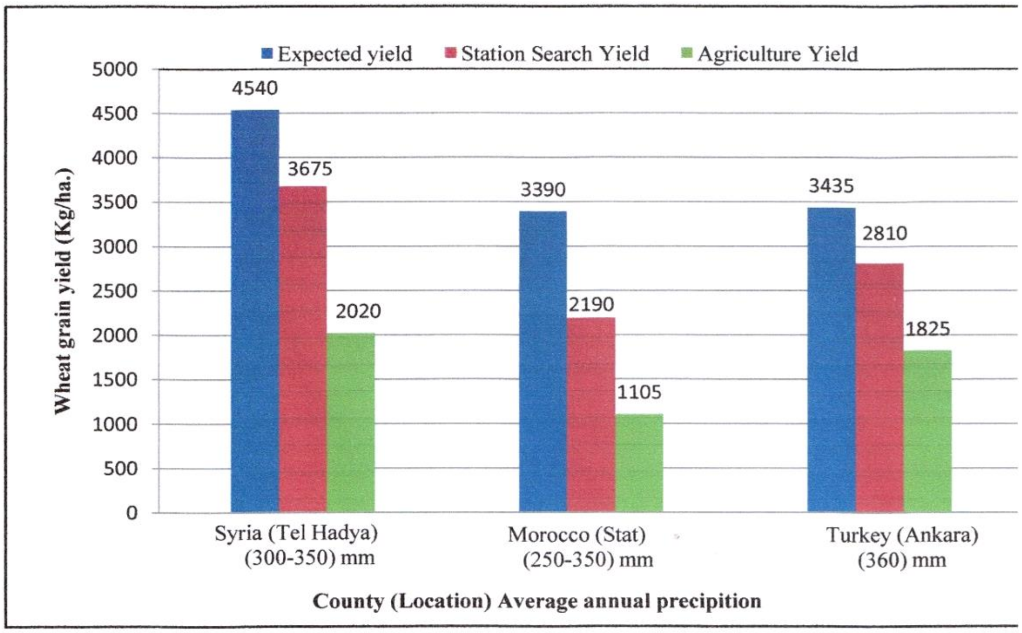

Figure 2: Wheat yield gap in selected areas of West Asia and North Africa

Among the appropriate agricultural policies, inputs such as soil fertility and the use of distressed varieties are among the most important. Transfer of technology such as supplemental irrigation and water harvesting requires coordination of efforts among all parties, including agricultural researchers, local organizations and farmers (Oweis and Hachum , 2003).

The analysis above, There are three main ways to improve rainfed crop production:-

1) Increasing rainwater productivity through improved water management and soil moisture monitoring.
2) Improving agricultural practices and inputs (varieties, fertility).
3) Applying supplementary irrigation as a very effective practice that achieves yield stability.

Supplementary Irrigation: Productivity

Supplementary irrigation can be defined as adding limited amounts of water to rainfed crops mainly with the aim of improving yields and increasing their stability during periods when rainfall fails to provide sufficient moisture to achieve normal and acceptable growth for the plant.

Unlike full irrigation, supplementary irrigation cannot determine the date and quantity of irrigation in advance due to the fluctuation of rainfall. Supplementary irrigation in rainfed areas depends on three main principles (Owies ,1997).

- Water in supplementary irrigation of a rainfed crop often gives some yield even without irrigation
- Rainfall is the main source of water for rainfed crops; supplementary irrigation is used only when rainfall fails to provide essential moisture to produce improved and stable crops.
- The purpose of scheduling supplementary irrigation quantities and dates is not to provide moisture stress-free conditions throughout the growing season, but to ensure the provision of the minimum amount of water during a critical stage of plant growth, which allows for an optimal yield (See Figure (3)).

