2017/4

2017 I FOURTH QUARTER

ICID NEWS

MANAGING WATER FOR SUSTAINABLE AGRICULTURE

MESSAGE FROM THE PRESIDENT

Dear Colleagues,

As I write this message, the on-going drought situation in parts of South Africa, particularly its devastating impact on the city of Cape Town, weighs heavily on my mind. According to usage and availability of the water, Cape Town will run dry on the 22 April 2018. And, I believe, it reminds all water sector professionals the severity of the global water situation in times to come, when such extreme events will almost become a new global norm due to climate change. It also calls for a determined preparation on our part. ICID family has been voicing such concerns from time to time and working hard to find science-based solutions to deal with growing water scarcity. Scarcities can be tackled, if we have a reliable estimate of our current demands and their growth in future. Water Accounting (WA) is emerging as a useful methodology in this direction that can guide long-term water planning and policy making, therefore, ICID is developing a draft WA position paper for the benefit and inputs of its members and partners. Separately, FAO is leading a group of experts, including experts from ICID, to prepare a White Paper on WA for policy makers that may be presented in the upcoming World Water Forum (WWF8) in Brazil.

A range of other ICID activities are planned for 2018, starting with the commencement of an e-Discussion in the ICID Young Professionals e-Forum (IYPeF). Several relevant topics have already been identified by this 300+ strong group of young professionals and mentors from around the world. We look forward to an active participation by all and wish them success for a useful outcome. Along the similar lines, ICID's Technical Support Unit (TSU), in collaboration with the Chinese National Committee on Irrigation and Drainage (CNCID) has planned to conduct a YP training program on the theme "Performance Assessment of Irrigation Systems" from 9-13 April 2018 at China Hall of Science and Technology, Beijing, China. I wish them the same success, too. Following this, the CNCID is also organising a 2-day workshop entitled "Innovations of Irrigation Technology" from 14-15 April 2018 at the same venue.

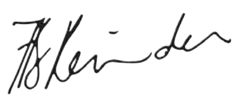
The 8th Asian Regional Conference (ARC) in Kathmandu-Nepal, slated to be held from 2-4 May 2018, has received a tremendous response with 100+ papers. Many conference sessions, a YP training and five symposiums, hosted by USAID, IWMI, ICIMOD, ICEWaRM, FMIST and the World Bank's Department of Irrigation, are some of the highlights. I will update more about the 69th International Executive Council of ICID along with the International Conference in Canada (August 2018) in the upcoming issues of the ICID News.

Now, I would like to take this opportunity to again request the National Committees (NC) to collaborate with TSU by nominating both short- and long-term experts from their countries/regions, and making full use of this platform exclusively mandated to entertain technical capacity building requests from NC's. Climate change does not carry any national passport and hence such international collaborations to share knowledge and expertise are the need of the hour.

To make collaborations little easier, the ICID Working Groups are in the process of making full use of interactive internet-based real-time conferencing to conduct their regular meetings as this will allow more time for focused technical discussions during Congresses, World Irrigation Forums and other ICID events. This reminds me of the powerful role of technology in solving problems of mankind, including water related. In this issue you will find technical articles that revolve around engineering and technology for better water management as well as institutional reforms that can facilitate a holistic approach.

As I close this message, on ICID community's behalf I would like to recognize and thank Er. Avinash C. Tyagi for his excellent contributions in uplifting ICID during his tenure from 2012 to 2017 as its Secretary General, and at the same time please join me in welcoming Er. Ashwin B. Pandya as the new Secretary General, who assumed the charge on the very first day of this exciting new year.

With regards,



Felix Reinders
President, ICID

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INSIDE

Institutional Reforms in Irrigation Sector for Sustainable Agriculture Water Management: A Global Review

Dr. Hafied A. Gany*

Institutional and organizational arrangements for irrigation and drainage development and management especially related to reforms undertaken have great influence on the quality of irrigation services provided to the farmers. Considering the importance of this issue, as part of the 23rd ICID Congress, a symposium on "Global Review of Institutional Reforms in Irrigation Sector for Sustainable Agriculture Water Management, including Water User Associations" was organized under the guidance of VPH Dr. Hafied Gany (Indonesia) as Chairman of ICID Working Group on Institutional and Organizational Aspects of Irrigation/ Drainage System Management (WG-IOA). This article is an extract based on the outcome of the Symposium.

