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REVIEW

Managing Scarce Water Resources in the Drylands of West Asia and North Africa: Review of Joint Research between ICARDA and Japanese Researchers

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Abstract

In the arid regions of the world, maintaining economic and efficient crop production has been among the most critical challenges. In this context, International Center for Agricultural Research in the Dry Area (ICARDA) has been leading in research-for-development for improved management of scarce water and land resources in the arid regions. In the new framework of the One CGIAR, the role of ICARDA will be more indispensable as climate change will make considerable negative impact on water resource availability and land sustainability in the dry areas. This review covers selected research works pursued in irrigated, rainfed and agro-pastoral systems in cooperation with Tottori and other Japanese Universities which represent longest history of cooperation between ICARDA and Japan. The review is structured into sub-sections summarizing joint research on supplemental irrigation (SI) for wheat cultivation to optimize water productivity in semi-arid region of West Asia and North Africa (WANA), and rehabilitation of Jordan's degraded agro-pastural lands with micro water harvesting technology. Joint ICARDA and Japanese Universities' research enhanced knowledge on the various adaptation technologies' effects on the soil-water-plant relationships, which supported the development of tailored solutions and scaling strategies. The results are internationally recognized as contributions to coping with scarce water resources and combating land degradation in arid and semi-arid environments.

Discipline: Agricultural Engineering
Additional key words: micro-catchment rainwater harvesting, rangeland rehabilitation, supplemental irrigation, water productivity, water yield relationship

Introduction

The International Center for Agricultural Research in the Dry Areas (ICARDA) is an international organization carrying out research-for-development and capacity building efforts in fifty countries across the world's dry areas to provide innovative, science-based solutions for communities across the non-tropical dry areas in partnership with research institutions, NGOs, governments, and the private sector to share advanced scientific knowledge, shape practices, and inform policy. ICARDA is a CGIAR Research Center which is world's largest global research partnership for a food-secure future.

Since establishment of ICARDA in 1977, eleven Japanese scientists have worked for ICARDA in different capacities. Among them Prof. Iwao Kobori (1997–2002), and Pres. Shinobu Inanaga (2002–2008) served as members of Board of Trustees. In addition, ICARDA received more than twenty Japanese scientists through Japan International Cooperation Agency (JICA), Japan International Research Center for Agricultural Sciences (JIRCAS), and Tottori University. Those include junior researchers who carried out different research activities in ICARDA. Amongst all Japanese scientists and researchers, Dr. Giro Orita, a JICA expert veterinarian starting his career at ICARDA in 1983 had made the longest and remarkable contribution to ICARDA's animal health research component, particularly in the field of small-ruminant pathology research to develop effective control measures on sheep and goat diseases and parasites. He strengthened relationship between ICARDA and Japanese organizations. In 1997, ICARDA built a new

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Animal Health and Nutrition Laboratory and dedicated it to Dr. Orita in recognition of his research contributions.

Through the long history of cooperation between ICARDA and Japan, ICARDA has conducted important collaborative research work with Tottori University especially the Arid Land Research Center (ALRC) and the International Platform for Dryland Research and Education (IPDRI). This paper reviews the research work conducted jointly between ICARDA and faculty members and scientists of Tottori University. Those have produced novel results reflect the potential impact of the cooperation, particularly in the field of water and land resource management in the arid region.

Concerning the fact that about 41% of the Earth's land area is classified as dryland (ISPC 2015), wherein the rainfed dry farming systems in temperate climates receives approximately 300–500 mm of annual rainfall, much of which falls in winter and spring (Hyman et al. 2008). The rainfall, which is not only insufficient but also irregular, constitutes a high risk 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 issue is how to store precipitation in the soil and how to retain it until needed by the plants. In drylands, water received as rain or snow can easily be lost before it can be utilized by a crop (Inanaga et al. 2005). Normally, evapotranspiration exceeds the seasonal rainfall amounts and the irregular rainfall results in periods of drought spells which stress crops and cause substantial yield. In the West Asia and North Africa (WANA) region, wheat yields average less than 2 t/ha, one-third of its potential (Oweis & Hachum 2012).