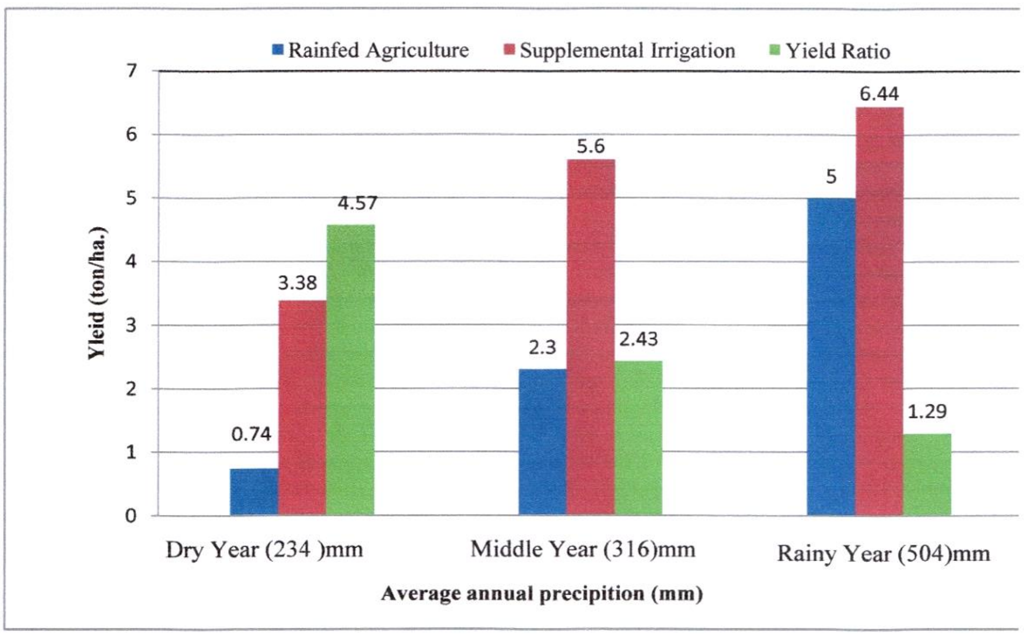

Figure 3: Yield of rainfed wheat irrigated by supplementary irrigation method (tons/ha) and the ratio of supplemental irrigation yield to rain-fed yield in dry, medium and wet years in northern Syria.

When planning supplementary irrigation of rainfed agriculture, the issue of irrigation water source is considered a fundamental issue. The water sources and irrigation devices used for full irrigation during the dry seasons can be used for supplementary irrigation during the rainy season. A good example of this is the North Al-Jazzera Project in Nineveh Governorate in northern Iraq, where about 25% of 60,000 hectare area of the project is planted with full irrigation in summer and 75% of the area with wheat rain-fed using supplemental irrigation in winter and the source of the water was the Tigris River (Adary , et al., 2002).

As a result, Supplementary irrigation (SI) is an effective response to mitigate the negative effects caused by soil moisture stress on the yield of rainfed crops during dry periods, and It is possible to use surface water more effectively than using full irrigation during the rainy seasons and winter.

Improving the Productivity of Land and Irrigation Water

Productivity per unit area is no longer the only goal or determinant of increasing productivity, but water harvesting and the ability to conserve water is the most important criterion in increasing productivity. The effect of supplemental irrigation goes beyond increasing yields to improving water productivity significantly, and if they use both the productivity of irrigation water and the productivity of rain water, it will improve further. (Sommer , et al., 2011) The average productivity of rain water for wheat in the dry areas of West Asia and North Africa is about 0.35 kg/m^3, and with improved management and appropriate rainfall, the water productivity can be increased to 1 kg/m^3, but the water used in supplementary irrigation is more efficient, as research conducted in ICARDA (International Center for Agricultural Research in the Dry Areas) showed The quantity of one cubic meter of water used at the correct time (when the crop suffers from moisture stress) can produce an amount of grain about 2.5 kg more than that of the rainfed. (See Figure(4))