Different countries have different institutional and organizational arrangements for irrigation and drainage development and management, especially related to reforms undertaken in the recent past in relation to the organizational arrangements. In an attempt to grasp the global perspective of such a large interdisciplinary areas of institutional and organizational aspects of irrigation and drainage and to deliberate on the issues related to institutional reforms needed for sustainable agriculture management, an international symposium on the theme 'Global Review of Institutional Reform in Irrigation Sector for Sustainable Agriculture Water Management, including WUA' was organized on 8 October 2017 during the 23rd ICID Congress at Mexico. For the symposium, a brief synthesis of institutional and organisational aspects in terms of issue and challenges, legal frameworks, approaches to PIM and its impact in 14 ICID member countries who submitted their country papers and case studies in these countries and regions is presented in this technical note.

The case studies represent a vast diversity of geography, climate, governance, socio-economic conditions and level of development which is very clearly reflected in their reports. While Australia represents a separate continent with its own unique geographical and climatic features, other countries and regions are monsoon governed - East, Southeast, and South Asia – on one hand and low-precipitation arid Middle East and Africa regions on the other. Turkey and Ukraine characterize to some extent the features of Europe. With regard to the main source of freshwater, variation in annual rainfall in spatial-temporal dimensions is quite significant among the countries as well as within the large countries such as Australia, China, India and Indonesia.

Agriculture has been a historical livelihood or subsistence activity in all these countries too and continues to remain a mainstay of many rural populations, its role in the national economy is gradually declining in most countries. However, the food security issue keep it as a development priority in national planning processes. In the countries with smaller land areas and high technology, such as Japan and Korea, agriculture is now viewed as technology-driven food factories of future. Countries with significant base population and population increase rates, such as China, India, and Indonesia, continues and will continue to dominate development debate in future. Newly established countries such as Ukraine have a different challenge, i.e., where to place agriculture in an open market economy environment; this is more of a policy issue rather than natural resources availability. On the other hand, Sudan, with large untapped potential in agriculture, views agriculture as the main national development platform.

Despite all the variations, national food security remains the main at the forefront in all the countries. Accordingly, the importance of irrigation and drainage in maintaining a satisfactory level of food security at present and in foreseeable future is recognized by all the countries. The other main common issue is the physical deterioration of national irrigation and drainage systems in addition to building the future water management infrastructure. Much of the development in major infrastructure took place after the Second World War and this infrastructure is rapidly aging, making repairs and maintenance more expensive every day and more challenging in emerging development models.

Legal and Institutional Framework for AWM: In terms of a legal and institutional framework for water management at different levels, very few countries have achieved a satisfactory state. The problem is compounded by diminishing priority to agricultural development as it is giving way to more remunerative sectors (industry, urban, consumers) in national development plans. Consequently, irrigation and drainage sector has suffered significantly due to its frequently changing parentage often tossing between ministry of food, ministry of agricultural or ministry of water management and water resources development. This policy blur at the national level has disturbed the traditional roles of local communities in running or managing local canals and other irrigation infrastructure.

While most countries have reported drafting of law and regulations or guidance for the formation of farmers' groups, under different names, their actual implementation at ground level is far less than satisfactory, and even disturbing the traditional rural socio-economic fabric. Quantitatively the reported numbers of such groups may be large, but the quality of their capacity has much to be desired. Few countries, such as South Korea, are not even encouraging the formation of such groups and have placed the O&M responsibilities with

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rural development agencies, departments or private companies.

Aging farming populations, lack of youth interest in rural livelihoods, confusing water pricing structures, inadequate government support and competing water demands from other sectors have all contributed in making agriculture water management and also family-based agriculture less attractive for youth and private investment. Such social and demographic phenomenon has further eroded the self-governance capacity of rural communities. Malaysia has reported some efforts to strengthen the water user groups, but it is too early and it would be interesting to see the outcome in future. Japan has its own unique model, named, Land Improvement District (LID), which has had significant success in stabilizing the rural water situation, and Japan International Cooperation Agency (JICA) is already testing the success factors of LID in 16 different developing countries. Several recommendations have emerged to make institutions responsible for water planning more broad-based, multi-disciplinary, coherent and holistic.

