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IMPLICATIONS OF FOOD LOSS AND WASTE AND ITS WATER FOOTPRINT IN FOOD PRODUCTION AND WATER RESOURCES

Bashir Adelodun[1], Seul Gi Lee[1], and Kyung Sook Choi[2]

ABSTRACT

Sustainability of water resources in global food production systems is of utmost priority. The reoccurring and prolonged drought periods, in addition to the accelerated urbanization and changing lifestyle in a water-scarce country like Korea create a daunting challenge on agricultural production. However, managing the prodigious food loss and waste (FLW) could have far-reaching benefits in terms of resources conservation and food security. This study quantifies and analyses the FLW of various food groups in each stage of the food supply chain (FSC) for Korean specific food production data (2007 - 2013) using the top-down approach of global FLW mass flow model. Furthermore, the quantity of water inherent in FLW was assessed using the representative water footprint of selected food types in Korea. The results showed that 14.14 million tonnes (0.78 kg/capita/day) equivalent to 54.92% of domestic production were either lost or wasted with only consumer stage responsible for 48.79%. The fruits and vegetables had the highest percentage (44.58%) of FLW by weight compared to cereals, starchy roots, oil crops and pulses, fish and seafood, meat, milk, and egg with 32.69%, 7.01%, 0.82%, 8.17%, 4.09%, 1.94%, and 0.68%, respectively. An average of 54.49 Gm^3/year of water resources was associated with the FLW, representing a considerable 44% of country's total water resources (129.7Gm^3). The study shows that minimization or management of food wastage, especially at consumer stage, can significantly improve available freshwater for food production in the country while using the resources sustainably.

Keywords: Food loss and waste, water footprint, food production, Republic of Korea

1. INTRODUCTION

Sustainable water resources and food security are the most significant concern of humanity as the two variables are virtually the basic necessity for human survival. The reoccurring and prolonged drought periods in many parts of the world especially in Korean peninsula of East Asia are daunting challenges to agricultural productivity and stringent law governing the use of limited available water resources(Jung et al., 2011; Kwon et al., 2016). Similarly, the growing global demand for food consumption and the increasing competition for water use are expected to increase the susceptibility of food insecurity and scarcity of water resources, predominantly in Asia and Africa (FAO, 2013; Davis et al., 2016). According to the United Nations, the world population is projected to increase from the current 6 billion to about 9.7 billion by 2050 with the majority in Asia and Africa continents (United Nations, 2015). The consequences of feeding the exponential population growth would require six folds of current freshwater demands and a 70% increase in global agricultural production (Searchinger et al., 2013).

One of the sustainable ways of ensuring food security and conservation of water resources is reducing FLW across the food supply chain. The global annual estimates

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of the edible portion of FLW is approximately 1.3 billion tons which is equivalent to one-third of annual food production (Gustavsson et al., 2011). This prodigious amount of FLW varies across the regions, countries, and among the food groups. For instance, the food loss which occurs mostly at the upstream of the food supply chain (FSC) is very prominent in the developing countries due to the low technology to tackle the food loss during production and post-harvest stages of food production (Parfitt et al., 2010). However, the food wastage in the high income and industrialized countries, particularly at the consumption stage of FSC, is of great concern due to the accumulation of resources along the supply chain in the food production including water and land (Wunderlich & Martinez, 2018). Aside the social menace of FLW on food security, the loss of resources embedded in FLW is worrisome. In spite of the numerous studies on the quantifications of FLW across the regions and in many countries, and most importantly its impact on water resources (Liu et al., 2013; Sun et al., 2018; Kashyap and Agarwal, 2019), there is still a knowledge gap in many parts of Asia, specifically South Korea. The existence of ecological deficit and persistence water crisis owing to burgeoning climate change impact in this region is of great concern (Hanjra& Qureshi, 2010).This study addresses the country's specific data gap by analyzing FLW across the FSC including production, postharvest, processing, distribution and consumer in South Korea. In addition, the study evaluates the water footprint of food waste in order to access potential water savings.

2. MATERIALS AND METHOD

2.1 Definition and Scope

There are different definitions attributed to food losses in the literature depending on the scope and scale of the study. However, there is some level of agreement that food loss occurs at the upstream of the FSC such as production, post-harvest storage, processing, and distribution while the food waste refers to the portion of food that is intended for consumption but wasted or lost during retail and consumption stages (Parfitt et al., 2010; Gustavsson et al., 2011; Salihoglu et al., 2018). The definitions for food loss and food waste as defined above are adopted in this study while the term FLW or food wastage encompasses all the discarded edible portions of food commodities including fruits and vegetable peels, uneaten cooked or uncooked meat, and raw egg without shell, which sometime refer to anything that animal can eat. The six food groups including grains, tuber crops, oilseeds and pulses, fruits and vegetables, meat, fish and seafood, milk, and egg in all the five stages of FSC as described in (Gustavsson et al., 2011) are considered in this study.

2.2 Food Production Data and Quantifying FLW along FSC

The national data on production quantities for individual food commodities was obtained from FAO database (FAOSTAT, 2019). Considering the annual variations in production of food commodities, an average recent production values of seven year data (2007 – 2013) was used. The fraction of FLW across the value chain, starting from production stage, was estimated using the mass flow model following the Gustavsson et al. (2013) and Dal' Magro & Talamini (2019). The inedible food and other food products, including seed, animal feeds, and other utilities, that are not intended for human consumption were excluded from the estimates using wastage percentage and conversion factors for industrialized Asia as described in Gustavsson et al. (2011). The estimated waste percentage in each stage of the FSC for industrialized Asia as reported by Gustavsson et al. (2013) was used.The quantity of FLW of each food commodities (in aggregated form of food group) at each stage along the FSC was then calculated by multiplying the food commodity value by the wastage percentage and conversion factors in that specific stage. The population data was obtained from the United Nations (2017) to estimate the per capital FLW across supply chain. The FLW was thereafter classified into two groups; plant-based and animal-based foods. Plant-based food commodities comprise grains, starchy roots, pulses and oil crops, and fruits and vegetable while animal-based foods include meat, fish and seafood, milk, and egg.

2.3 Estimation of Water Footprint of FLW

The water footprint of FLW in this study is based on the selected representative food items for each food commodity. The selected food types are the commonly consumed food items which are based on the availability of such data. The reported values of the water footprint of food product types in Korea used in this study are presented in Table 1. The water footprints of common food items for plant-based in Korea was obtained from for plant-based food and Mekonnen and Hoekstra (2012) and Lee et al. (2015) for animal-based food as compiled by Yoo et al. (2016).

Table 1. Food commodity group and water footprints representative food items.

Food commodity group	Representative food type	Water footprint of food item (m^3/tonne)	Food commodity group	Representative food type	Water footprint of food item (m^3/tonne)
Plant-based			Animal-based		
Cereal crops	Rice	994.8	Meat	Bovine meat	14023.1
	Wheat	1060.2		Pork meat	163.9
	Barley	795.9		Poultry meat	2427.7
	Maize	1039.7		Edible viscera	9041.0
	Others	2298.1			
Starchy roots	Potato	135.8	Milk	Whole milk powder	1893.5
	Sweet potato	370.0		Skim milk powder	4721.3
				Liquid milk	1015.3
Pulses and oil crops	Soybeans	3346.7	Egg	Egg	2932.4
	Red beans	3166.9			
	Pulses, others	2644.0			
	Oil crops, others	4545.0			
Fruits	Fruits	573.1			
Vegetables	Vegetables	137.9			

Source: (Yoo et al., 2016)

The WF_{FLW}, embedded water footprint associated with the wastage of representative food commodity type, was then quantified using equation 1.

$$WF_{FLW} = \sum_{i}^{n} WF_i \times FLW_i \qquad (1)$$

where FLW_i is the total quantified food loss and waste of food commodity n, WF_i is water footprint of common food items in each food commodity n.

3. RESULTS AND DISCUSSION

3.1 FLW Across the Supply Chain

The results of national FLW for the average 7-year period under this study is estimated at 10.41 million tonnes. On the per capita basis, using the mean population data for 2007 – 2013 from the United Nations (2017), the estimated quantity of FLW was 0.78 kg/capita/day. The quantity of FLW generated amounts to 54.92% of annual domestic production (25.74 million tonnes) of the same period (Table 2).

Table 2. Annual average FLW generation in Korea (2007 – 2013) in 1000 tonnes

Food commodity group	Domestic production[a]	Food loss	Food waste	Total FLW
Cereals	4174.71	756.10	3865.41	4621.51
Tuber crops	943.43	399.70	591.95	991.66
Pulses and oil crops	194.57	25.70	90.84	116.54
Fruits and vegetables	13477.00	2699.36	3603.69	6303.05
Meat	1978.14	174.13	404.38	578.51
Fish and seafood	2244.14	564.68	590.80	1155.48
Milk	2115.00	120.74	154.82	275.56
Egg	618.86	40.23	55.99	96.22
Total	**25745.86**	**4780.65**	**9357.88**	**14138.52**

[a]Average domestic production of food commodity group in 1000 tonnes for 2007 – 2013 periods obtained from FAOSTAT dataset, 2019.

Our estimate of FLW is in contrary to the annual food waste estimate of about 6.2 million tonnes generated in Korea as quoted by Thi et al. (2015) from grey literature. In the reported study, the food waste at the consumption stage was only considered while the annual variations in the quantity of food waste generation were ignored. Compared to other national FLW studies, Liu et al. (2016) calculated 0.81 kg/capita/day (37.81 million tonnes) of food waste in Japan's FSC for the year 2011 Dal' Magro and Talamini (2019) estimated about 1.17 kg/inhabitant/ day for Brazil between the year 2007 and 2013 which are however relatively higher than our own estimate of 0.78 kg/capita/day. While in South Africa, Oelofse and Nahman (2013) estimated 0.48 kg/capita/day, and also about 0.40 kg/capita/day were reported by National Environmental agency of Singapore (National Environment Agency, 2017). The food losses at the upstream stages of the supply chain amount to 33.81% of the total FLW while the food waste during the consumption stage is 48.79%. It is however worthy of note that there could be significant variations in the current status of food wastage at the consumption stage of supply chain due to recent policy implementation on food waste. The policy requires households to pay a certain amount of money based on the quantity of food waste while disposing of it. The policy has reportedly caused drastic reduction in food waste generation (Thompson & Rothman, 2017).

The mass distributions of various food commodities in the total FLW across the FSC is shown in Figure 1 while the percentage contributions of each food commodity on the FLW is presented in Figure 2. There are significant variations in quantities of food commodity lost or wasted across the FSC with cereals, and fruits and vegetable account for the most substantial food commodities wasted in consumer stage whereas significant losses were noted for starchy roots, and fruits and vegetables at the processing stage of the supply chain. The overall breakdown showed that the fruits and vegetables had the highest percentage (44.58%) of FLW by weight compared to cereals, starchy roots, oil crops and pulses, fish and seafood, meat, milk, and egg with 32.69%, 7.01%, 0.82%, 8.17%, 4.09%, 1.94%, and 0.68%, respectively, across the FSC.