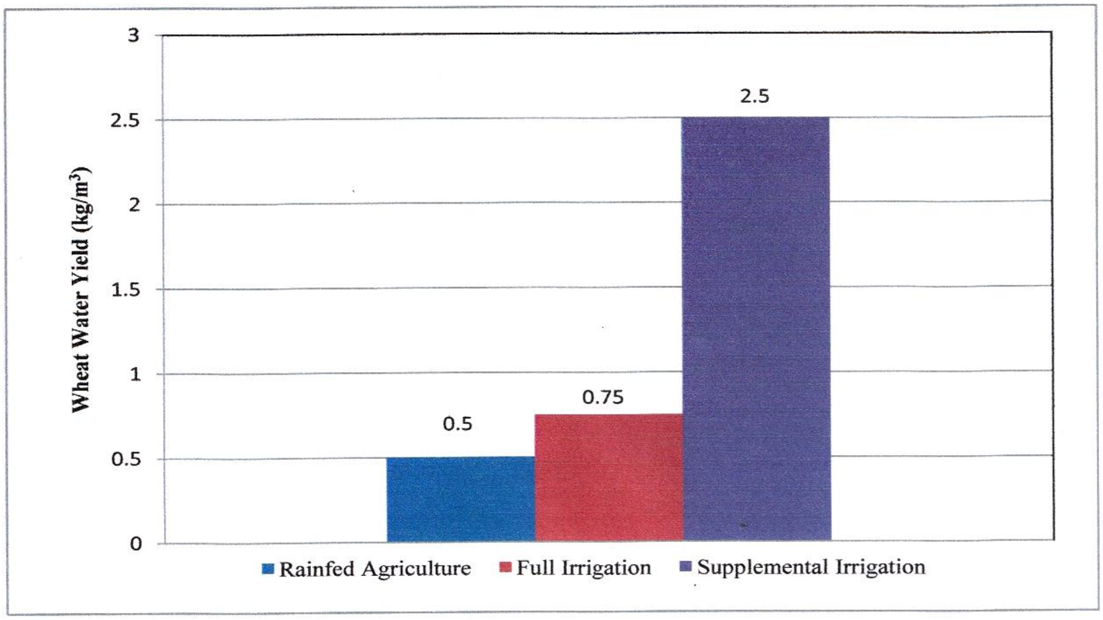

Figure 4: Average water productivity of green water (rain-fed only) and blue water (Full irrigation with little or no rain) and supplementary irrigation water for wheat crop in Syria

The very high water productivity is due to the effectiveness of small amounts of water in relieving intense moisture stress during the most drought-sensitive stages of the crop growth and when grains are full and the supplementary irrigation is used to activate such conditions and reach the highest yield possible.

Compared with the water productivity in fully irrigated areas (where the effect of rainfall is negligible), the productivity of irrigation water is higher using supplementary irrigation. When irrigated wheat produces grain yields of about 6 tons/ha, it uses about 800 mm of water in a water productivity of about 0.75 kg/m3 and this represents one third of the water productivity if used in supplementary irrigation.

This means, it is better to allocate water shares for supplementary irrigation purposes when other physical and economic conditions are favorable. Water productivity and efficiency of its use are indicators of the benefits and returns of the water consumed by the crop, and in areas with limited water resources where water is the biggest obstacle to production the efficiency of water use is the main criterion for evaluating the performance of agricultural irrigation systems.

When Should Farmers Apply Supplementary Irrigation.

Perhaps one of the most difficult decisions in the management of supplementary irrigation is determining the date of irrigation and the amount of water to be added, as many farmers, and perhaps most of them, use a large amount of water if they obtain it at a reduced or no cost (such as Iraq). Supplementary irrigation is no exception. Farmers tend to use water excessively in supplementary irrigation when water costs are low in order to reap significant benefits, but in most cases it is not sustainable. The goal of any successful supplementary irrigation management program is to provide enough water to irrigate crops in a timely manner and to discourage farmers from over-irrigating.