A vast extent of the global drylands receives less 300 mm average annual rainfall, often cited as a lower limit of traditional rainfed production systems in temperate climates. Whilst those marginal drylands are hardly suitable for rainfed agriculture, they can be vital for extensive agro-silvo-pastoral systems. ICARDA and its partners have profound experiences in revitalizing degraded and low productive marginal landscapes, towards thriving native rangelands, agro-pastures and agro-forestry systems, and to enhance rural farmers' livelihoods under most harsh and dry climate conditions.

The first research review is on micro-catchment rainwater harvesting based rehabilitation of Jordan's degraded agro-pastures by Drs. Theib Oweis and Stefan Strohmeier from ICARDA and a team of Tottori University comprising Mr. Kota Akimoto, Ms. Sayo Fukai, Prof. Norikazu Yamanaka, Prof. Sadahiro Yamamoto with support from Kyoto and Hokkaido Universities. The other review is on SI for improved crop and water productivity in dryland agriculture led by Drs. Vinay Nangia, Theib Oweis and Osman Abdalla (ICARDA) and Ms. Atsuko Ogawa, Prof. Katsuyuki Shimizu, Prof. Haruyuki Fujimaki, Dr. Iwao Sakaguchi (Tottori University), and Profs. Takahiro Sato and Tetsuo Sakuratani (Kyoto University).

ICARDA is in the transition to One CGIAR which refers to the integration of 15 CGIAR Research Centers' partnership, knowledge, assets and global presence for a new era of interconnected research towards the SDGs. Aligned with the One CGIAR's mission, ICARDA is introducing the DryArc Initiative which enforces research-for-development approach with different international and national stakeholders to deliver stronger and relevant agenda for today's world of change under fewer institutional boundaries. ICARDA, within the One CGIAR, will take an essential role in arid regions hand-in-hand with international and local partners, including partner institutes in Japan, to end hunger through science to transform food, land and water system in a climate crisis ensuring that expertise and priorities of funders, clients, partners, and scientists are included.

Micro-catchment rainwater harvesting-based rehabilitation of Jordan's degraded agro-pastures

Around 90% of Jordan receive less than 200 mm average annual rainfall (Ababsa 2013) forming a dry rangelands environment called the '*Badia*'. Overexploitation, mismanagement and climate change triggered the degradation of the vulnerable *Badia* ecosystem, which has a traditional value for agro-pastoral communities (Al-Tabini et al. 2012). Nowadays, the uncovered and crusted soils increase surface runoff and erosion, impede the emergence and growth of the native vegetation, generate dust storms and push people to migrate to urban areas.

With the aim to rehabilitate the ecosystem and enhance the productivity of degraded agro-pastures, ICARDA, in collaboration with Jordan's National Agricultural Research Center (NARC), for the first time researched, developed and applied mechanized micro water harvesting (MWH) packages in the early 2000s during the 'Water Benchmarks' Project in Central and WANA (Oweis et al. 2006, Karrou et al. 2011). The so called 'Vallerani-Plow' technology (Antinori & Vallerani 1994; Gammoh & Oweis 2011) (Fig. 1) modifies the landscape's surface and thus its hydrology. The 'Vallerani' moldboard plow deep-rips the depleted and crusted soils up to around 0.5 meters depth. Through up- and downwards moving of the plow, the technology develops intermitted

MWH pits along the contour of the terrain. The spacing between contours in hillslope-thalweg direction depends on various local climate, terrain and soil conditions; a recommended contour-spacing in Jordan's Badia usually ranges between 5.0 and 15.0 meters. The single MWH pits' lengths can be manually adjusted. A widely recommended design in Jordan's Badia foresees around ~ 4.0 to 4.5 meters long MWH plowed pits with ~ 0.5 to 1.0 meters spacing between the intermitted pits along the contour line (Strohmeier et al. 2021). Depending on the individual plow adjustments, driving speed of the tractor, and the local soil conditions, the single pits' bottom and ridge are around 0.5 meters wide, of which the top of the ridge exceeds the natural surface by around 0.3 to 0.5 meters (Gammoh & Oweis 2011). The bottom of the pit is mostly around 0.2 to 0.4 meters deeper than the natural soil surface. In each created MWH pit, and mainly depending on the adjusted pit plowing-length, several native plant seedlings can be out-planted; a common recommendation is to plant two seedlings per pit. The eventually modified landscape effectively intercepts and collects the surface runoff generated during erratic rainstorms. The MWH-retained water locally deep-infiltrates into the soil profile, where it remains largely withdraw-able for the native shrub seedlings out-planted inside the MWH pits.