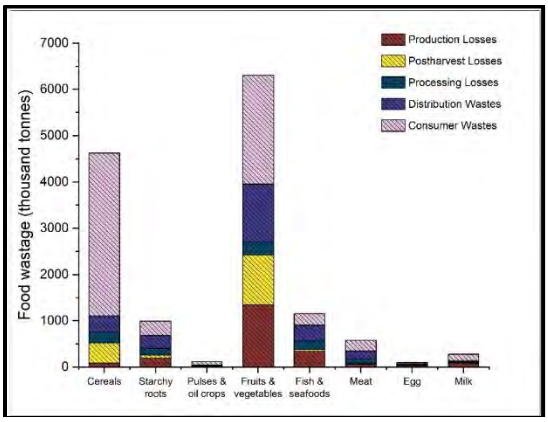

Figure 1. Mass distribution of food commodity group

Rice is the staple food in Korea; as a result the most, frequently consumed food commodities are cereal and cereal products (Park et al., 2018). Similarly, the Korean diets are very rich in vegetables with growing consumption of fruits among the adults (Choi et al., 2010).The likelihood of wasting more food from the most frequently purchased and consumed food items cannot be ruled out (Lee, 2018), and it is not surprising why cereals, fruits and vegetables are the most predominant wasted food commodities at the consumption stage. However, the high levels of total FLW in the country are alarming considering the ecological deficit, limiting resources available for food production, and continuous reliance on food importation (Gabriela 2017).

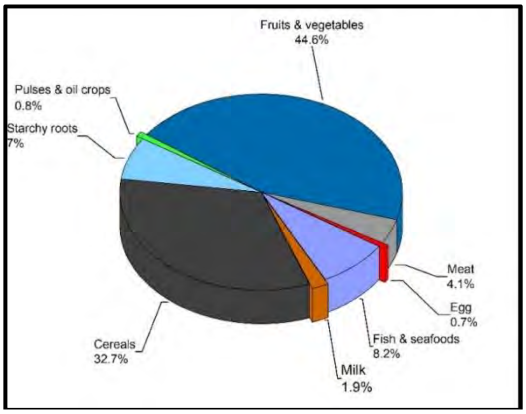

Figure 2. Food commodity group contributions to FLW

3.2 Water Footprint of FLW

The average annual water footprint of food wastage discarded across the supply chain in Korea is 56.49 Gm^3. The computational contributions of food commodity groups to the water losses due to food wastage is presented in Figure 3. The relatively high volumes of water losses due to wastage of cereals food commodity reflect the high percentage wastage of cereals food commodity (32.69%), out of which consumption stage contributed the most significant amount (Figure 1). Similarly, the high volume of water footprint requires for the production of meat and meat products such as water use for drinking, servicing, and growing feed crops during the production stage, as well as excessive water use during processing of meat in slaughter houses (Lee et al., 2015) is responsible for the relatively high volume of embedded water losses along with meat and meats products. For fruits and vegetables, despite the reported low water footprint required for their productions (Table 1), the high quantities of wastage (44.58%), especially during consumption stage (Figure 1), account for the third-ranked water losses due to wastage of fruits and vegetables among the food commodities investigated in this study.

On the contrary, high volumes of estimated water footprints of food items in oilseeds and pulses commodity group (Table 1) are primarily accountable for the water losses due to their wastage, since the percentage mass wastage across the supply is very low (1%).For tuber crops, the low water footprint of food items; potato and sweet potato (Yoo et al., 2016), countered the high wastage of the food commodity across the supply chain, which results in low volume of water losses due to food wastage (Figure 3).For milk and egg; not surprisingly, since the mass wastage of milk and egg commodity products are very low (Figure 1), the water losses embedded in these products tend to be in small quantity (Figure 3).However, the high amounts observed in water losses due to milk as compared to egg was due to the food items with high volumes of water footprint contained in the milk such as whole milk, skim milk, and liquid milk (Yoo et al., 2016).

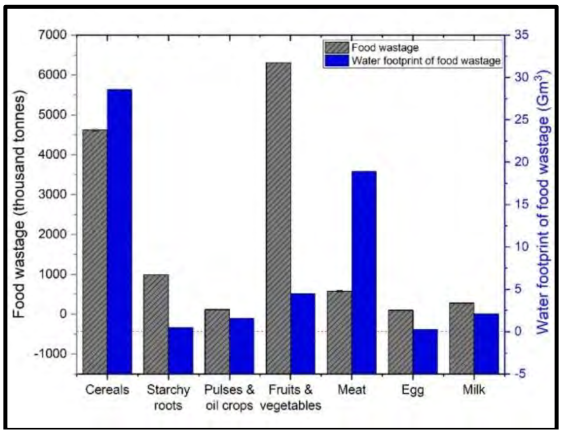

Figure 3. Water loss due to FLW

3.3 Impacts of FLW on Water Resources and Policy Implications

Food wastage is considered as social and environmental menace notwithstanding the considerable loss incur on water resources during food production. Food wastage entails the loss of water resources used in the production of such food. Our study shows the loss of a large volume of water resources due to food wastage, which significantly varies among the food commodity groups. Succinctly, an average of 56.49 Gm^3 of water resources associated with food wastage, which represents 34% higher than the nationally available freshwater for use, was lost during 2007 - 2013. Water loss due to animal-based food wastage, specifically meat and meat products, has the largest significant impacts on water resources. The meat productions are resources intensive since they require a significant additional volume of water to grow their feeds. Yet, the per capita consumption rate of meat has continued to increase recently (Kweon & Oh, 2014). Similarly, the wastage of cereals food commodity group shows large implication on the loss of water resources. Currently, the country has attained significant self-sufficiency in rice production which however come at the expense of depleted water resources.

At the same time, about 28.60 Gm^3 was lost through cereal food group wastage in which rice accounts for the largest share. Moreover, considerable sources of freshwater for food production and other uses are through surface and underground reservoirs (blue water), with combined supplying capacity of 67% of water resources(Korean Statistical Information Service, 2018). Consequently, agriculture water resources in recent time have witnessed a decline in its percentage allocation in the face of stiff competitions among the water users (Korean Statistical Information Service, 2018). Salvaging the enormous food wastage is a feasible alternative to reduce the food demand, sequentially conserve the water resources without negative effects on food security. Besides, Yoo et al. (2016) estimated potential water requirement of 1.26 Gm^3 to achieve 55% calorie-based self-sufficiency ratio by 2020. The projected volume of water resources required to self-sufficiently meet the calorie demand in the country is just 2.23% of the total freshwater resources lost through food wastage. The strategy on water resources conservation in the face of water scarcity and persistent drought periods can be actualized through discerning policy planning and implementation, most especially through food wastage reduction. The efforts should intensify more on the cereals and animal-based food commodity wastages considering their large percentage contribution on the loss of fresh water resources.

Most importantly, there is a need to recognize the fact that food wastage translates to the loss of water resources and other resources used during food production. Furthermore, efforts to achieve target self-sufficiency in food production due to the economic reality of continuous food import-dependent, and impending vulnerability of disruptions in the food supply chain as a result of exponential population growth need an appropriate policy.

4. CONCLUSIONS

The role of freshwater resources on food production is indispensable, and without which the world will cease to exist. However, the water resources are getting depleted, and at the same time, the portions of already produced food is being lost or wasted. This study evaluates the impacts of food wastage along with the embedded water loss on the water resources in Korea. The need for policy intervention on food wastage to sustain the finite water resources was also revealed. The estimate of an average 7-year period (2007-2013) food wastage generation across the supply chain was 14.14 million tonnes (0.78 kg/capita/day), of which the food loss at the upstream stage is 4.78 million tonnes, and the food waste at the downstream stage is 9.36 million tonnes. Cereals and fruits and vegetables account for the large proportion of food waste at the consumption stage while significant portions of tuber crops, fruits and vegetables, and meat are lost during the distribution stage.

Food wastage impacts significantly on water resources. The water footprint associated with food wastage was 56.49 Gm^3, representing34 per cent higher than the nationally available freshwater for use. The wastage of meat, which is animal-based food had the most substantial impact on water resources, followed by cereal, a plant-based food group. A considerable percentage of fruits and vegetables were either lost or waste; however, the relative impact on the loss of water resources is quite low.

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Although, the estimate of FLW and the loss of water resources associated with the food wastage might not reflect the current situation in the country considering the stringent implementation of “pay as you throw” policy on food waste, however this study indicates that water saving potential and the sustainability of food production are achievable by avoiding food wastage. It is imperative to conduct further studies that reflect the current situation of food waste and the associated resources lost, most especially water resources. This will adequately ensure an appropriate policy to be employed in tackling the food waste issue in addition to the existing policy, under the goal of resources sustainability.

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IMPROVING WATER PRODUCTIVITY WITHIN WATER, FOOD & ENERGY NEXUS IN, AFGHANISTAN

Najmuddin Anjum[1], Naseer Ahmad Fayez[2] and Rahmatullah Rahmani[3]

ABSTRACT

In Afghanistan, about 80% population is engaged in agriculture and is mainly dependent on irrigation because of arid to semi-arid climate of the country, Over 70 percent of its food production comes from irrigated agriculture and productivity of rainfed agriculture is quite low as compared to irrigated agriculture. Agriculture is one of the main contributor to the economy and contributes almost a third to the GDP while also provides over two thirds of employment. Irrigation has therefore been given high priority in government plans and programs. Water plays equally important role in rangeland management and in maintaining ecological bio-diversity supporting to the livestock sector, which is another important contributor to the economy. It is essentially a water dependent economy and sustainable irrigation will be central in government's development agenda for many years to come.

Decades' long war and conflict has deteriorated irrigation infrastructure of the country and eroded local social structure and creating huge irrigation water scarcity which subsequently threatens livelihood of the farming communities. To improve the existing irrigation system, the Ministry of Agriculture, Irrigation and Livestock (MAIL) has given high priority to restore and sustainably manage the physical and institutional aspects of irrigation sector in the country. It is implementing several irrigation development projects and programs with financial assistance from various donors.

The "On Farm Water Management (OFWM)" Project is one such project and is co-financed by the Afghanistan Reconstruction Trust Fund (ARTF) and managed by the World Bank (WB). It is being implemented in all of the five regions including 23 provinces, namely: Central region (Kabul, Kapisa, Parwan, Logar, Wardak, Ghazni, Paktia and Panjshir provinces), West region (Herat, and Ghor provinces), Bamyan (Bamyan, Takhar, Kundoz and Baghlan provinces), East region (Nangarhar, Laghman, Nuristan and Kunar provinces) and North region (Samangan, Balkh, Faryab, Saripul, and Jawzjan provinces).

This paper describes that on farm development works i.e. construction of diversion structures. Canal lining, Laser land levelling, improved agronomic practices has significaltly increase conveyance efficiency and water productivity (WP) in five region of country and has enormous impact on water, food & energy nexus.

On average, the water productivity for wheat crop in different Irrigation demonstration sites (IDSs) of five regions where the data was collected is, 0.94 KG/m3 while the maximum water productivity is 1.40 kg/m3 in GulBafa irrigation Demonstration Site, Herat region and the minimum water productivity is 0.63 kg/m3 in Safi &Alikhil Irrigation Demonstration Site, Balkh region. In general, the WP figures well match with international standard value of WP for wheat crop.

Conveyance efficiency has significantly improved due to water course lining, installation of field turnouts and effective operation & maintenance by communities. The study findings from lined section of irrigation canals shows the overall

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conveyance efficiency is 81% where the maximum conveyance efficiency was measured 98 & 97% in Mangalan and Qalandar irrigation Irrigation schemes of Kabul and Balkh regions while the minimum efficiency was 65% in KuzSafdari irrigation scheme of Nangarhar region. On average there is 25-30% losses control due to canal lining and effective operation & maintenance of irrigation canal.

Keywords: Conveyance efficiency, Water productivity of wheat, canal/ water course lining, On Farm Water Management Project (OFWMP).

1. INTRODUCTION

1.1. CROP WATER PRODUCTIVITY IN AFGHANISTAN

Ensuring water security remains critical in Afghanistan for future agricultural production and to satisfy other livelihood needs. Agriculture contributes roughly a third of national economy and over two third of employment, especially in rural areas. Agricultural growth remains a key component of national growth and employment, and it also provides a foundation for successful structural transformation of the national economy. Due to arid to semi-arid climate of country, agriculture is dependent to a large extent on the availability of irrigation water. Hence, Afghanistan's economy is essentially water dependent.