In the higher lands like in (North Syria): the frost comes and lasts between December and March, and the field crops remain in a state of hibernation. Usually, the first rain for seed germination (the first precipitation) comes late (November) and leads to a low germination density in the crops when the frost occurs in December. As a result, rainfed yields are much lower than when planting density is early before frost and that is because of the supplementary irrigation. It is possible to reach a good density in the crop before frost through early planting and from 50 to 70 mm of supplementary irrigation. The supplementary irrigation given at early planting leads to significant increases in wheat yield and water productivity.

In the Turkish highlands, giving 50 mm of supplementary irrigation to an early planted wheat crop increased the grain yield by more than 60%, adding more than 2 tons/ha to the average yield of rain-fed wheat of 3.2 tons/ha.(llbeyi , et al., 2006). (See Figure (5))

The water productivity reached 4.4 kg/m3 of consumed water compared to the water productivity of wheat from 1 to 2 kg/m3 in traditional practices. Similar results were also found in the highlands of Iran for wheat and barley crops.(Tavakoli , et al., 2010).

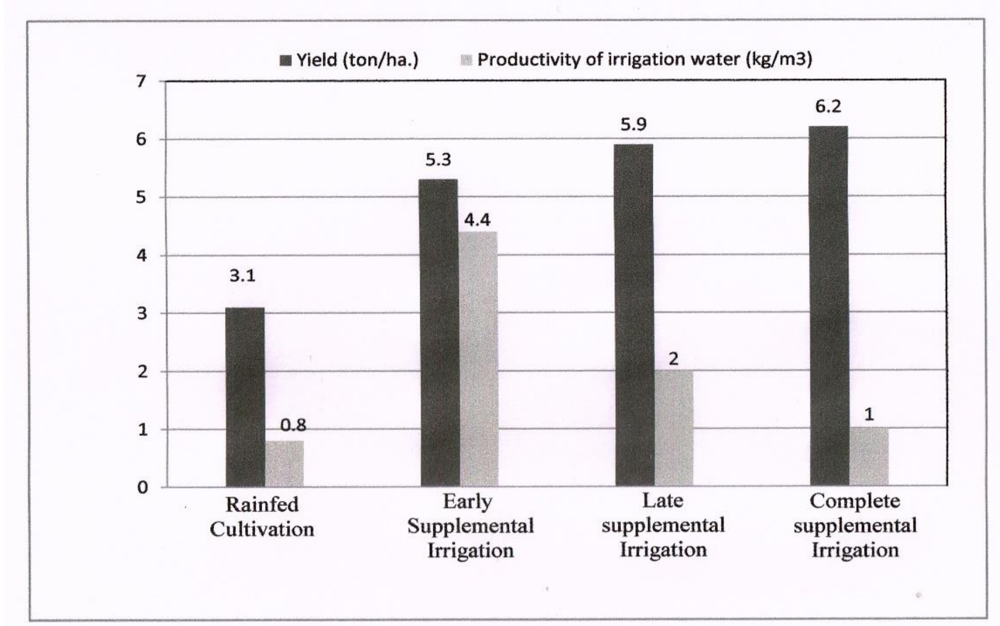

Figure 5: the effect of early cultivation of wheat on yield and water productivity in the highlands of Turkey

Most farmers in the area rely on personal experience in relation to the amount of rainfall received and the appearance of the crop, but farmers generally tend to irrigate earlier and more frequently when water is available.

Climate change adaptation

Sooner or later, climate change will have negative impacts on water resources and agriculture within the dry areas, and rain-fed agro-ecosystems in particular will be subjected to more stresses as a result of high temperatures and reduced rainfall during drought periods. The negative impacts of climate change are expected to affect crop productivity, water resources and ecosystem services. There is a possibility that high temperatures and carbon dioxide levels in the atmosphere will change the growth patterns and periods of crops. Higher temperatures will shorten the growth cycle of field crops and change the timing stages of the growth stages, but higher temperatures in the spring with a decrease in the number of frost days will improve Early growth and vigor of plants.(llbeyi , et al., 2006).