The technique secures and boosts both i) the growth of the out-planted shrub seedlings as well as ii) the emergence of plant genetic material sourcing from the eroded topsoil of the hillslope interspaces between the intermitted contour lines. The MWH habitat creates moist and protected conditions thriving the development of biodiverse vegetation patches, which subsequentially outspread (Strohmeier et al. 2021). Meanwhile, the Jordanian Government out-scales the promising MWH technology to the country's vast degraded areas. However, the varying long-term rehabilitation success so far largely relates with post-implementation management issues and the heterogeneous socio-ecological context. The complexity behind the context-specific success and/or failure creates space for well-targeted research, especially on the long-term ecosystem transition and its drivers. Successful pilot research and potential out-scaling of the micro water harvesting package of the Jordanian Badia has been well documented and published in a review paper (Oweis 2017), supported by IPDRE of Tottori University. This work particularly fostered the collaboration with Japanese Universities as outlined below – which elaborates on the remaining research questions and bottlenecks that challenge out-scaling.

Tottori University lead scientists and their exchange students, supervised by Profs. Norikazu Yamanaka and Sadahiro Yamamoto, in collaboration with Hokkaido and

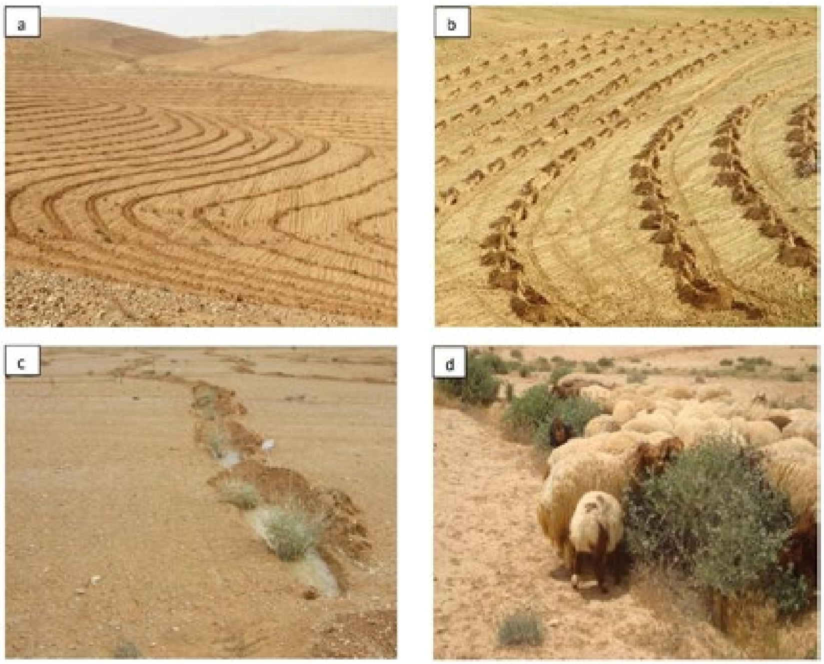

Fig. 1. Mechanized MWH: (a) 'Vallerani tractor plow' created contour lines across a dryland terrain, (b) Contour lines with intermitted MWH structures, (c) MWH pits with around one year old out-planted Atriplex and Salsola seedlings after a rain storm, (d) Sheep grazing on the vegetation in the rehabilitated landscape after > 2 years of development (Oweis 2017) Photos by Theib Oweis.