As competition over water increases under the combined effects of population and economic growth, improving water productivity will be increasingly essential to satisfy the multiple and conflicting demands from various sectors. Many river basins experience issues of water stress and populations live with an inadequate level of water security. Water stress affects food security, energy production and the ecological status of the basin. It also adversely affects the health and livelihoods of its populations. Afghan river systems are already the most stressed river systems in Asia (with Helmand river at top) and probably in the world. Table 01, shows the major rivers basin with percentage of coverage area and water share of country.

Table.1 River Basins of Afghanistan

Riverbasin	Area(%)	Water(%)	Rivers
Amu Darya	14	57	Amu Darya, Panj, Wakhan, Kunduz, Kokcha
Hari Rod-Murghab	12	4	Hari Rod, Murghab, Koshk
Helmand	41	11	Helmand, Arghandab, Tarnak, Ghazni, Farah, Khash
Kabul (Indus)	11	26	Kabul, Kunar, Panjshir, Ghorband, Alinigar, Logar
Northern	11	2	Balkh, Sar-i-Pul, Khulm
non-drainage area	10		

Source: Favre and Kamal, Watershed Atlas of Afghanistan (topology of Irrigation System in Afghanistan, Bob Rout 2008).

As in the rest of the world, climate change and the associated increases in climate variability, as well as other global and regional changes such as declining groundwater tables, are expected to exacerbate water issues. Afghanistan is particularly vulnerable given its mountainous environment and snow-based hydrology. (source: Irrigation modernization by enhancing water productivity through water accounting by Suman Sijapati).

Lack of available Irrigation water is an important impediment in improving the agriculture productivity in Afghanistan. The World Bank (WB) has been a long term partner of the Ministry of Agriculture, Irrigation & Livestock (MAIL) in supporting construction and rehabilitation of Irrigation Schemes to increase farmers' access to irrigation water. As part of the efforts, On Farm Water Management Project (OFWMP) has been initiated with an objective to improve the agricultural productivity in the project areas by enhancing the efficiency of water used. The Project has started its operation since March 2011 with a 41.0 million USD financial resource from the Afghanistan Reconstruction Trust Fund (ARTF) under the management of World Bank (WB). it seeks Additional Finance (AF) of 45 million USD in 2016 to support scaling up of activities and restructure the original project to match with the growing needs and demands of the communities based on the lessons learned.

Currently the project is working in five regions (Central, Bamyan/Baghlan, Herat, North, East regions) covering 23 provinces of country in service to provide effective and efficient irrigation system to improve the conveyance & application efficiency and increase water productivity. Refer to the figure 01 with rehabilitated and coverage map of of OFWMP.

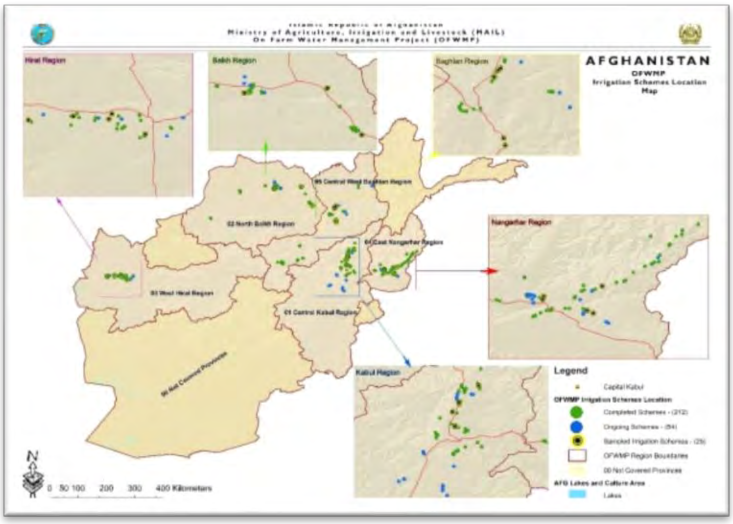

Figure.1 Rehabilitated Irrigation schemes location and coverage map of OFWMP (Source: impact evaluation report of OFWMP. 2018)

1.2. OFWM Project and Crop Water Productivity

As stipulated in the present OFWMP documents, the overall Project Development Objective (PDO) is to improve crop water productivity in project areas by enhancing efficiency of water use. The project mainly aimed at improving water use efficiency to increase agricultural production, building capacity of local staff to implement similar projects in the country and educating farmers to adopt high efficiency irrigation systems (HEIS) and other modern agricultural practices. The project comprises following components:

I. Irrigation Rehabilitation and Management.

This component would have the following two sub-components,

(a) Establishment and strengthening of irrigation associations (IAs), and
(b) Improvement of Irrigation infrastructure for the existing irrigation schemes typically less than 1,000 hectares.

II. Support for Enhancing Productivity.

Support for enhancing agriculture and water productivity through demonstration of Modern Irrigation (HEIS etc..), Agronomic practices activities and technical assistance;

III. Institutional Strengthening and Capacity Building of the MAIL.

Institutional strengthening and, technical and administrative capacity building of the MAIL including developing a legal framework for the irrigation and drainage subsector.

IV. Project Management, Coordination, Monitoring and Evaluation:

This component directly supports the incremental operating cost, project staff cost, logistics (vehicles), and critical office equipment pertaining to project implementation so as to ensure sound management of the project.

Increase in Water Productivity is one of the key indicators proposed to measure success of the Project in terms of degree of achievement of the overall PDO, and its best assessment would be of great importance for the decision-makers in the Government and other stakeholders involved in the planning and prioritizing investment in the development of Agriculture sector.

2. ASSESSMENT OF CROP WATER PRODUCTIVITY (CWP)

The concept of Crop Water Productivity (CWP), in general, is taken as a robust measure of ability of the agricultural systems to convert water into food and fiber production. While it has been used principally to evaluate the function of irrigation systems as the amount of 'crop per drop', usually expressed in terms of kg/m3 or tons/ m3, being the most meaningful indicator where water resources become increasingly scarce. The basic purpose of CWP is to enable comparisons between water use systems in space and time i.e. 'before and after' or 'without and with" project implementation of irrigation related agricultural projects.

The time period for the assessment of CWP would cover at least one complete crop cycle, extended over a complete year (winter and summer crop seasons) to account for productive and non-productive water use. However, the assessment may be extended over several years to derive estimates of average, minimum or maximum crop water productivity within each season.

2.1. Measuring Crop Water Productivity

For measuring water productivity, the amount of water directly consumed by the cropping system (evaporation and transpiration) as well as amount of water supplied from different sources. As we move upscale from field to farm to basin, we wish to know how much water has been depleted in agricultural production, which accounts for actual evapo-transpiration (Et) and water use by different crops.

At field, farm and system (command area) scale, the denominator of water use is potentially made up following dominant constituents:

Water Used = SI + GI + Rainfall (cubic meter)

Where:

SI = Surface irrigation water (canal) supply
GI = Ground water irrigation (tube-well) supply

For simplicity, the CWP would be measured / calculated, in irrigation schemes of OFWM Project, as yield per unit of water used (depleted) by the crop at a farm, i.e. average crop product per unit of water consumed as under:

Crop Water Productivity (CWP) = $\frac{\text{CropProduce (kg)}}{\text{WaterUsed (cu.m)}}$

It may be noted that problem of estimating CWP becomes more complex for large and heterogeneous areas containing complex land uses and diversified cropping patterns. Also, discrepancy of measuring CWP by different users (farmers) can obstruct comparison of different water users within a single area. To simplify this, the method of water accounting may help track different water depletion flow paths.

2.2. Approach

For assessment of CWP, a representative sample of 5 completed rehabilitated irrigation schemes, have taken within each of the five regions (Nangarhar, Kabul, Bamyan, Herat and Mazar-e-Sharif).

The selection of representative Irrigation Schemes and farms have been carried out jointly by the Irrigation Agronomist and Water Management Specialist of the respective Area teams in consultation with the Core team counter-parts.

A team of two (2) Field Assistants / Graduate Internee, from the Project or local DAIL, have assigned for collection of irrigation data during each irrigation rotation (turn) as well as crop yield data (at harvest) for major crops grown at selected farms of the Irrigation Scheme. The rainfall data have collected by installing Rain Gauge at the farm or alternatively obtained from nearby Weather Station /DAIL Observatory.All the field activities and data collection carried out under the supervision and guidance of Area Team Irrigation Agronomist and Water Management Specialist who were responsible data analysis and reporting.

2.3. Methodology

The steps involved in determination of the crop water productivity of irrigated crops have include the following steps:

(a) Preparation of Farm Map clearing showing the details, including: irrigated fields (plots), irrigation channels (watercourses or ditches), farm structures and location of tube-well, etc. and record the size of each field (dimensions), in particular.

(b) Taking soil samples from each field and get analyzed for soil type and other characteristics if possible like water holding capacity, organic matter, pH and NPK, etc.

(c) Prior to coming crop season (winter or summer), preparation of Crop Calendar or Plan clearly indicating the schedule of different activities like land preparation/tillage, sowing/planting, fertilization, irrigation, and harvesting, etc.

(d) Installation of flow measuring device (preferably a cut-throat flume) permanently at the farm gate for recording the inflow (discharge) for different crops at the farm during each irrigation rotation (turn).

(e) Installation of Rain Gauge at the farm. The concerned farmers shall be trained in recording rainfall data immediately after rain. Alternatively, it shall be obtained from nearby Weather Station /DAIL Observatory.

(f) Estimation of actual evapotranspiration (Eta) using reference potential evapotranspiration (Eto) and crop factor for the area.

(g) Recording irrigation data (time/duration of inflow and discharge) for different crop fields (plots) during each irrigation rotation (turn).

(h) Calculation of water inflow from both irrigation and rainfall during crop period in terms of cubic. meter / ha (Denominator).

(i) At the harvest of each crop, obtain crop yield data as well as data on straw and green fodder production in terms of kg/ha (Enumerator).

(j) Calculation of water productivity (CWP), with respect to both total water.

Supply (inflow) and Eta, using the formula: CWP = $\frac{Enumerator,\ Step{-}9}{Denominator,\ Step{-}8}$ kg/cubic .mtr

2.4. Result and Discussion

On an average (Table; 02) the crop water productivity for wheat crop in different IDSs of five regions where the data was collected is, 0.94 KG/m3 while the maximum water productivity was 1.40 kg/m3 in GulBafa irrigation Demonstration Site, Herat region and the minimum water productivity was 0.65 kg/m3 in Mir Roza Dar Irrigation Demonstration Site, Balkh region. In general, the CWP figures had compares with the international potential CWP values of the wheat crop and CWP values from five region lies in accepted range for wheat crop (0.60-1.7 kg/cubic meter).Table& figure 02 illustratethe crop water productivity values in different regions of project.

Table 2. Crop Water Productivity values in different regions.