Rainfed agriculture needs strategies that focus on water management, yield improvement, and cultural, social and economic practices, where supplemental irrigation plays an important role in efforts to adapt to climate change in rainfed ecosystems.

ICARDA is currently investigating the effects of climate change using crop biophysical models. The results of the first scenario simulations shed light on the positive impact of supplementary irrigation in mitigating the negative impact of climate change, especially on year-to-year variability in expected crop yields and the consequences of climate change in the near future (2011-2050). (See Figure (6))

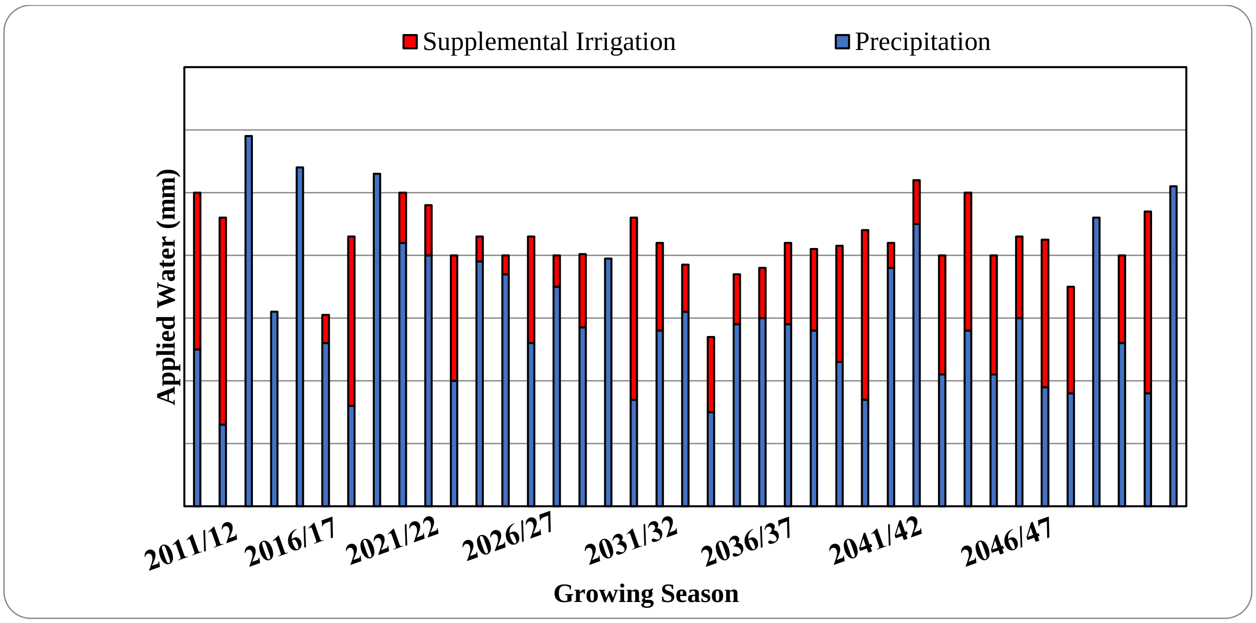

Figure 6: Simulation of future requirements of supplementary irrigation for wheat crop under expected climate change conditions for the period (2011/12 – 2049/50)

The supplementary irrigation administration resulted in giving irrigation water between 0 and 330 mm (at an average of 122 mm) through one to three irrigations (six as a maximum) per season. The simulation model showed that there is no need for supplementary irrigation in six out of 49 years. Thus, it is possible to achieve an average increase in yields of up to 2.6 times with supplementary irrigation compared to the yield without it, and also an increase in the related water use efficiency (precipitation + irrigation) from 0.50 kg / m^3 in rain-fed conditions to 0.99 kg / m^3 under complete supplementary irrigation.