PPP in Irrigation and Drainage Systems: Major irrigation and drainage infrastructure have always been the mandate of national governments and it will continue to be so for many decades. Water as an input for food production has never been an economic or monetary entity in itself, unlike fertilizer or seeds or pesticides, skewing the food price calculations in open market systems. Even the capital cost of farming-family land generally does not figure in such calculations. Private sector being profit-oriented comes into picture only when the agricultural raw material is harvested and arrives in the market for further processing, storage, packaging, retailing and value addition. Or, the agricultural inputs such as fertilizer or seeds, which are not considered natural resources or public good, are able to draw the attention of the private sector. PPP models in rural infrastructure developments, including roads and irrigation-drainage systems have rarely demonstrated success, let alone a proven business model. In the country reports discussed here private sector involvement is indicated generally in the O&M part and that too in very few countries when water user groups failed. Lack of policy clarity across the countries and social value attached with water rather than its economic value are considered major hurdles in large private sector investments in irrigation-drainage infrastructure. Though, like electrical power distribution, water may incentivize private sector involvement and eventual investment in this rather neglected, yet future critical, sector for sustainable development.

Way Forward: All reports have indicated some activity on this front at least at a planning stage. Climate change, increasing population pressure in some cases, food security, depreciation of irrigation-drainage infrastructure, uneven or declining availability of freshwater for food are some of the major determiners of future plans. At the governance level, inclusive planning and equitable allocation are major considerations. While some countries have reported intentions for more specific investments in irrigation-drainage infrastructure, others have identified human capacity building at the water use level as a priority. Integrated water management plans right from nation and province/state to local district/village levels seem to be an emerging consensus in all reports. Some of the institutional reforms have been more like trial runs or experiments, rather than some long-term vision-based commitments. Inter-community, inter-sector, inter-state and even international cross-boundary water conflicts are rearing their heads, and therefore, international networks have much bigger challenges to deal with when it comes to agricultural water management. All kinds of collaborations, joint deliberations, human resource sharing, research cooperation, and capacity building are the main keywords that will guide the future path of sustainable development in an uncertain climate.

Saemangeum Sea Dike: Sustainable Development of Tidal Areas

Bon Hoon Lee*

The Saemangeum Sea dike, located on the southwest coast of the Korean peninsula, is the world's longest man-made sea barrier (33.9 km). The mammoth project, which began in 1991 as the first phase of the Saemangeum land reclamation project, was officially completed on 27 April, 2010. The longest dike was built by the Ministry of Food, Agriculture, Forestry and Fisheries and the Korea Rural Community Corporation (KRC). The Saemangeum Dike is listed in Guinness World Records as the longest man-made sea barrier in the world.

Saemangeum dike is twelve times the length of Golden Gate Bridge (USA) - wide enough to accommodate five lanes of traffic - and 50% longer than Manhattan Island. On 2 August, 2010 it was listed in the Guinness World Records as the longest seawall in the world ever built measuring 33.9 km after it broke the record of Zuiderzee dike (32.5 km) in the Netherlands. The average width of the earth dam is 290 m with 535 m at its widest and the average height 36 m with 54 m at its highest.

Located in North Jeolla Province, the great seawall is a testimony of its engineering feat to the civil engineering community around the world. The entire construction process of the dike - from design to completion - was carried out by the Korea Rural Community Corporation's (KRC) engineering technology in waters more than 50 m deep, unlike ordinary dikes that are usually built in shallow waters. The engineers in Saemangeum also overcame a massive obstacle- the high speed of the current, which stood at seven meters per second- to build the giant dike.