Kyoto Universities scientists Drs. Chikae Tatsumi and Takeshi Taniguchi, joined forces with ICARDA to take a deeper look into often neglected small-scale interactions of soil, water and plant dynamic processes affected by MWH. Thus, to eventually feed-back on potential biophysical drivers of rehabilitation success and failure - towards better targeted MWH implementation and out-scaling strategies. Advanced soil scientific approaches including micro-biological assessment tools and know-how from Japan aimed at investigating the soil, water and plant dynamics occurring at ICARDA's Badia Research Site (BRS), approximately 30 km south-east of Amman, Jordan. Akimoto (2021) observed and described soil physical and chemical properties which eventually affect plant growth inside the pit (Fukai et al. 2018, Fukai, 2019), but also the emerging vegetation in upslope proximity (Akimoto 2021; Strohmeier 2021) (Fig. 2).

Adding to the physiochemical conditions, Tatsumi et al. (2021) investigated and confirmed the driving and underlying soil micro-biological interactions apparent through MWH treatment. The authors conducted field experiments on soil microbial assessment including abundance, community structure, community composition, diversity, network complexity, and decomposition function and their relations with the local environment in proximity to ICARDA's BRS. Both sites (BRS and soil microbial research site) are located in the central Jordanian Badia, receive between 100–200 mm average annal rainfall (distributed from September to May), have comparable soil textures (silt loam, silty clay loam and clay loam), and their altitudes range between around 700 to 850 meters above sea level. The obtained soil samples' physiochemical and DNA related properties (e.g. amplification of rRNA genes) were analyzed using advanced laboratory equipment available at Kyoto University, Japan. Based on the proven environmental similarities the results retrieved by Tatsumi et al. (2021) are considered comparable to the processes appearing at ICARDA's BRS. Eventually, the MWH-based rehabilitation approach alters the soil-ecosystem, particularly soil water retention and infiltration, moisture storage, and subsequent provision of water to the upcoming vegetation patches.

Fig. 2. Soil sampling conducted by Prof. Sadahiro Yamamoto and his students Ms. Sayo Fukai and Mr. Kota Akimoto – at ICARDA's BRS in March 2018. Photo by Stefan Strohmeier.

Fukai et al. (2018, 2019) and Strohmeier et al. (2021) investigated the intra-seasonal pattern of soil moisture, controlled by a specific rainy and dry season from December 2017 to December 2018. The study performed by Fukai et al. (2018, 2019) and Strohmeier et al. (2021) underlined the MWH techniques' positive impact on substantially reducing soil-water stress on the out-planted shrub seedlings. Robust soil moisture provision, in turn, diminishes implementation failure and boosts a rapid shrub-ecosystem development.

Advanced Japanese soil-water-plant relationship research, including soil structural, soil moisture, and vegetation cover development over time, eventually built a basis and input for field to watershed scale hydrological modeling (Strohmeier 2019) and long-term surface runoff simulations conducted by Haddad et al. (2018). The watershed level interactions of surface runoff, infiltration and soil moisture zonal development, simulated by Strohmeier et al. (2019), eventually feed-back on the effectiveness of a specific MWH implementation design. ICARDA's and NARC's joint MWH piloting research, supported by Japanese advanced soil micro-biological assessment facilities, yielded various publications including an endorsement as successful approach for combatting desertification by the Intergovernmental Panel on Climate Change (IPCC) in its special report on 'Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems' (IPCC 2019). Joint on-the-ground research also created a local validation database for an ex-ante out-scaling study conducted by Sarcinella et al. (2020) merging remote sensing products with global modeling tools.

The collaborative research conducted between Japanese Universities and ICARDA merits an endorsement as international success story. However, the outstanding research questions yet unanswered, e.g. injecting and fostering beneficial micro-biological development towards targeted soil structural change, will allow new chapters to be written by the alliance of Japanese and ICARDA scientists - towards coping with water scarcity, combatting land degradation and enhancing agricultural productivity of drylands.

Supplemental irrigation for improved crop and water productivity in dryland agriculture

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 enough moisture for normal plant growth (Oweis & Hachum 2012). SI is an effective response to alleviating the adverse effects of soil moisture stress on the yield of rainfed crops during dry spells. 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. SI, 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 et al. 1998). 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 & Hachum 2009).