Supplementary irrigation adds a small amount of water in the event of a decrease in rainfall and stores moisture and relieves water stress in the soil during drought periods. Figure (7) shows the possibility of supplementary irrigation to mitigate the effects of climate change on wheat yields in the Aleppo region at different levels of rainfall. (Sommer , et al., 2011).

It is worth noting the increased demand for supplementary irrigation with improved productivity.

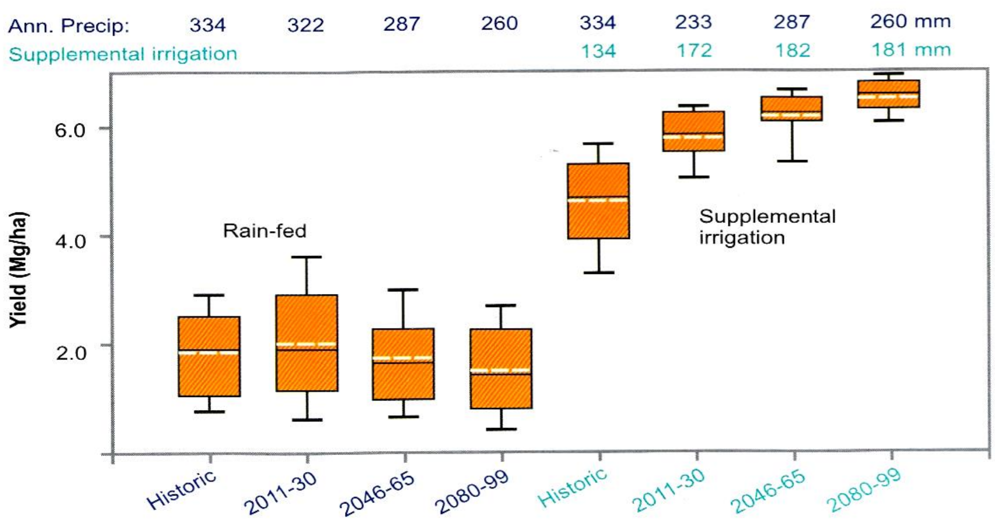

Figure 7: Possibility of supplemental irrigation to mitigate the effects of climate change

Suitable Areas for Supplementary Irrigation

A GIS-based methodology has been developed using a combination of a simple model to determine and calculate the rain-fed areas that can be irrigated with water saved by switching from fully irrigated spring/summer crops to winter/spring crops based on supplementary irrigation (As illustrated in Figure(8).

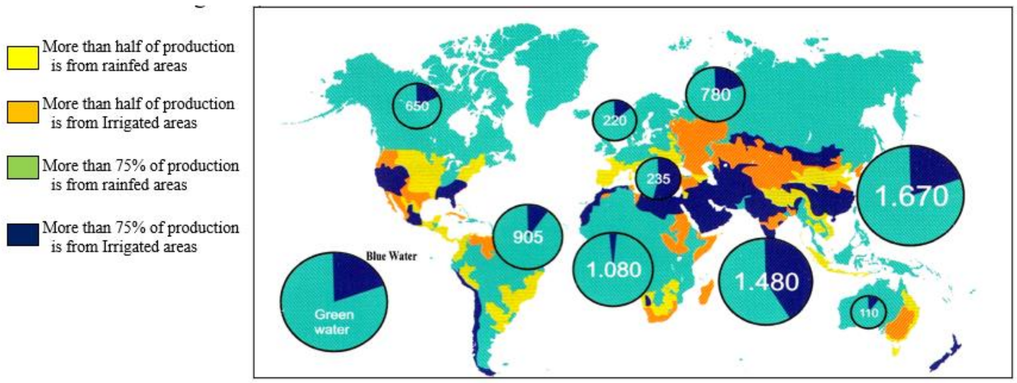

Figure (8) Areas that depend mainly on rain-fed agriculture (green water) to produce agricultural crops and global rain-fed areas