Regions	Average Wheat Yield (Kg/Ha) (1000)	Average Water Applied (m^3) (1000)	Water Productivity (Kg/m^3)
Kabul	2.1	1.6	1.33
Nangarhar	4.4	6.4	0.68
Balkh	4.0	5.5	0.73
Baghlan	3.6	4.3	0.84
Herat	4.8	5.7	0.88
Overall	***3.7***	***4.4***	***0.94***

(Source: Impact evaluation report of OFWMP)

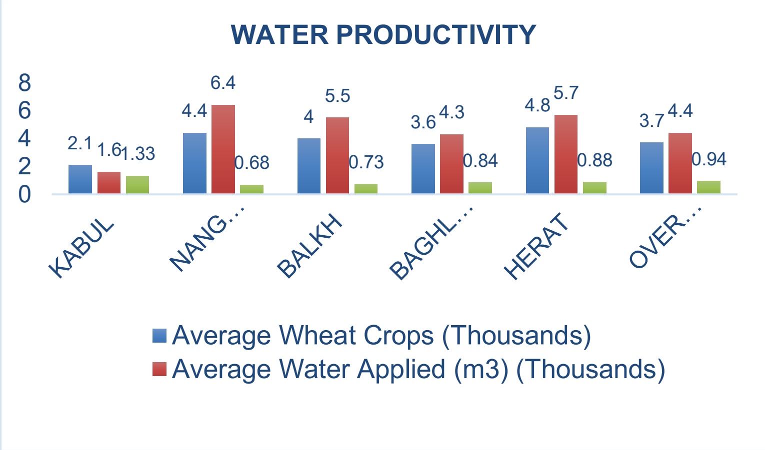

Figure.2 Graphical representation of Water Productivity data of Wheat crop from five regions (Source: impact evaluation report of OFWMP, November 2018)

3. CONVEYANCE EFFICIENCY

The conveyance losses or delivery efficiency is a measure of irrigation channels within command of irrigation schemes. A significant percentage of irrigation water losses occur from main and branch as well as field (farmer's) irrigation channels. The conveyance efficiency has significantly improved due to water course lining, installation of field turnouts and effective operation & maintenance by communities. The survey's findings from improved irrigation schemes shows the overall conveyance efficiency 81% where the maximum efficiency was measured 94% in Bahrabad and Mir Roza Dar irrigation canal of Nangarhar and Balkh regions while the minimum efficiency was 65% in Gulbafa irrigation canal of Herat region. Table 03, illustrate the conveyance efficiency in a rehabilitated irrigation canals of each region.

Table 3. Conveyance Efficiency

Regions	Conveyance Efficiency (%)
Kabul	76%
Nangarhar	93%
Balkh	94%
Baghlan	80%
Herat	73%
Overall	81%

4. CONCLUSION

The study explored that there is significant increase in crop production, water productivity, water saving with the implementation of different On-Farm Water Management inteventation and high-tech agronomic practices. As a result government should continue with such kind of irrigation projects on national level to provide efficient irrigatin system to the farmer and other agricultural incentives.

Afghanistan faces a complex array of problems in agriculture and irrigation sectors and the primary limiting factor to crop production and sustainable on-farm irrigation system is the use of already limited water resources in efficient way. Afghan farmers have a poor understanding of modern On-Farm irrigation practices to save water and to grow more crop per drop. Capacity development of the farmer community and IAs is of utmost importance towards the sustainability of on-farm irrigation systems.

Although during recent years, there is a progress seen towards the development of irrigation sector, still the government need to focus much on sustainable on-farm irrigation systems by taking solid steps to save water for tomorrow.

MAIL has to developed National Irrigation Policy and National Irrigation Program where they should take into considerations the facts on how to sustain on-farm irrigation systems to increase conveyance efficiency and Water Productivity. MAIL and other line ministries also work on new irrigation area development irrigation projects in different river basins of a country. MAIL and Donor-funded projects should continue their efforts to support the irrigation sector of Afghanistan. There is a hope that after the implementation of Irrigation Sector Reform, a strong platform will be available for the farmer community to get timely irrigation support services which will increase crop production.

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INNOVATIVE COMBINED DRAINAGE SYSTEM AND IT'S TECHNICAL-ECONOMICAL APPROVAL

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ABSTRACT

Considering the climate change, in order to use the arable agricultural lands in efficient way on the high-humidity soils of Georgia, particularly on the lowland of Kolkheti Black Sea Aquatoria, an innovative combined three tier drainage structure has been presented, the scientific-technical priority of which was approved by the Georgian Patent Certificate. For improvement of the efficiency of three tier innovation structure, the methodology of hydraulic computation of the drainage system and maximum discharge water flow rate have been developed taking into consideration hydrological, climatic and geological factors. For the purpose to apply and use the theoretical results in practice, the field research of the innovative structure, which was installed in the West Georgia, on the lowland Kolkheti, vil. Jikhaishi, were carried out, which became as a basis for the approval of the technical and economical priority of the functioning innovative technology. Aiming at increasing the drying capacity of wetlands on Kolkheti Valley, a field stand of a Combine Three Tier Drainage was installed in village Didi Jikhaishi, Samtredia Region, west Georgia. By considering the mechanical-physical properties of the soil, and groundwater level and climatic factors, the water conductivity effect of the Combine Three Tier Drainage was identified.

Keywords: Combined Three Tier Drainage, innovative structure, wetlands, Georgia.

1. INTRODUCTION

According to Georgian legislation, drainage systems including hydraulic engineering structures are state property. However, it is unclear whether the issue of ownership of river banks control dykes (embankments) is unclear.

During the 90sof the last century these structures were handed over to local self-government bodies, but they do not have proper funds and in fact the constructions (dykes) remain in bad condition. At present, dykes (embankments) are damaged and washed out at many places.

After the collapse of the Soviet Union, financing of the amelioration sector has declined sharply. There were years when it was not financed and the operation of the damaged systems infrastructure was stopped in many places. As a result, most drainage and drainage systems, hydraulic structures and pumping stations have failed. This led to a secondary bogging of land.

Since 2012, within the framework of targeted funding allocated from the state budget for reorganization (revitalization) of the amelioration sector, restoration of reclamation systems, including drainage systems, was successfully carried out. As a result of the rehabilitation works, during this period, 37,900 hectares of land were drained.

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Drainage systems including hydraulic engineering structures in Georgia are financed from the state budget. Donor organizations also play an important role, namely: World Bank (WB), International Fund for Agricultural Development (IFAD), etc.

The main elements of drainage systems recently operating on the territory of Georgia are: the total length of the main and marshy canals is 592 km, collectors - 760 km and water collecting canals - 1581 km. Drainage systems include 1944 different types of hydraulic engineering structures (regulating junctions, bridges, pipe-bridges, etc.) and six pumping stations. Over 1500 km of operating routes (roads) are arranged along the canals for maintenance and operation of amelioration infrastructure. On the banks of the rivers 236 km of the total long-standing riverbanks (embankments) are arranged.

Based on the above mentioned, and according to the drainage systems operating in different regions of Georgia, the total number of drained and exploited land is 115,682 ha. Removal of excess water from 27,168 hectares of land is carried out mechanically using pumping stations. Figures 1 & 2 illustrate Irrigation and Drainage systems' actual utilization in each municipality of Georgia.

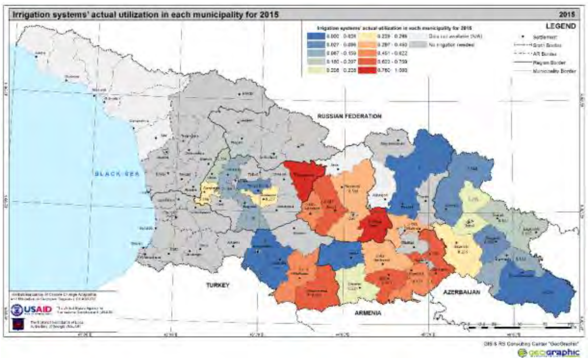


Figure 1. Irrigation systems' actual utilization in each municipality for 2015.

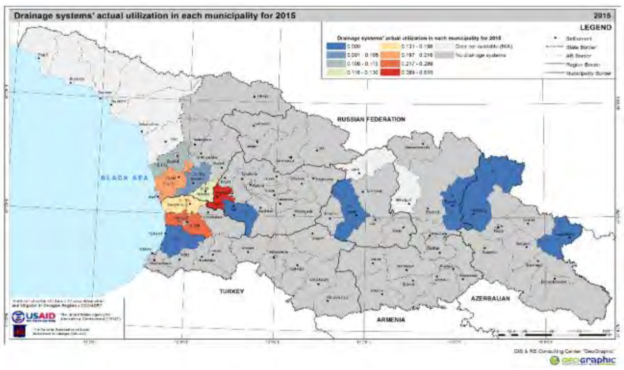


Figure 2. Drainage systems' actual utilization in each municipality for 2015.

On the background on the climate change, aiming at efficiently cultivating the wet agricultural plots of field (with the area of 225.000 ha) on Kolkheti Valley, Georgia (the maximum average annual amount of precipitations varies between 2100 and 2300 mm), an option of installing a field stand to study a Combine Three Tier Drainage (Georgian Patent Certificate No. GE P 2005, 3573 B) is considered.

2. METHODS

2.1 Identifying the Distance between the Drains

A design model given in Figure 3 was used for hydraulic calculations of the Combine Three Tier Drainage.

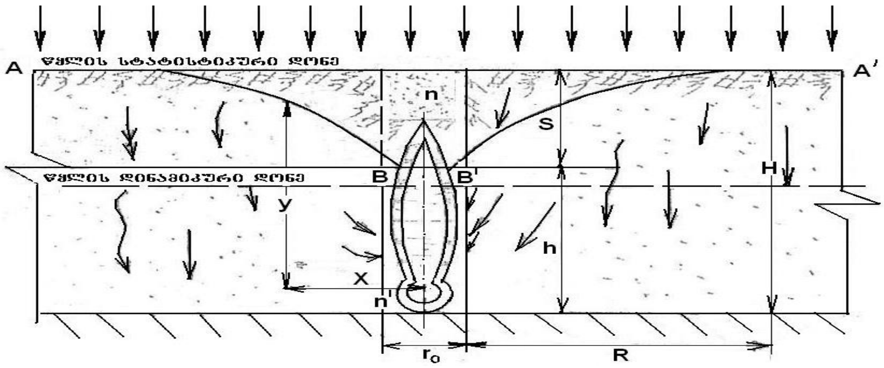


Figure 3. Design model of a Combine Three Tier Drainage.

The mathematical calculations made it clear that the water conductivity of the Combine Three Tier Drainage (Q) is calculated with the following expression:

$$Q = \frac{Lk\left(H^2 - h^2\right)}{\ln \frac{R}{\eta r_0}} \quad \text{(l/sec)} \qquad (1)$$

Where L is the drainage length, k is the proportionality factor, the same as the filtration coefficient (cm/sec); H - is the depth of drainage installation (m) and η is the form coefficient of the elliptic nod of the Combine Three Tier Drainage, which depends on the radius of curvature of the elliptic nod of the three tier perforated drainage (m).

Identifying the distance between the drains is of a great practical value. In addition, it depends on many complex factors, such as the intensity of fallen precipitations, height of ground water, soil and other principal factors.

The distance between the drains (b) must be selected in the manner as to ensure efficient ground level reduction at the given time, which must be in compliance with the optimal requirements of air and water regime of agricultural crops.

By knowing the ground water depth, as well as soil, hydro-geological and climatic conditions, the air and water mode of the agricultural crops can be regulated by using the Combine Three Tier Drainage.

Figure 4 illustrates the design model to identify the distance between the drains.

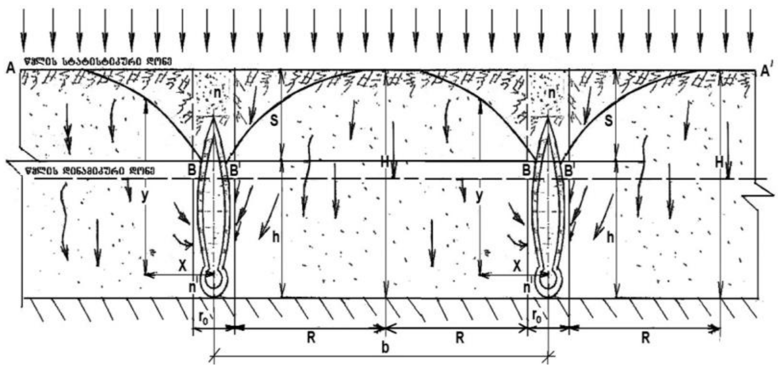


Figure 4. Design model to identify the distance between the drains

Let us simplify expression (1):

$$Q(\ln b - \ln 2\eta r_0) = 2KHS \qquad (2)$$

Let us identify the distance between the drains (b) from expression (2). We will gain:

$$b = \exp\left(\frac{2KHS}{Q} + \ln 2\eta r_0 \right) \text{ (m)} \qquad (3)$$

We identify the distance between the drains (b) as follows: if the agricultural plots of field are cultivated by installing the Combine Three Tier Drainage system, then the distance between the drains is calculated with formula (3), but when it is necessary to install a combined drainage in the areas occupied by perennial plantations, the drainage system is installed in the middle of inter-row, between the rows of perennial plantations. By means of calculations, it is also possible to install the drainage system with more than one drainage line in the inter-row of the rows of perennial plants.