Saemangeum dike runs between two headlands and separates the Yellow Sea and the former Saemangeum estuary. Connecting Gunsan city and Buan county on the west coast of Korea, it has reduced the transport distance between the two by more than 50 km thus, shortening the travel time by nearly one hour to 30 mins. A whopping amount of almost 3 trillion won (US$ 2.6 billion) was pumped into the project employing eco-friendly construction methods along with 2.37 million workers per year to build the giant seawall.

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Saemangeum: Korea's Green Hope — (An Overview)

Background

- Project plan began when rice was imported due to drought, food insufficiency, and damage from cold weather during the 60s ~80s
- Project commenced in November 1991 through the processes such as the feasibility study, environmental impacts assessment, inhabitants' agreements, discussion with related organizations, and approval of sea reclamation from '80.

Project Outline

- Project name: Saemangeum Comprehensive Development Project
- Aim : Develop into an economic center of the East North Asia
- Location : Around Gunsan-si, Gimje-si, and Buan-gun, Jeollabuk-do
- Area : 401^2 (land 283^2 / freshwater lake 118^2)
- Main construction : 33.9 km Sea dike, 2 sluice gates, 68.2 km water blocking embankment
- Project period : Sea Dikes (1991~2011) / inside development – Stage 1 (2010~2020) / water blocking embankment (2010~2015)

The Korean President Lee Myung Bak dedicated the project to the Korean people at a gala opening ceremony organized by the Republic of Korea's Ministry for Food, Agriculture, Forestry and Fisheries (MIFAFF) on 27 April, 2010. Over 2000 high profile officials, politicians, and delegates from countries around the world, including Former Secretary General, M. Gopalakrishnan, ICID gathered in Gunsan to be a part of the historic celebrations. During the ceremony, Korean President Lee Myung Bak expressed that Saemangeum Seawall is not merely a dike but an "economic highway for Korea to reach the world beyond Northeast Asia." It is a part of an ambitious plan to achieve low-carbon green growth in Korea, along with the four-river restoration project. The project, initially conceived to secure more land for farming back in 1991, will create a business hub linking the economies in Eurasia and the Pacific region. Over the years, the project has been upgraded to include free economic zones, industrial viability, leisure and tourism to attract foreign investment and become a growth engine for South Korea's global economy.

Saemangeum, the Special Land

Saemangeum (say-MAHN-gum) is a newly made term meaning 'to reclaim new plain fields.' The word "Sae" means 'New', while "Man" is derived from Mangyeong Plain Field, and "Geum" is taken from Gimje Plain Field, located in the Dongjin River Basin.

Saemangeum is an estuarine tidal flat on the coast of the Yellow Sea in South Korea. Due to its fertile land, the wetland has traditionally served as the country's water storage and played an important role as a habitat for migratory birds. It is renowned as "the field that saved the whole country from poor harvest years" and "the country's essential repository."

The Saemangeum dike marked the beginning of the largest tidal reclamation project in the history. South Korea originally launched the project for the estuary, about 200 km south of Seoul, decades ago to revive its sluggish economy. As food was short, reclamation seemed like a good way to increase farmland in the mountainous and cramped country. The project of filling in the estuary began in 1991 but was slowed by a series of court actions by political parties and environmentalists.

After years of legal wrangling and changes in how to use the land, construction started on the project in 1999 with hundreds of thousands of boulders dumped into the Yellow Sea estuary to form the dike that was completed in 2006. The natural wetlands were replaced with artificial ones and riverbeds were turned into man-made lakes. Through this project, 291 km^2 of new land is to be reclaimed and 118 km^2 of lake was created after the construction of the Sea Dike.

Since its opening, within three months, more than 3.5 million people including overseas tourists have visited the Saemangeum dike, making it a new tourist attraction. The seawall has also become a special venue for many leisure and sports activities like marathon running and cycling. The Korean government hopes that the 'Great wall on the Sea' will help attract foreign investment and export Korea's dike construction technology. The nationwide reclamation effort supports a massive construction industry and tens of thousands of jobs. The project, built at a cost of nearly $3 billion, will bring industry to North Jeolla, a province that has traditionally been the agricultural breadbasket of the country but lacks industrial growth.