Unlike full irrigation, the timing and amount of SI is difficult to be determined in advance given the rainfall variability. SI in rainfed areas is based on the following three basic aspects (Oweis & Hachum 2012):

1. Water is applied to a rainfed crop that would normally produce some yield without irrigation.
2. Since rainfall is the principal source of water for rainfed crops, SI is only applied when the rainfall fails to provide essential moisture for improved and stable production.
3. 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. SI can be applied to field crops, fruit trees and even landscape areas.

Water-yield relationship and optimum SI of wheat in a Mediterranean climate

As stated before, Jordan is amongst the most water scarce countries in the world, and agriculture is the largest user of water. Rainfed crops cover most agricultural areas in the country, and cereal yields are low and variable in response to inadequate and erratic seasonal rainfall. One way to improve yields is the application of SI, which can make up for the deficits in seasonal rains. Ms. Atsuko Ogawa of Tottori University conducted a field study (Fig. 3) for her master's degree thesis (Ogawa 2016) under joint supervision of Profs. Katsuyuki Shimizu (Tottori University) and Nangia in Madaba, central Jordan, during the 2014–2015 growing season on deep clay soil with 10 varieties of durum wheat (*Triticum durum*) to evaluate the effects of SI on water-yield relationship. Four irrigation treatments were tested (rainfed, 25% field capacity (FC) SI, 50% FC SI, and 100% FC SI). Soil moisture was measured at weekly intervals, and all irrigated plots were irrigated using drip irrigation when the soil moisture of the 100% FC SI treatment had lost 50% of the total available water. Biomass water productivity was highest in the 50% FC SI treatment in five varieties (Berghouata1, Icamoram7, Azeghar2, Korifla, and Secondroue), in the 25% SI treatment in four varieties (Icakassem2, Icambel, Omrabi5, and Miki3), and in the rainfed treatment in one variety (Icarasha2). Due to unusual frost conditions during flowering stage of wheat growth, the measured yield was adversely affected. To overcome this, the study used literature reported harvest index (HI) value to estimate yield from measured biomass. HI values of 0.34, 036, 0.38 and 0.40 were assumed for rainfed, 25% FC, 50% FC and 100% FC SI treatment, respectively based on a long-term study conducted in Syria (four varieties of wheat over five years and under similar level of SI and rainfed treatment as this study) and reported by Zhang et al. (1998). The results demonstrated that the 100% FC SI irrigation amount does not necessarily coincide with the highest grain water productivity in durum wheat (Table 1). Therefore, under water-limited conditions, maximizing water productivity may be considered a higher priority than maximizing land productivity which can be achieved by applying SI at less

Fig. 3. Hand planting of treatments on the small experimental plots in Mushaqqar, Madaba, Central Jordan. Photos by Atsuko Ogawa (2016).

Table 1. Grain and biomass yield (t/ha) of ten durum wheat varieties measured during the SI experiments at Mushaqqar, Madaba, central Jordan during 2014–2015 growing season (Ogawa 2016).

Variety	0% SI		25% SI		50% SI		100% SI	
	Grain	Biomass	Grain	Biomass	Grain	Biomass	Grain	Biomass
Icarasha2	1.23	4.87	1.36	5.14	1.49	5.40	1.09	3.80
Omrabi5	1.02	4.05	1.38	5.20	1.09	3.97	1.16	4.06
Berghouata1	1.22	4.84	0.90	3.38	1.84	6.68	1.32	4.62
Icamoram7	1.27	5.03	1.16	4.39	1.69	6.14	1.75	6.12
Azeghar2	1.27	5.04	1.48	5.60	1.66	6.03	1.66	5.80
Korifla	1.18	4.69	1.67	6.31	2.03	7.38	1.50	5.24
Icakassem2	0.92	3.62	1.39	5.25	1.18	4.27	1.46	5.10
Icambel	1.06	4.20	1.55	5.87	1.18	4.27	1.21	4.21
Miki3	0.91	3.60	1.56	5.89	1.34	4.85	1.13	3.95
Secondroue	1.13	4.48	1.20	4.55	1.58	5.74	1.14	3.96
Mean	1.12	4.44	1.37	5.16	1.51	5.47	1.34	4.68

than 100% FC level.