2.2 Field Study of the Combine three Tier Drainage

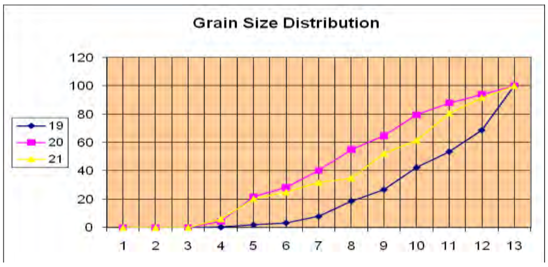
Aiming at conducting the field experiments of the Combine Three Tier Drainage, a study polygon was organized on the experimental base of the Agrarian College of Georgian Technical University in village Didi Jikhaishi, Samtredia Region (See Figure 5).

Figure 5. Field experimental plot in village Didi Jikhaishi.

Two trenches sized 18 m (length), 1,2 m (depth) and 0,6 m (width) were laid in two rows. The model of the combined field three tier drainage is as follows: the first stage – split drain (with the depth of 0,30 m) to regulate the surface flow; the second stage, which is the vertical circular polyethylene perforated structure (with the diameter of 0,10 m) to discharge ground waters (length of 0,40 m) and the third stage is the water intake pipe/main collector to discharge the surface and ground waters (with the diameter of 0,50 m).

During the trench excavation, different layers of ground were identified which were sampled and studied at the laboratory. The relevant graphs are given in Figure 6, and the average diameters are calculated with the following expression:

D_0 (mm)



P_i (%)

Figure 6. Grain-size curve – (21) soil depth – 0,30 m. (20) – soil depth – 0,50 m. (19) – soil depth – 1,0 m.

Climatic data series were divided in four time periods: P_0, P_1, P_2, and P_3. The first, P_0, is related to the recent past and corresponds to the average of climate variables for the 1961 to 1990 base period. The P_1, P_2, and P_3 scenarios define the average of monthly values for periods between 2014 and 2040, 2041 and 2070, and 2071 and 2098, respectively. Average monthly values were generated for the climate variables of temperature and precipitation for each time period for A1B scenario. The climate data for the 1961 to 1990 period were obtained from “Los Mochis” meteorological station (25.82° N, 109.0° W, and 14 m altitude), which is considered representative of the study area as reported by Ojeda-Bustamante et al. (2011).

Let us calculate the mean diameter (D_0) for each sample with the following formula:

$$D_0 = \frac{\sum_{i=1}^{n} P_i \cdot d_i}{100}, \tag{4}$$

Where P_i is the weight indicator of each fraction in the ground mass, and d_i is the diameter of the sieves (mm).

Soil depth - 0,30 m:

$$D_0 = \frac{\sum_{i=1}^{n} P_i \cdot d_i}{100} = \frac{5 \cdot 8{,}4 + 8{,}5 \cdot 11{,}0 + 6{,}0 \cdot 19{,}2 + 4{,}0 \cdot 9{,}2 + 2{,}5 \cdot 17{,}2 + 1{,}5 \cdot 3{,}2}{100} +$$
$$+ \frac{0{,}75 \cdot 6{,}8 + 0{,}375 \cdot 4{,}6 + 0{,}175 \cdot 14{,}2 + 0{,}08 \cdot 6{,}2}{100} = 3{,}07 \quad (mm)$$

Soil depth – 0,50 m:

$$D_0 = \frac{\sum_{i=1}^{n} P_i \cdot d_i}{100} = \frac{5 \cdot 5{,}9 + 8{,}5 \cdot 6{,}1 + 6{,}0 \cdot 8{,}4 + 4{,}0 \cdot 14{,}9 + 2{,}5 \cdot 9{,}7 + 1{,}5 \cdot 14{,}7}{100} + \\ + \frac{0{,}75 \cdot 11{,}9 + 0{,}375 \cdot 6{,}7 + 0{,}175 \cdot 17{,}3 + 0{,}08 \cdot 4{,}4}{100} = 2{,}52 \quad (mm)$$

Soil depth – 1,0 m:

$$D_0 = \frac{\sum_{i=1}^{n} P_i \cdot d_i}{100} = \frac{5 \cdot 31{,}2 + 8{,}5 \cdot 15{,}2 + 6{,}0 \cdot 11{,}2 + 4{,}0 \cdot 15{,}6 + 2{,}5 \cdot 8{,}0 + 1{,}5 \cdot 10{,}8}{100} + \\ + \frac{0{,}75 \cdot 4{,}6 + 0{,}375 \cdot 1{,}4 + 0{,}175 \cdot 1{,}6 + 0{,}08 \cdot 0{,}4}{100} = 4{,}55 \quad (mm)$$

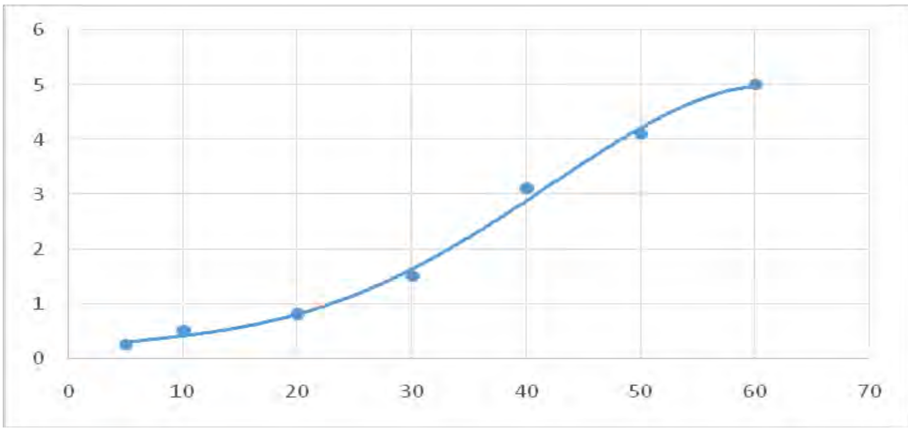
Figure 7 illustrates the full technological cycle to design the model of the Combine Three Tier Drainage.

Figure 7. Full cycle of the installation of the three-tier drainage.

Based on the field studies, the water intake capacity of the Combine Three Tier Drainage from the agricultural plots was calculated.

Figures 8 and 9 illustrate the graphs of the water discharge transported from the first and second drainage pipelines.

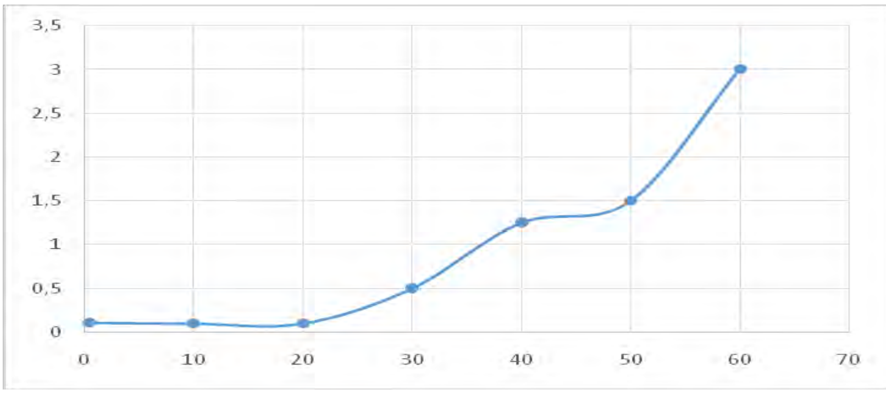
Q_1 (l /sec)



t_1 (sec)

Figure 8. Graph of dependence $Q_1 = f(t_1)$ for the first drainage pipe.

Q_2 (l /sec)



t_2 (sec)

Figure 9. Graph of dependence $Q_2 = f(t_2)$ for the first drainage pipe.

3. CONCLUSIONS

(a) Aiming at reaching an efficient drying of wetlands on Kolkheti Valley, a new structure of the Combine Three Tier Drainage was developed.
(b) The theoretical studies were used to fix the proper distance between the drains of the Combined Three Tier Drainage system.
(c) Based in the theoretical values, a field stand of a Combine Three Tier Drainage was installed in village Didi Jikhaishi, Samtredia Region, west Georgia.
(d) An integral curve of the grain size of the soil and ground fractions sampled from the field polygon was developed in the laboratory, and consequently, the mean diameter of the soil and ground was calculated.

(e) The water conductivity effect of two drains of the Combine Three Tier Drainage system was identified through the field studies.

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A CASE STUDY OF ACHIEVING WFE- NEXUS: DRIP IRRIGATION WITH BRACKISH WATER FOR RECLAMATION OF COASTAL SALINE SOIL OF CHINA

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ABSTRACT

Saline land is an important resource in coastal areas, and with the development of urbanization process, there is an urgent need to meet such demand. Reclaiming this saline land might be possible by replacing saline soil with non-saline soil for depths of 0-100 cm (which is expensive and unsustainable due to existing of shallow and saline groundwater), or by leaching of salt using large quantities of fresh water (which is very limited in coastal regions), therefore a technology of low cost, rapid and sustainable re-vegetation of coastal saline land is needed. A field experiment was conducted on sandy saline soil formed by sea reclamation at Caofeidian District near the Bohai Gulf in 2012-2014. Five treatments of salinity levels of 0.8, 3.1, 4.7, 6.3 and 7.8dS/m of drip irrigation water were applied and Chinese rose (Rosa chinensis) was chosen as the representative plant. A gravel-sand layer was created at 100 cm depth. Tensiometers were inserted at a depth of 20 cm to control the soil matric potential (SMP), keeping the SMP over –5 kPa at first year, over –10 kPa at second year, and over –15 kPa at third year. Salt leaching characters and root growth and distribution were determined. The results showed that soil salinity decreased significantly in 0-100 cm soil profile under drip irrigation with water salinity < 7.8 dS/m, especially in 0-40 cm soil layer. Applied irrigation water salinity were 160-220 mm, and 7-11 mm of water depth is needed for decreasing soil salinity of 1 dS/m. The soil leaching process could be described by the logistic equation, and it was divided into three stages including rapid, slow and stable leaching. More than 94% of the roots are mainly distributed in the topsoil of 0-20cm. The root biomass decreased significantly with increasing irrigation water salinity, and the root development in the deep soil was affected by increasing irrigation water salinity. More winter irrigation was needed when there was less rainfall after October to prevent salt accumulation in topsoil in the spring of the following year. The results showed that the approach of using drip irrigation with saline/brackish water combined with SMP control could be used for reclaiming salt-affected soils, but the appropriate irrigation water salinity threshold should be determined according to salt tolerance of plant. This paper highlights this approach as a good model for W-F-E Nexus with the consideration of fresh water and energy amounts which were saved, in addition to the added values from cultivating high cash crops.