The interior area of Saemangeum Seawall will be the focus in the coming decades and is being developed to become a tourism and industrial complex by 2020. According to the finalized comprehensive action plan for Saemangeum, the interior area of 28,300 hectares (two-thirds the size of Seoul) will be divided into eight sites, including industrial, tourism, leisure and international business. The Saemangeum provides eco-friendly and hi-tech land for agriculture, industry and tourism. The arable land will be used for the production of high-quality grain, hi-tech garden products, floriculture, and agriculture that will create a high-technology production base for crop exports. The KRC, which hosts the Korean Committee on Irrigation and Drainage (KCID), will undertake to refurbish agricultural infrastructures such as farmland re-plotting and irrigation development by developing reclaimed land into useful farmland. The KRC will also support establishment of large scale agricultural and fishery companies.

It is estimated that by the year 2020, the first stage, a total 85.7 km^2 (30.3%) of the reclaimed land in the vicinities of Mangyeong River and Dongjin River will be developed for agriculture to foster high-quality food exports in an increasingly competitive global market. The strategy to achieve this includes establishment of (a) pilot-complex for eco-friendly organic farms, green growth farms and high-tech agriculture, (b) export base for large agribusinesses involved in horticultural and other high-value products, and (c) infrastructure for eco-tourism through agriculture theme parks, rural villages, nurseries, tree plantations, and arboretums.

It is expected that such facilities will help secure national competitiveness and branding in international markets through eco-friendly agricultural practices and ecological crop cultivation using state-of-the-art technologies in greenhouses; integrated R&D facilities linked to food industry; and cluster-based manufacturing hub.

Saemangeum will have a high-class transportation infrastructure such as a new sea port, highway system, and railway as well as an expanded Gunsan airport. The entire development of the area is expected to cost upto $18 billion, which includes significant private sector investment. There are on-going efforts to attract foreign and domestic investments, and to invite companies involved in green industries, entertainment and tourism businesses.

One of the aims is also to develop 20.3 km^2 (7.2%) area from reclaimed lands into a world class renewable energy hub. Within this area will be located a research and experiment complex (4.3 km^2), bio-crops pilot farm (4.0 km^2), landfill (0.5 km^2), and reserved area for solar power plant and bio-crop cultivation farm of private sector and other organizations (11.5 km^2). The planned renewable energy hub is expected to form and foster an internationally competitive industrial base for new and renewable energy using a core technology value-chain approach by integrating R&D, pilot-scale incubation and commercial scale manufacturing complexes.

Saemangum will be the venue of the 25th World Scout Jamboree, hosted by the Korea Scout Association to be held in 2023. South Korea through its national project envisions Saemangeum to transform into a global city and become a frontrunner of Korea's first real 'green city' that can help make it stand out from the other economic zones.

State of Knowledge of Irrigation Techniques and Practicalities within given Socio-economic Settings

Dr. Ding Kunlun*

The recently concluded 23rd ICID Congress deliberated on the topic "State of Knowledge of Irrigation Techniques and Practicalities within Given Socio-Economic Settings" as Question 61. A total 64 papers were considered from 24 countries, including Mexico, China, Ukraine, Indonesia, India, Iran, Egypt, Brazil, Sri Lanka, South Africa, Philippines, Pakistan, Argentina, USA, Uzbekistan, Thailand, Iraq, UK, Hungary, West Africa, Chinese Taipei, Finland, Russia and The Netherlands. This article presents a brief on Question 61.

Freshwater scarcity is of global concern and is feared to be aggravated in the future due to population growth and climate change. As expected, a number of researchers have addressed this issue and stressed on efficient use of the water resources to minimize undesirable and avoidable losses of water in its storage, conveyance, application and use. Loss or wasted irrigation water manifests in the soil salinization, waterlogging, unworkable soil condition, particularly in shrinking and swelling clay soils. The water quality aspect has not lost the researcher's attention. This is an important aspect and a management issue, on the one hand, freshwater cannot be created, and poor quality water always increases in quantity and deteriorates in quality due to anthropogenic activities of the ever-growing population.

Water scarcity is also a critical issue in agriculture. In a world, where agriculture must continue, to compete for a water supply that is becoming scarcer, it is important now, more than ever, for agriculture water users to conserve water.