Numerically optimized SI depths for wheat cultivation in semi-arid region of WANA

Since water resources are scarce in the dry areas, a water application recommendation that can lead to minimum water application and maximum profit for farmer is needed for the planners. A methodology developed by Fujimaki et al. (2014) for optimization of SI depth using a numerical simulation model of simultaneous heat and mass transfer in soil including crop growth and the freely accessible weather forecast databank was applied to winter wheat cultivation in WANA dry areas of Jordan (during 2016 growing season) and Morocco (during 2017 growing season). Fujimaki et al. (2014) reported that the purpose of irrigation was not necessarily to obtain highest yields or highest water use efficiency but to maximize net income. Even though the timing of irrigation depends on social factors, the amount of irrigation is under control of irrigator. During their joint research experiments in Jordan and Morocco, Fujimaki and Nangia focused on the optimization of the irrigation amount to maximize the virtual net income. For these field experiments, three different experimental treatments (numerically optimized deficit irrigation using this proposed methodology, automated full irrigation controlled by solenoid valve, and rainfed), drip irrigation system, and monitoring devices for change in soil-water content were installed (Fig. 4). From the measured grain yields and amount of irrigated water, gross and net incomes, and monetary cost of irrigated water were calculated. Figure 5 compares the cost, net income for each treatment. The cost was calculated by multiplying total amount of irrigation water and the price of water. The net income was the difference between the income and the cost. Totally applied depth for numerically optimized deficit irrigation treatment was 238 mm. The income was obtained from the averaged actual yield of each treatment (2.44 t ha^{-1} for rainfed, 3.20 t ha^{-1} for automated full irrigation, and 3.94 t ha^{-1} for numerically optimized deficit irrigation) and the sale price of crop. The income from the two irrigated treatments was significantly higher than that of the rainfed, while the net income of the rainfed was the highest. This might be caused by the unusually high yield of the rainfed treatment possibly due to the abnormally greater than average precipitation that year (280 mm average versus 487 mm in the year of study) and underestimated drought tolerance and root growth modeling parameters in the numerical simulation. But in a normal precipitation year with a crop with high sale price, the numerically optimized deficit irrigation treatment should give highest income with least amount of water. These results (Fujimaki et al. 2017a,b) are novel because they consider the cost of water applied, the sale price of commodity being produced and the weather forecast which help to calculate the economic water

Fig. 4. Programming and installing soil moisture sensors. Photo by Vinay Nangia (2017).

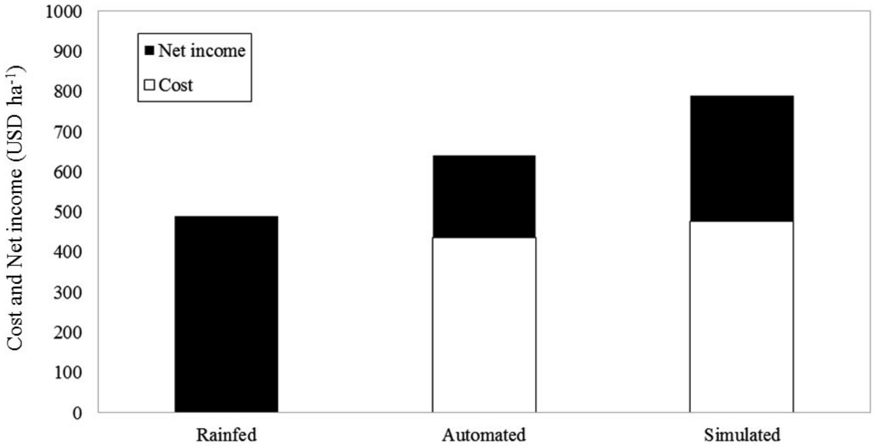

Fig. 5. Cost and net income for each treatment (Fujimaki et al. 2017b).

productivity ($/m³). In past, researchers have only looked at maximizing physical yield (kg/ha) or minimizing water application (m³/ha) leading to calculation of physical water productivity (kg/m³).