Keywords: Coastal saline soil; drip irrigation with brackish water; salt leaching; soil matric potential; root, Chinese rose, landscape, water saving, energy saving, high cash crop

1. INTRODUCTION

Coastal saline soil accounts for about 7% of the saline soil area in China, which is considered an important resource for expanding cultivated land area in coastal

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regions. While most of the coastal saline lands are usually quite saline and the soil sodium adsorption ratio (SAR) is high and when the soil water content reaches saturation, soil porosity is filled and the permeability of soil is reduced. In addition, the groundwater table is high and most of them are saline water (Wang et al., 1993; Chu et al., 2013; Li et al., 2015). Thus it has been a difficult problem for agricultural development and vegetation estabulishment in these regions due to above conditions and in addition to the shortage of the freshwater resources. With the further development of coastal areas in China, the planning and construction of Binhai New area has entered the stage of rapid development. Most of these newly developed land has been dominated by saline lands which have not been exploited, meanwhile with increasing of urbanization and population, there is an urgent demand for vegetation landscape construction in coastal saline lands (Li et al., 2017; Li et al., 2016). Presently the main method of vegetation rehabilitation is to replace saline soil with non-saline soil for depths of 0–100 cm. However, this method is expensive and unsustainable due to the shallow and saline groundwater.

In recent years, a regulatory method forscheduled drip-irrigation of fresh water comnined with soil matric potential (SMP) control under a gravel-sand layer for vegetation in saline soils was applied successful in coastal saline lands of Tianjin and Tangshan cities which near Bohai gulf, respectively (Sun et al., 2012; Chen et al., 2015). Results showed that maintaining an SMP of -5~-10 kPa at 20 cm depth under the emitter could result in a downward gradient of soil water potential which promote salt leaching and compensate for the reduction of soil permeability due to the salinity,and maintaining a high total soil water potential in the root layer. The severely saline soils changed to mild saline soils in 0-90 cm layer and the survival rate of plants could reach more than 85% after one year. However it is also a problem to apply in large area of coastal regions due to the shortage of freshwater. Brackish water, which is an alternative resource and has been successfully used for irrigating crops. But there is less information on using saline water for vegetation in coastal saline lands by drip irrigation, which needs a careful management to safeguard the environment.

The United Nations is encouraging a new set of goals and targets which aims to achieve the long-term sustainable development through achieving sustainable water use, energy use and agricultural practices, as well as promoting more inclusive economic development (United Nations, 2014).It is likely that the concept of nexus could vary around the world depending on the short, middle and long term goals of the region and sector (Ringler et al., 2013). FAO (United Nations Food and Agriculture Organization) (2014) defined that “water–energy–food nexus has emerged as a useful concept to describe and address the complex and interrelated nature of our global resource systems, on which we depend to achieve different social, economic and environmental goals. Ringler et al. (2013) highlight that the concept of nexus is linked with the concept of integrated water resource management (IWRM). However, while IWRM is water sector oriented and narrows the contact with other sectors, nexus is opened to more sectors that could facilitate collaboration with other sectors by encouraging resource use efficiency. Activities of the water–energy–food nexus were promoted through integrated water resource management (IWRM) (Bogardi et al., 2012).The objectives of this study were : (1) evaluate the approach of using saline drip irrigation combined with soil matric potential control for urbanization and reclamation of coastal saline soil of china and the establishement of Chinese rose as a conventional landscape flower plant ; and (2) highlight the evaluated approach as a model for water, food, energy Nexus.

2. METHODOLOGY

2.1 Experimental Site

The research area is located in Caofeidian District, in the south of Tangshan city, east China, and north of Bohai Gulf.The station has a typical semi-humid monsoon climate with annual precipitation of approximately 554.9 mm, mostly during June-September which accounts for about 74% of the total annual precipitation.The soil of the experiment station is formed by sea-filling and soil physical and chemical properties are shown in table 1. The soil was sandy loam soil, and the initial soil bulk density was in the range of 1.7-1.85 g/cm^3. Soil was removed to a depth of 100 cm, a 15-cm thick gravel layer was laid in the bottom and then covered with a 5-cm thick layer of sandwith native soil placed back above the sand, and a rotary tiller was used to break clay blocks. The soil bulk density decreased to about 1.3-1.7 g/cm^3 after tillage, and the average ECe, SAR and pH of the soil are 27.47 dS/m, 52.66 (mmol/L)$^{0.5}$ and 7.94 in the 0-100 cm soil profile.

Table 1. Soil properties in experimental research area

Soil profile /cm	Soil mechanical composition/%			Soil texture	Bulk density	Ece	pH	SAR
	＜0.002 mm	0.002~0.05 mm	0.05~2 mm		/(g·cm^{-3})	/(dS·m^{-1})		/(mmol/L)$^{0.5}$
0~10	0.25	40.90	58.85	Sandy loam	1.30	28.85	7.83	54.28
10~20	0.51	42.67	56.82	Sandy loam	1.43	28.73	7.83	55.53
20~30	0.42	44.70	54.89	Sandy loam	1.55	28.11	7.86	55.14
30~40	0.45	47.44	52.11	Sandy loam	1.69	27.62	7.97	53.53
40~60	0.36	42.46	57.18	Sandy loam	1.65	25.41	8.09	52.43
60~80	0.49	41.39	58.12	Sandy loam	1.70	26.75	7.99	47.89
80~100	0.60	45.10	54.31	Sandy loam	1.66	26.84	7.98	49.85
Average	0.44	43.52	56.04	Sandy loam	1.57	27.47	7.94	52.66

2.2 Experimental Design

Five treatments with EC of irrigation water (ECiw) of 0.8(K1), 3.1(K2), 4.7(K3), 6.3(K4) and 7.8(K5) dS/m were designed, with saline water composed by mixing fresh well-water (EC=0.4-1.2 dS/m) and highly saline shallow-groundwater (13.8-22.4 dS/m) in different proportions. Ionic composition of irrigation water is shown in Table 2, the concentration of Na ions and SAR showed an increasing trend, and the pH decreased from 8.92 to 8.50 with irrigation water salinity increasing. Each treatment had three replications and the 15 plots were laid out permanently following a completely randomized block design. There were 56 roses planted at a spacing of 0.5 m × 0.6 m in each 4.0 m × 4.0 m experimental plot (Figure. 1).

Table 2. Ionic composition of irrigation

Treatments	ECiw（dS/m）	Ionic concentration（mmol）					pH	SAR
		Na^+	K^+	Ca^{2+}	Mg^+	SO_4^{2-}		/(mmol/L)$^{0.5}$
K1	0.8	11.88	0.35	1.35	0.41	0.17	8.92	8.95
K2	3.1	25.07	0.52	2.50	2.10	2.51	8.67	11.69
K3	4.7	35.72	0.74	3.72	3.39	4.22	8.66	13.39
K4	6.3	48.61	1.04	3.89	5.39	6.21	8.59	15.96
K5	7.8	59.79	1.25	5.46	6.68	8.13	8.50	17.16

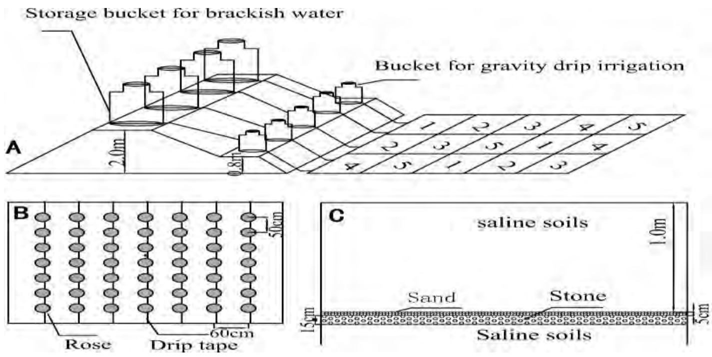

Figure 1. The layout of experiment plot

2.3 Irrigation and Field Management

Each treatment had a separate gravity drip-irrigation system consisting of a 200-L tank and 21 drip tubes (seven tubes per plot). The tank was installed 0.8 m above the ground to contain irrigation water, and drip tubes with 0.2m emitter intervals and 2.7 L/h flow (0.1 MPa) were placed in position at 0.05 m from roses.

After rose transplanting, freshwater was applied for all treatments,the irrigation was stopped if there waswater ponding and appearance of runoff on the soil surface during irrigation, and only irrigation started again when the water on the soil surface disappeared. during rainfall, the irrigation time was increased in order to prevent the salt at the perimeter of the surface wetted soil moving back toward the plant in any water flow from the perimeter to the emitter or the rose root-zone. When soil salinity of 0-10 cm layer decreased to < 4 dS/m, irrigation started based on SMP, one vacuum gauge tensiometer (WST-1, China) was installed 0.2 m directly underneath the emitter located in the center of the plot for each treatment. The tensiometer was observed twice daily (at 8:00 and 18:00 h) and when SMP fell below –5 kPa, all treatments were uniformly irrigated to maintain SMP at –5 kPa, until all rose plants had successfully established in the experimental soil.

After about 25 d to provide favorable soil moisture for roses survival, water treatments based on different ECiw were initiated. The optimal SMP threshold was –5, -10 and -15 kPa for the three years. The amount of water for each irrigation event of all treatments was 6 mm when SMP reached the threshold value, which considered the maximum daily evapotranspiration of plants in the local area.During November 2012 and November 2013, 24 and 18 mm of freshwater irrigation was applied to each treatment and then irrigation was terminated until April due to the onset of winter. During April 2013 and April 2014, 24 and 18 mm of freshwater irrigation was applied to each treatment to provide a suitable soil moisture environment for plant sprouting in spring.

2.4 Observation and Measurements

(1) Rainfall: A standard rain cylinder was installed to determine rainfall in May 2012.

(2) Soil matric potential: One vacuum gauge tensiometer (WST-1, China) was installed 0.2 m directly underneath the emitter located in the center of the plot for each treatment. The tensiometer was observed twice daily (at 8:00 and 18:00 h).

(3) Soil chemical index: Soil cores were obtained from each plot using an auger (2.0 cm diameter, 15 cm high; China) on 5 June, 4 July and 28 October 2012; on 12 March and 12 November 2013; and on 24 March 2014. The samples were obtained at 0, 10, 20 and 30 cm from the emitters, respectively, and all sample depths were the same: 0–10, 10–20, 20–30, 30–40, 40–60, 60–80 and 80–100 cm. The three replicatesoil samples were mixed into one sample per treatment. All soil samples were air-dried and passed through a 1-mm sieve. Soluble salt estimates, soluble cations and soil pH were based on extracts of saturated soil. The EC and pH were determined using a conductivity meter (DDS-11A, REX, Shanghai) and a pH meter (PHS-3C, REX), respectively. Soluble cations including Ca2+, Mg2+, Na+, K+ and SO42– were measured with ICP-OES (Optima 5300DV, USA).

(4) Plant indicators: At the end of 2013, a standard plant was chosen in each replicate, and root distributionwas observed by taking soil samples to a depth of 50 cm in 10-cmincrements in a square of 30 cm × 30 cm using the plant as center and roots dry weight was determined.

2.5 Statistical Analyses

(1) Description equation of soil desalination process:

$$F(x) = a/(1+exp(-k(x-xc))) \quad (1)$$

Where xc is the vertex of the equation curve, a is the maximum Y value of the equation curve, and K is the steepness of the equation curve.

(2) Root distribution coefficient (β), which present the the growth characteristics of plant root system. The calculation formula is as follows:

$$Y=1-\beta^{d} \quad (2)$$

Where Y is the cumulative percentage of the root system down from the soil surface (%) and d is the soil depth (cm).

All data gathered in the study were recorded and classified usingMicrosoft Office Excel 2010, and figureswere created using Origin 8.0 (Origin Lab Inc., MA, USA).The soil salinity is analyzed by using the horizontal weighted average method, and the weighted average value =Σ (sample content x horizontal distance/entire horizontal range).