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Two methods for combating water scarcity in agriculture are precision irrigation and improving surface irrigation.

The Question 61 covered three sub-questions briefly discussed below:

Adopting precision irrigation and improving surface irrigation to combat water scarcity

The definition of precision agriculture evokes different understanding amongst the irrigation and drainage community covering a wide range of options and technologies for application management at the field level and also the necessary decision support in a spatial and temporal manner for directing water in a required manner.

Methods for maintaining drip emitter flow include physical filtration, pH control (e.g., adding acid), and biological control (e.g. adding chlorine). These are standard practices that have been published and available for nearly 40 years. The papers presented for this question demonstrate that providing appropriate water quality for drip irrigation in a cost-effective manner is a continuing struggle for applying drip irrigation, particularly in remote areas.

Accurate irrigation scheduling with refined estimates of ET is also considered precision irrigation. ET based irrigation scheduling has the potential to improve on-farm efficiency. Yet precision irrigation should consider both accurate irrigation scheduling to define the amount of water needed by the crop and accurate application of the required water (e.g., with both efficient and uniform application).

It is a fact that surface irrigation by gravity flow of water is the most common used method world over. Among the surface irrigation methods, there are border, furrow, basin methods of land preparation, suitable for different crops. It is, however, recognized by all concerned that all the methods of surface irrigation are wasteful in water use. Since, freshwater resources are limited and the much feared climate change may cause great aberrations in the availability and time-space distribution of rainfall, which is the primary source of all freshwater on the earth, the renewed concern on the scientific use of the available water resources and minimize its misuse is highly justified. Since, agriculture is the largest consumer of freshwater resources and agriculture must be sustained to enable feeding the ever-growing population of the world, scientific management of water in its agricultural use assumes great importance.

Using ICT, remote sensing, control systems and modelling for improved performance of irrigation systems

Efficient water management has been identified as one of the priorities to ensure food security in many areas of the world. On the other hand, smart technologies are nowadays spreading in all the sectors of human activities. Remote sensing, modeling, sensors, remote control system, application of information and communication technologies (ICTs) are potential tools to improve the efficient use of water to achieve improved performance of irrigation systems, including geospatial and drones to improve management of soil, water and crop, and to predict and mitigate the impacts of extreme weather conditions of droughts and floods. Advances in technologies like, ICT and cloud based computing models for real time decision support coupled with accurate determination of the status in the field using drones enable the application to large areas with multiple holdings as against large farms only in the past.

A number of software tools are available for simulating for irrigation system evaluation, design and operational analysis. Further progress in this area is required for using better infiltration models while maintaining computational speeds. Computer software packages can also be utilized to make recommendations to improve the performance of surface irrigation systems. A number of software programs have been developed over the last three decades. For example, SIRMOD (Utah State University) and WinSRFR (USDA, ARS) are two of the earlier versions. The WinSRFR program, developed by the United States Department of Agriculture's Agricultural Research Service, is an integrated hydraulic analysis software package for surface irrigation systems that combines a simulation engine with tools for irrigation system evaluation, design, and operational analysis. These and other programs continue to develop to provide additional tools that can be useful for improving surface irrigation performance.

Adaptability and affordability of new technologies under different socio-economic scenarios

Land tenure and size of landowners are important factors for adaptation of new irrigation technologies particularly in developing countries. However, new approaches like land pooling and cooperative farming can provide windows of opportunities to implement the techniques and thereby improve efficiencies.

The importance of organizing small farm holder community and ensuring institutional support is required for making the benefits of modernization reach them effectively. Role of operating decisions play an important part in improving irrigation efficiencies and it is required that operations may be kept simple to avoid irrigator errors.

New technologies have to be adaptable in order to reap benefits after their implementation. Scaling up effects should be properly understood before large scale implementation and adoption by the user communities. Adaptability of the technologies should be seen in various contexts of climatic conditions, environmental and socio-economic conditions and then their validity should be determined.