Source: An analysis conducted by the International Water Management Institute in the comprehensive assessment of water management in agriculture using (Watersim) model, chapter two

The methodology is based on mapping the existing water resources within rain-fed areas and irrigated areas in summer using data taken from remote sensors, and considering that the amount of water used per hectare in full summer irrigation is 4 to 5 times greater than the amount used in winter supplementary irrigation. The researcher found that the potential areas for supplementary irrigation will expand around the areas planted with summer crops according to ratio, so the suitability of the land and the economic aspects are taken into account, however maps of areas that can be supplemented with irrigation can be drawn and water needs determined for them. (De Pauw , et al., 2008).

It is of utmost importance to determine the areas in which supplementary irrigation can be implemented also to know the required amount of water and the consequences that it may leave at the bottom of the stream, as planning officials at the state level must take this into consideration, taking into account the possibility of making maximum use of the productivity of supplementary irrigation and reducing irrigation losses.

Research Gaps and Future trends

When considering current conditions and the potential for supplementary irrigation technology, experience has shown that the most effective approach to introducing new technology or improving existing practices or both it will be through integrated and participatory research programmers. Perhaps any program for development and applied research, or one of them, neglects or slightly values the role of the farmer, is inevitably destined to fail. Therefore, one of the conditions for the success of supplementary irrigation techniques is its acceptance by farmers.

Understanding the specific needs of the local community or a group of beneficiaries is an essential issue for designing and implementing an appropriate system. The farmers' acceptance of new technology depends on their attitude towards production risks and their awareness of those risks.

To summarize the lessons we learned from the practice of supplemental irrigation and to reach the maximum benefit, we show the following:-

- The best irrigation water supply system that is suitable for supplementary irrigation is the “on-demand supply” system, and this is the case in small-scale farms that use wells or nearby surface water sources.
- The supplementary irrigation should be appropriately integrated with other production inputs including crop and soil management options, climate change, and other options necessary to achieve the required results.
- The poor farmers in dry rain-fed areas cannot pay for modern irrigation systems because of their limited resources. Carefully planned interventions at the socio-economic level must be provided and implemented through appropriate policies to assist and support these farmers.
- Iraq is facing water shortages and problem is becoming more serious with time. So, the farmers have to use supplementary irrigation technique. According to researches the best place to use supplementary irrigation is in the Northwest of Iraq, where the amount of precipitation is acceptable and sufficient to use this type of irrigation system.
- The farmers need to understand the technology transferred to them and how to properly employ and manage it. Here, agricultural extension and human capacity building must

play a key role in this field. Long-term training and advisory programs must be designed and implemented at various levels.

- Perhaps any development and applied research programs that neglect or underestimate the role of the farmer will inevitably fail. Therefore, one of the conditions for the success of (SI) techniques is acceptance by both male and female farmers.
- Natural resources, especially land and water, are used more efficiently when this use is on a collective basis rather than on an individual basis. Water user associations are a good example of an effective approach to collective water use and management.

References

Adary, A., A. Hachum,T. Oweis, and M. pala (2002). Wheat Productivity under Supplemental Irrigation in Northern Iraq. On Farm Water Husbandry Report Series, No.2. *International Center for Agricultural Research in the Dry Areas (ICARDA),* Aleppo, Syria.

De Pauw, E., T. Oweis, B. Nseir, and J. Youssef. (2008) Spatial modeling of biophysical potential for supplemental irrigation a case study in Syria. A research report. *The Comprehensive Assessment of Water Management for Agriculture International Center for Agricultural Research in the Dry Areas (ICARDA)*, Aleppo, Syria.

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

Oweis, T. and A. Hachum. (2009). Optimizing Supplemental irrigation: tradeoffs between profitability and sustainability. *Agricultural Water Management* ,96: 511-516.