Effect of SI on physiological parameters of wheat and role in scheduling water application in northern Syria

Increasing water use efficiency in agriculture requires thorough understanding of plants transpiration and its efficiency under different soil-water conditions and their interactions with plant physiological processes (Zhang et al. 1998). Furthermore, determining SI timing is another challenge in rainfed systems because irrigation is given only occasionally and that some soil moisture stress is allowed to maximize water use efficiency. This is unlike fully irrigated systems where means for determining time of irrigation are well developed (Oweis et al. 1998).

The impact of SI on bread wheat stomatal conductance (SC) was studies by Mr. Takahiro Sato (Sato et al. 2006a, b) in a field experiment at the ICARDA Tel Hadya research station (Fig. 6). SC reflects the level of plant leave stomatal opening in response to the plant water stress. SC decreases with higher moisture stress as a mechanism plant use to avoid drought impacts. The experiment was a collaborative research program between ICARDA and Kyoto University. The SC of the bread wheat grown in the field during the transition period was examined in relation to the vapor pressure deficit of the air, solar radiation, and the soil available water under full and deficit SI strategies. The seasonal estimates of SC showed an apparent decline under high evaporative demand in both full and deficit irrigation. It is evident that the effect of SI on stomatal opening had declined toward the end of the planting season which suggests that it may be advisable to delay irrigation of winter wheat until later stages of growth. This strategy would likely to increase water use efficiency of wheat grown in this area. Although weather conditions prevailed during the experiment were average, but the findings may also help optimizing SI scheduling during other years. The accumulation of longer-term field data, however, is recommended for more efficient SI practices (Sato et al. 2006a, b).

Fig. 6. Wheat SI experimental plots at ICARDA research station in Tel Hadya, Aleppo, Syria. Photo by Theib Oweis.

The collaborative field research had also evaluated the potential for using predawn leaf water potential (LWP) as an indicator for SI scheduling. LWP is another indicator that reflects water status of the plant and is used as a self-dehydration avoidance mechanism. The trial included five field-grown wheat cultivars with both full and deficit SI strategies. The relationships between LWP and rooting system, soil water, and vapor pressure were examined. It was concluded that LWP as an indicator was unable to detect plant water stress before apparent morphological changes appear. So, LWP alone was not recommended for determining irrigation timing as stress indicated by LWP may cause a decline in yield. The impact on water use efficiency was not evaluated but likely to be positive especially when using more weather parameters it can help in establishing better indicators for irrigation scheduling (Sato et al. 2006b).

Conclusions

ICARDA's mission in the dry areas can be more successful with the support of advanced institutions of Japan, especially those mandated to conduct research in and serve the arid and semi-arid environments. The collaboration between ICARDA and Japan has produced fruitful results recognized internationally through refereed publications in high impact journals. Outputs of the research have contributed to improved water and land management in the dry areas and to building research capacity of national systems in this region. The complementarities between scientists and resources of Japanese institutes and ICARDA help in filling many gaps and allow to tackle complex research questions arising in the dry areas, especially those associated with increasing water scarcity, land degradation and climate change. The combination of technological advancements of Japan which is represented by the comprehensive support of government and researchers to help modernizing Japan's agricultural sector through cutting-edge technologies developed in Japan's manufacturing sector with ICARDA's adaptive capacity can produce, test, disseminate and scale innovations using modern approaches. These achievements facilitated countries and communities to build resilient livelihoods, include more women and youth in agricultural enterprise, and forge robust food-security systems that will be essential for the global recovery from the ongoing COVID-19 pandemic. ICARDA is the only CGIAR Research Center to be headquartered in the non-tropical drylands and with over four decades of trusted and official partnerships in the region, that makes us uniquely placed to partner with regional government, National Agricultural Research Systems and other key national institutions, the private sector, and most importantly the rural communities who live there. Together we provide real-life solutions that work, in order to help deliver on CGIAR's vital mission towards a world free of poverty, hunger, and environmental degradation. For that, it is recommended that the cooperation between Japan and ICARDA be continued and further developed to meet the new challenges in the dry areas and to benefit from the new One CGIAR system.

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