These are some of the outcomes derived from the papers submitted for Question 61. For more information, please download the 23rd ICID Congress Transaction < http://www.icid.org/23rdcong_absvol_2017.pdf>

Field Evaluation of Irrigation Scheduling Strategies Using A Mechanistic Crop Growth Model

Sabine J. Seidel[1], Stefan Werisch[1], Klemens Barfus[1], Michael Wagner[1], Niels Schütze[1] and Hermann Laber[2]

ICID instituted the 'Best Paper Award' to recognise the outstanding paper contributed to 'Irrigation and Drainage', the Journal of ICID. The award consists of a citation plaque and either US$ 500 cash or US$ 800 worth of Wiley books from M/s. Wiley Blackwell (UK). The Wiley-Blackwell 2017 Best Paper Award was awarded to this paper published in the ICID Journal (Volume 65, Issue 2 in 2016). The award was presented during the 68th IEC meeting on 10 October 2017, Mexico City, Mexico. Full paper can be accessed from http://onlinelibrary.wiley.com/doi/10.1002/ird.1942/full

The worldwide demand for fresh water is increasing steadily, especially in water-scarce areas, producing an unprecedented need for efficient water use in irrigated agriculture. In contrast, irrigation is often conducted as full irrigation to reach soil water content near field capacity in order to increase yields and improve fruit quality. To determine the timing and amount of applied water, different irrigation scheduling strategies can be employed, varying in their complexity, technical infrastructure and required expertise. Crop irrigation management is a complex and difficult task in which three questions need to be answered: (i) How much water should be applied? (ii) When should it be applied? (iii) How should it be applied? Irrigation scheduling is conventionally based on either experience, SWB calculations, crop growth simulation models, soil water measurements, or on sensing of the plant's response to water deficits.

In a field experiment with white cabbage (Brassica oleracea L. var. capitata (L.) alef.) between 2012 and 2014 in Germany, three irrigation scheduling approaches were tested: (i) three sprinkler irrigation schedules (SWB1-3) based on soil water balance calculations using different development-dependent crop coefficients; (ii) automatic drip irrigation based on soil water tension thresholds (T); (iii) irrigation scheduling by real-time application of a partially calibrated mechanistic crop growth model (D). Multi-objective calibration was applied to derive a fully calibrated model as a diagnostic tool to identify the water loss terms of the individual irrigation strategies.

Irrigation based on the partially calibrated mechanistic crop growth model resulted in the lowest yields (but yield did not differ significantly from treatment SWB3) due to the underestimated soil water dynamics and crop development, but still performed better than the sprinkler irrigation treatments (SWB1 and SWB2) regarding water productivity or irrigation efficiency. Performance of the model can be drastically increased if more measures (higher resolution and further plant variables) of crop growth and soil water dynamics are included in the optimization task, resulting in better prediction of the required irrigation water amounts and application timing. However, extensive data collection is required and disqualifies this approach for everyday irrigation practice in farming. Nevertheless, fully calibrated models serve as powerful tools for detailed investigation of irrigation strategies and associated potential water losses, which are becoming more and more important under the increasing demand for high-yielding water-efficient horticultural production. With these challenges ahead, common approaches should be evaluated properly and new approaches need to be tested. To improve simulation reliability and enhance model calibration and validation results, long-lasting experiments with the same variety are required.

Considering that the treatments SWB3 and D estimated realistic irrigation water demands but resulted in the lowest yields and the sprinkler treatments with higher yields required far more water, this proved the importance of correct timing, application rate and application technique to achieve highly efficient irrigation strategies. Moreover, the target wetness of the soil in the root zone in the 'Geisenheim' methodology (90% of the available water capacity) could be too high and neglects the fact that plant water uptake is mainly driven by pressure gradients between the soil and the root system. The soil water tension at a certain soil water content on the other hand depends strongly on the site-specific soil and can already be high (more sandy soils), causing reduced uptake rates, or be still very low (more clay content).

However, an extended observation strategy is required to analyse possible reasons in further detail and to make site-specific adjustments. These extended observations should include measurements of evapotranspiration using lysimeters, Bowen ratio or eddy covariance approaches to define the real transpiration rates and support model calibration. Additional soil water content measurements could also help to define the water balance, but measurements with three different capacitance probes failed in the 2013 experiments, probably due to the high background electrical conductivity in the clayey soil layers.