Oweis, T.(1997). Supplemental Irrigation: a Highly Efficient Water-use Practice. *International Center for Agricultural Research in the Dry Aeas (ICARDA),* Aleppo, Syria. 16pp.

Oweis, T. and A. Hachum. (2011). Reducing peak supplemental irrigation demand by extending sowing dates. *Agricultural Water Management* ,50:109-123.

Oweis, T. and A. Hachum. (2003). Improving water productivity in the dry areas of West Asia and North Africa. Pages 179-198 in Water productivity in Agriculture: Limits and Opportunities for Improvement(W.J. Kijne, R. Barker, and D. Molden. Eds) CABI Publishing, Wallingford, UK.

Rockstrom, J., J. Barron and P. Fox. (2021). Rainwater management for increased productivity among small-holder farmers in drought prone environments. Pges 319-330 in *Proceeding of the 2nd WARFSA/Water Net Symposium Integrated Water Resources Management*.

Rockstrom, J., S. Wani, T. Oweis, and N.Hatibu.(2017). Managing water in Iran-fed agriculture. Pages 315-348 in water for food water for life: *A comprehensive Assessment of water Management in agriculture. Earth Scan, London and International water management institute*, Colombo, Sri Lanka.

Singh, P., P.K. Aggarwal, V.S. Bahatia, M.V.R. Murty, .M Pala, T. Oweis, B. BENLI, K.P.C. Rao, and S.P.Wani, S.P. (2009). Yield gap analysis: modeling of achievable yield at farm level. Pages 81-123 in Rain-fed Agriculture: *Unlocking the potential comprehensive assessment of water management in agriculture*, Volume 7. (S.P.Wani, j. Rockstrom, and T.Oweis, eds). CABI International, Wallingford, UK.

Sommer, R., Oweis, T. and L. Hussein. (2011). Can supplemental irrigation alleviate the effect of Climate Change on the 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.

Tavakoli, A., T. Oweis, H. Farahani, S. Ashrafi, A. Hormoz, H. Siadat, and A. Liaghat. (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.

Some Readings and Results of Agricultural Research

- Supplemental irrigation potential for wheat in the central Anatolian plateau of Turkey. T.Oweis, A.B. Salkini, H.Zhang, A. IIbeyi, H. Ustum, Z. Dernek, and G. Erdem, Rural Services Research institute (ARIRS), Ankara, Turkey, ICARDA, Aleppo (Syria). 2001. No.m1:37 pp. On –Fram water husbandry research report series. ISBN 92-9127-109-8.(En).

- Wheat productivity under supplemental irrigation in Northern Iraq. A.Adary, A.Hahum, T. Oweis, M. Pala, IPA Agricultural research center, Baghdad(Iraq) Mosul University, Mosul, Iraq, ICARDA, Aleppo, Syria. 2002. No. 2:38 p. On-Farm Water Husbandry Research Report Series. ISBN 92-9127-125-X. (En).

- Water for Food Water: Water for Life (Summary). A comprehensive Assessment of Water Management in Agriculture (Earthscan, 2007). London: Earthscan, and Colombo: International Water Management Institute (IWMI). Chapter2. 15 p.

- Rain-fed wheat productivity with supplemental irrigation in Al-Hasakeh, northern Syria. G. Somme, T. Owies, F. El Omar, A. Bruggeman, and Akhtar Ali. 2004. On- farm water husbandry in WANA. Research report No. 4. International Center for Agricultural Research in the Dry Areas (ICARDA),Aleppo, Syria, iv+27pp. En. ISBN: 92-9127-162-2

- Supplemental Irrigation in Iran: increasing and stabilizing wheat yield in Iran-fed highlands. A.R. Tavakoli, T.Y. Owies, F. Ferri, A. Haghighati, V. Belson, M. Pala, H. Siadat, and H. Ketata 2005 On-Farm Water Husbandry Research Report No. 5. ICARDA, Aleppo, Syria, xii+46 pp. ISBN: 92-9127-1665. (En).