The average value in this paper refers to the weighted average.

3. RESULTS

3.1 Rainfall and Irrigation

The total rainfall was 895.2, 514.9 and 415.6 mm in 2012-2014 during the experiment period (Table 3 and Fig. 2), respectively. It showed rainfall decreased with time. The precipitation in the same period(5/29-11/30)was 895.2, 458.9 and 371.5 mm, and the rainfall frequency was 4.43, 5.64 and 8.07 d in 2012-2014, respectively. The rainfall from July to September was 530.0, 384.9 and 275.2 mm, respectively, which accounting for 69.9, 81.2 and 61.2 of the total rainfall, respectively.

Table 3. The rainfall during the experimental period

Year	Month									Rainfall during 5/29-11/30 mm	Rainfall during 7/1-9/30 mm	Rainfall percentage ratio during 7/1-9/30 %
	3	4	5	6	7	8	9	10	11			
2012	-	-	12.0	187.0	188.0	262.0	80.0	68.4	97.8	895.2	530.0	69.9
2013	18.0	8.0	30.0	49.0	69.2	240.9	74.8	20.0	5.0	458.9	384.9	81.2
2014	0	3.3	40.8	42.8	38.6	112.6	124.0	27.5	26.0	371.5	275.2	61.2

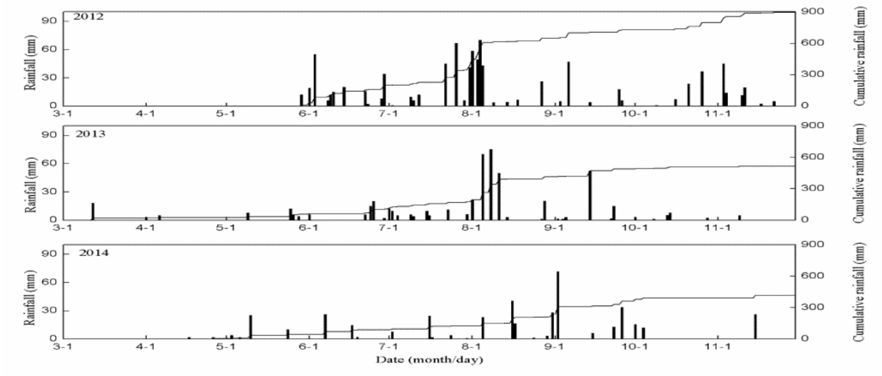

Figure 2. Rainfall characteristics during the experimental period

As shown in Table 4, 138 mm of freshwater was applied for salt leaching in 0-10 cm soil layer with ECe < 4 dS/m and 25 d for roses established. After treatments, the roses growth periods were 133, 217 and 218 d in 2012-2014, respectively. 198-228, 222-288 and 180-264 mm were applied for five treatments in 2012-2014 and corresponding irrigation frequency was 3.5-4.0, 4.5-5.9 and 5.0-7.3 d, respectively.

Table 4. Irrigation during the experimental period in 2012~2014

Year	Treatment	Seasonal water depth/ mm	Water depth for intensive salt leaching /spring irrigation/ mm	Water for winter irrigation/ mm	During treatment		Water depth from June to November /mm	Irrigation time /day	Irrigation frequency /day/one time
					Irrigation times	Water depth /mm			
2012	0.8 dS/m	390	138	24	38	228	228	133	3.5
	3.1 dS/m	378	138	24	36	216	216		3.7
	4.7 dS/m	384	138	24	37	222	222		3.6
	6.3 dS/m	372	138	24	35	210	210		3.8
	7.8 dS/m	360	138	24	33	198	198		4.0
2013	0.8 dS/m	336	24	24	48	288	168	217	4.5
	3.1 dS/m	306	24	24	43	258	150		5.0
	4.7 dS/m	288	24	24	40	240	138		5.4

Year	Treatment	Seasonal water	Water depth for	Water for	During treatment		Water depth	Irrigation time	Irrigation frequency
	6.3 dS/m	270	24	24	37	222	132		5.9
	7.8 dS/m	276	24	24	38	228	138		5.7
2014	0.8 dS/m	300	18	18	44	264	138	218	5.0
	3.1 dS/m	270	18	18	39	234	108		5.6
	4.7 dS/m	300	18	18	44	264	126		5.0
	6.3 dS/m	276	18	18	40	240	132		5.5
	7.8 dS/m	216	18	18	30	180	102		7.3

It showed that irrigation amount decreased and irrigation frequency increased with year, which mainly due to the decreased threshold of SMP. In the present study, irrigation amount decreased with ECiw increasing, it can be attributed to two reasons. Firstly, roses growth decreased significantly resulting in reduction of water consumption. Secondly, the soil osmotic potential decreased with ECiw increasing which lead to reduction of total soil water potential, thus it is limited for root water absorption, which resulted in weaken of SMP change.

3.2 Soil Salinity Changes

Before roses planting, the initial soil average ECe values in 0-40 and 0-100 cm soil profile were 28.33 and 27.13 dS/m (tables 1 and Figures3 and 4), respectively, and soil salinity distributed more uniform in all layers. Soil salinity decreased significantly for all treatments after salt leaching using drip irrigation. At the end of 2014, soil ECe values was less than 8 dS/m in 0-100 cm soil layer for all treatments (Fig. 3).

As shown in Figure 4, after nearly one months of salt leaching and roses established, the average soil ECe for five treatments were 8.67 and 14.69 dS/m in 0-40 and 0-100 cm soil profile, respectively, which decreased by 69.41% and 46.69% compared with the initial values. In October 2012,the average soil ECe for five treatments were 3.17 and 7.25 dS/m in 0-40 and 0-100 cm soil profile, respectively, which decreased by88.81% and 73.27% compared with the initial values. In the next two years, soil salinity of 0-40 cm soil profile changes to stabilized and that of 0-100 cm soil layer decreasing and then changed to stabilized after November 2013.

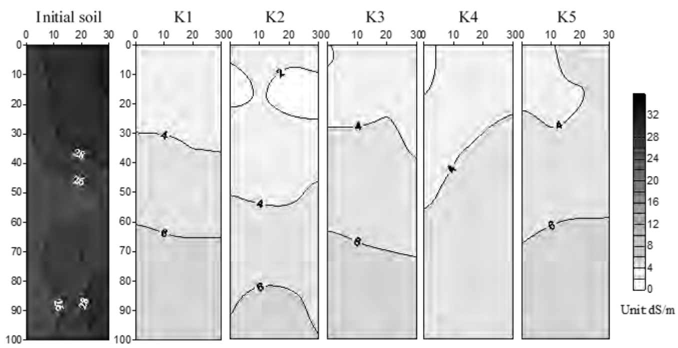

Figure 3. The spatial distribution of ECe in the vertical transects perpendicular to the drip lines before transplanting rose and in November 2014

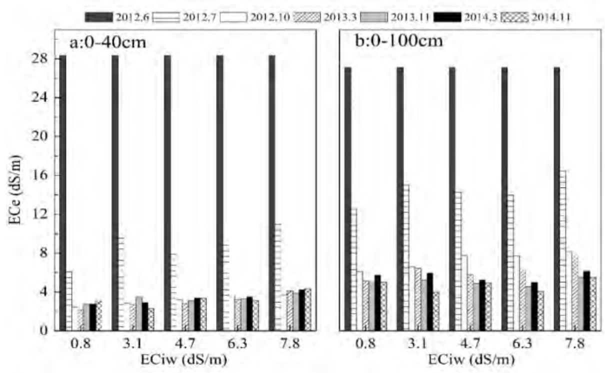

Figure 4. The average ECe values of 0-40 cm (a) and 0-100 cm (b) soil profile during the experimental period

As shown in Figure 4, soil average ECe values in 0-40 cm soil profile was all < 4 dS/m for K1-K4 and was < 5 dS/m for K5 after October 2012. Corresponding values in 0-100 cm soil profile was all < 6 dS/m for K1-K4 and was < 7 dS/m for K5. At the end of 2014, the average soil ECe values in 0-40 cm soil profile were 3.14, 2.30, 3.37, 3.12 and 4.32 ds/m for K1-K5 treatments, respectively. Corresponding values in 0-100 cm soil layer were 5.05, 3.97, 4.93, 4.09 and 5.49 dS/m, respectively. It was interesting that soil salinity increasing with the increasing in irrigation water salinity in 0-40 cm soil profile while no obvious trends obtained in 0-100 cm soil layer.

3.3 Soil Desalination Process

As shown in Figure 5a, the soil desalination process with time could be described by logistic function equation, and it can be divided into three stages including rapid, slow and stabilization soil desalination stages. As shown in table 5, the stable ECe values were all < 4 dS/m for K1-K4 treatments in 0-40 cm soil profile and showed an increased trend with ECiw increasing. Times needed for stable ECe and ECe < 4 dS/m in 0-40 cm soil profile were nearly same about one month.

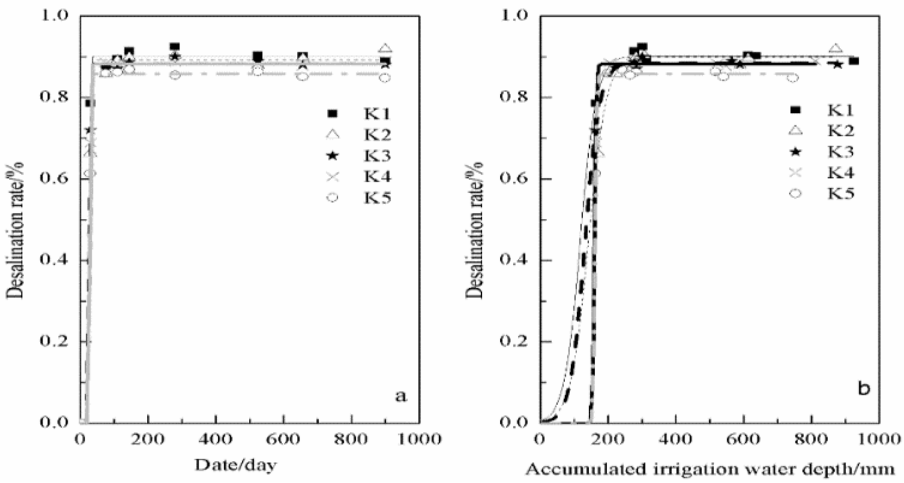

Figure 5. The response of ECe in 0-40 cm soil profile for all treatments to time (a) and accumulated irrigation water depth (b)

As shown in Figure 5b,the soil desalination process with irrigation amount could also be described by logistic function equation. As shown in table 5, the stable ECe values were nearly same as calculated using cumulative irrigation amount and time. Water depth needed for stable ECe and for reduction of 1 dS/m were all increased and then decreased with ECiw increasing. In the present study, 160-220 mm of water was needed for soil salinity decreased from 28.33 dS/m to < 4 dS/m in 0-40 cm soil profile when using drip irrigation with ECiw < 7.8 dS/m, and it was 8-20 mm for reduction of 1 dS/m.

3.4 Plant Root

As shown in Figure 6a, root dry weight decreased in the whole 0-50 cm soil profile and also in each 10 cm interval layer with ECiw increasing. It was reduced from 39.12 g at ECiw of 0.8 dS/m to 12.11 g at ECiw of 7.8 dS/m in the 0-50 cm soil profile. Root dry weight decreased with depth for all treatments. In the present study, rose root was mainly distributed in the 0-20 cm soil layer, and which account 94.65%, 94.69%, 94.07%, 95.49% and 97.81% of total root for K1-K5, respectively. βvalues increased and then decreased at ECiw of 7.8 dS/m with ECiw increasing (Fig. 6b). Which indicated that rose root grow was deep under higher salinity condition but this trends weakened as suffered severely salinity stress for example irrigated with 7.8 dS/m of water.