A fully calibrated mechanistic crop growth model was applied as a diagnostic tool

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TABLE. Average measured dry matter head yields (Yobs), simulated yields (Ysim), as well as measured (Bobs) and simulated (Bsim) biomass above ground at harvest for all treatments: RF indicates a hypothetical rain-fed baseline scenario. Furthermore, the applied irrigation water (I) is given along with the water loss terms components, namely: evaporation from canopy (Ec), soil evaporation (Es) deep percolation (DP) and their sum (∑L). The irrigation efficiency (IE) is given to express the amount of irrigation water that can effectively be used by the crop as percentage value.

	Y_{obs}	Y_{sim}	B_{obs}	B_{sim}		I	E_c	E_s	DP	∑L	IE
	[t ha^{-1}]					[mm]					%
SWB1	8.3	9.6	15.8	16.4		410	158 (+79)	92 (+9)	462 (+185)	712 (+273)	33.4
SWB2	8.3	9.6	15.3	16.4		306	147 (+68)	92 (+9)	380 (+103)	619 (+180)	41.2
SWB3	7.9	9.3	16.2	16.1		108	109 (+30)	89 (+6)	289 (+12)	487 (+48)	55.5
D	7.5	9.3	15.7	16.1		106	107 (+28)	89 (+6)	289 (+12)	485 (+46)	56.6
T	8.5	9.4	16.6	16.1		105	75 (-4)	88 (+5)	277 (-)	440 (+1)	99.0
RF	-	6.5	-			0	79	83	277	439	

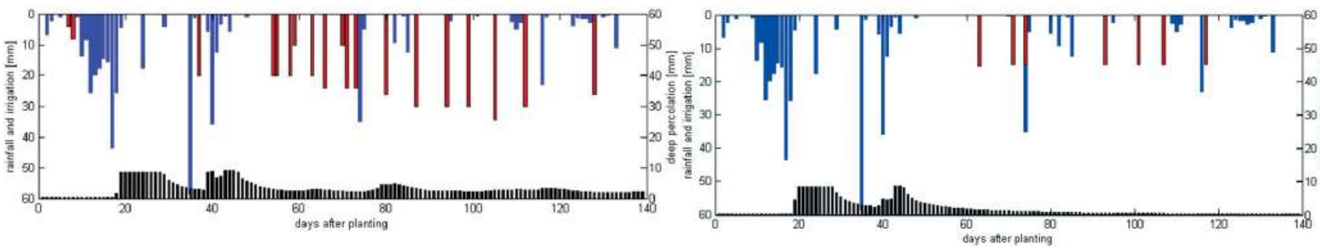

FIGURE. Simulated deep percolation (black bars on bottom) of treatment SWB1 (First Figure) and treatment T (Second Figure) in 2013. The bars on top denote rainfall (blue) and irrigation water applied (red)

to analyse the effectivity of the tested irrigation strategies and define the major sources of water losses. Most of the water is lost by percolation for the wet sprinkler treatments SBW1 and SWB2, while evaporation from the crop canopy is the main source in the treatments SBW3 and D. Percolation water losses, especially, are not only costly, but lead at the same time to negative off-site effects like fertilizer leaching or groundwater pollution which should be avoided. Water losses by canopy evaporation can only be circumvented by microirrigation strategies, such as drip irrigation, which proved to be superior in the 2013 experiments as almost no irrigation water was lost and the highest yields and above-ground biomasses were achieved.

The performance of the fully calibrated model as a predictive tool for real-time irrigation scheduling needs to be tested further in future experiments. Moreover, the shortcomings of the models need to be analysed in order to gain more knowledge about the main driving processes controlling the drought stress response of white cabbage under German growing conditions.

The authors concluded with an opinion that common irrigation scheduling approaches for vegetables such as cabbage should be evaluated properly and new approaches need to be tested. To improve the simulation reliability and enhance the model calibration and validation results, long lasting experiments with the same variety are required.

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