Table 5. the fitting characteristics for desalination ratio in 0-40 cm soil profile with time and accumulated irrigation water depth

Parameters	Treatments	ECiw (dS/m)	Y=a/(1+exp(-k(X-Xc)))					Stable ECe/dS/m	Time/irrigation water depth needed for stable ECe	Time/irrigation water depth needed for ECe < 4dS/m	Irrigation water depth needed for decreasing 1dS/m
			a	Xc	k	r^2	Sig				
Time	K1	0.8	0.90	26	0.7439	0.9972	***	2.82	48d	30d	-
	K2	3.1	0.89	27	0.4979	0.9958	***	3.05	37d	33d	-
	K3	4.7	0.88	27	0.7019	0.9988	***	3.31	34d	32d	-
	K4	6.3	0.88	27	0.7742	0.9995	***	3.33	34d	32d	-
	K5	7.8	0.86	28	0.7232	0.9993	***	4.01	34d	39d(<4.02)	-
Accumulation irrigation amount	K1	0.8	0.90	118	0.0423	0.9976	***	2.78	443mm	189 mm	17 mm
	K2	3.1	0.90	142	0.0383	0.9983	***	2.85	500 mm	222 mm	20 mm
	K3	4.7	0.89	131	0.0467	0.9991	***	3.26	422 mm	206 mm	17 mm
	K4	6.3	0.88	160	0.4085	0.9995	***	3.33	193mm	169 mm	8 mm
	K5	7.8	0.86	161	0.4125	0.9993	***	4.01	193 mm	168 mm	8 mm

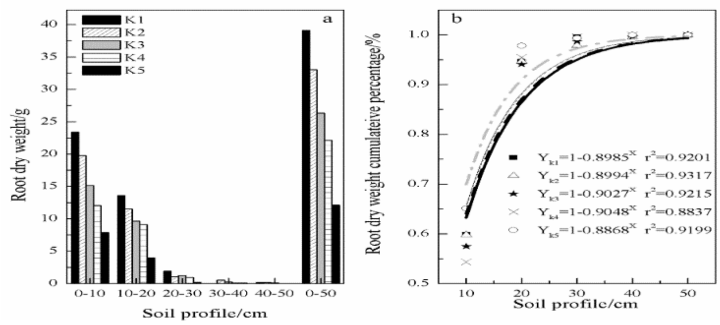

Figure. 6 The distribution of root dry weight (a) and the response of root dry weight cumulative percentage to soil depth (b) in 0-50 cm soil profile

4. DISCUSSION

As shown in Figure 4, decreasing soil salinity obtained during the winter in 2012 to spring in 2013, while salt accumulation obtained in the spring of 2014. Which could be attributed to less rainfall occurred after October 2013 than that of 2012, and reduction of winter irrigation in 2013 maybe another reason. Thus it is recommended that more winter irrigation amount should be applied for a year with less rainfall. The lack of winter protection in 2013 may be another reason for the salt accumulation. Winter protection not only helps the plants to resist cold, but also reduces soil surface evaporation, which may have an important role in reducing the buildup of salinity in soil layers (Li et al., 2015).

At the end of experiment, soil ECe reduced by 88.93, 91.90, 88.11, 88.98 and 84.74% in 0-40 cm with values < 5 dS/m and by 81.39, 85.36, 81.82, 84.94 and 79.78% in 0-100cm with values < 7 dS/m for K1-K5, respectively. The soil desalination process could be divided into three stages including rapid, slow and stable desalination stages. Soil salinity decreased from 28.33 to < 4 dS/m in 0-40 cm soil layer within one month and then changed to stabilized. It was showed that soil salinity increasing with ECiw increasing especially in the surface layer as much salt was brought into soil with higher level salinity of water. While well salt leaching obtained in all depth and treatments when using drip irrigation with water EC < 7.8 dS/m, which further indicated effectiveness of drip irrigation in reclamation saline lands and using brackish water (Jiao et al., 2007; Wang et al., 2011; Zhang et al., 2013; Malash et al., 2008; Meiri et al., 1992).

In the present study, the stable ECe in 0-40 cm soil profile and soil ECe values in each end of 2013-2014 were all < 4.5 dS/m, while 4.7-7.8 dS/m of irrigation water was applied, thus it indicated that rainfall played an important role in leaching of salt through irrigation water. 160-220 mm of water depth was needed for reduction of soil salinity from 28.33 dS/m to < 4 dS/m in 0-40 cm soil layer under drip irrigation with water salinity < 7.8 dS/m, which indicated that drip irrigation saved much water compared with overflow irrigation in reclamation of saline lands as 400 mm of water depth needed for reduction of 70% soil salinity (Prichard et al., 1985).

The root system is an important organ for plants to absorb water and nutrients, and the growth and distribution of root system have an important influence on the growth of the plant stem, leaf and fruit.More than 94% of rose root accumulated in the 0-20 cm soil layer after 17 months under drip irrigation conditions and root dry weight decreased with ECiw increasing. A response mechanism to salinity stress for rose is that root grow deep to enlargewater absorption space when suffered drought stress cased by salinity, which obtained in the present study.

China is one of the most dynamic regions of the world in terms of population growth, economic progress, urbanization, and industrialization. The demographic, economic, and environmental changes in China have increased the demand for natural resources and intensified their uses, which has serious implications for food, water, and energy security in the country. Food and water are essential for human existence, energy is the key to human development and access to these resources and their sustainable management is the basis for sustainable development. The global community has turned its attention to the concept of the food, water, and energy nexus after recognizing the important of efficient use of these limited resources for sustainability (Golam Rasul, 2014). Living with very limited Water resources in addition to the existing of saline soil are great challenges facing coastal areas of north china, which eliminate the sustainable development in these important areas. In the other side, as in many parts of the world the competition is high for using fresh water for food, or for energy for industries or for domestic or for others.In North

China, the first priority is given for fresh water for domestic use and others resources such as desalinization water, treated waste water and saline water are the alternatives for other users. The water efficiency of irrigation for agricultural purposes depends substantially on the type of irrigation. Pressurized water application methods, such as drip irrigation are considered to be the leading water saving irrigation technologies. Adjusting the irrigation process in response to variations in soil moisture content and local weather data further improves water efficiencies (ESCWA, 2017).

Ways to connect local Water, Food and Energy (WFE) Nexus activities within a community to broader national and global nexus issues and themes were often missing from site-specific case studies. This paper was trying to high light the current local approaches for achieving sustainable development to the global level and for more understanding the philosophy of Nexus as an integrated and collaborative tools among different users for better utilization of all available resources.In this case study, saline water was used for the reclamation of saline soil and soil matric potential control was applied combined with drip irrigation system to cultivate high cash crop (Chinese rose), which could be considered an integrated approach for water saving, increasing the water use efficiency, indirect energy saving and improving crop yield (by cultivation high cash crop). With the consideration of how much energy and costs needed for desalinization of seawater to be used in such reclamation and urbanization project and comparing it with the applied approachin this study, it could be concluded that this study provides a good model for achieving the sustainable development goals and water, food, energy Nexus.

5. CONCLUSIONS

Drip-irrigation with brackish water was used for reclamation of very severely coastal saline sandy loam soil and its effect on Chinese rose was evaluated. Regardless of salinity level of irrigation water, soil salinity decreased significantly with time and the severely coastal saline soils changed to mild even non-saline soils. The soil desalination process could be divided into three stages including rapid, slow and stable desalination stages. Rose root accumulated in 0-20 cm soil layer and root dry weight decreased significantly with irrigation water salinity increasing. Rose root grown deeper when suffered salinity stress was considered as a response mechanism to enlarge water absorption space.

Overall, SMP above −5 kPa at 20 cm depth under the emitter in the first year and −10 and -15 kPa in the second and third year, and 6 mm of irrigation water, cold be used as indicators for rose drip-irrigation scheduling using brackish water at <7.8 dS/m in initially saline sandy loam soils with a gravel–sand layer after tillage.

The water, food energy nexus approach was promoted through an integrated approach for using saline water through drip irrigation combined with soil matric potential control for cultivation of high cash crop and reclamation of saline soil in north china.

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MANAGING WATER CONSUMPTION FOR TOMATO PRODUCTION UNDER DRIP IRRIGATION IN GREENHOUSE

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ABSTRACT

In order to improve the yield and quality of tomatoes, water production efficiency, save water and increase output of greenhouse in North China, a field experiment involving seven soil matric potential (SMP) thresholds to trigger irrigation were tested. The SMP values at 20 cm depth immediately under the emitters in the flowering and fruit setting period, and in the fruiting period, were respectively regulated at -15 kPa and -15 kPa (S1), -15 kPa and -30 kPa (S2), -15 kPa and -45 kPa (S3), -25 kPa and -25 kPa (S4), -30 kPa and -15 kPa (S5), -30 kPa and -30 kPa (S6), and at -30 kPa and -45 kPa (S7). The temporal changes of the soil moisture, the yield, fruit quality, water consumption and water use efficiency were studied. The results showed that the soil moisture at the depth of 0-100 cm was significantly affected when irrigation was applied by the SMP thresholds at 20 cm depth. During the flowering and fruit setting period, when the SMP was controlled at -30 kPa or higher, the soil moisture in the depth of 0-60 cm was mainly consumed; the soil moisture to a depth of 80-100 cm could be utilized when the SMP threshold was reduced to -45 kPa or lower during the fruiting period. For the treatments with low SMP thresholds in the flowering and fruit setting period, the abnormal fruit rate was low and the soluble solids content of fruit was high, and there was a trend for the abnormal fruit rate to decrease, and the soluble solids content of fruit to increase with the decrease of SMP in the fruiting period. The tomato yield was the highest when the SMP threshold was -45 kPa in the fruiting stage. With the increase of SMP, the irrigation amount and water consumption increased obviously, while the irrigation water use efficiency and water use efficiency decreased significantly. Considering tomato yield, fruit quality, and water consumption, the SMP threshold at -30 kPa in the flowering and fruit setting period, and at -45 kPa in the fruiting period was recommended to trigger drip irrigation for tomato production in greenhouse in North China. Compared with the drip irrigation management according to the manager's experience, after adopting the above irrigation regime of SMP regulation, tomato yield increased by 72.7%, water saved by 68.8%, irrigation water efficiency increased by 5.5 times, and energy saved at least 60%. The results indicate that managing drip irrigation by SMP regulation for tomato production proved to be an excellent tool for achieving the water, food, energy nexus approach.

Keywords: Solar greenhouse; Soil matric potential threshold; Drip irrigation regime, Water and energy saving, W-F-E Nexus.

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1. INTRODUCTION

According to statistics, the area of protected vegetable cultivation in China was 3.9 million hm^2 in 2017, ranking first in the world. The production of protected vegetables has played a great role in the supply of vegetables in China, especially in northern China. Because under the protection of covering, the vegetables are basically impossible to make use of rainfall, and the production in greenhouses almost completely depend on irrigation. So, the irrigation methods, irrigation amount, irrigation frequency and so on are very important to the yield and quality of vegetables.

At present, most of the greenhouse vegetable production in China is still dominated by traditional flood and furrow irrigation. The irrigation amount is based on experience, and excessive irrigation is very common. According to the investigation, the irrigation amount for protected vegetables in China is generally 825-900 mm, and some even as high as 1200 mm. The waste of water resource is very serious; at the same time, many fertilizers leached with the deep leakage, resulting in the loss of nutrients and the pollution of groundwater. Besides, the air humidity in the greenhouse increases, which is easy to cause the occurrence and spread of diseases.

Drip irrigation, as a modern irrigation technology, can directly apply water and soluble fertilizer to vegetable roots according to the requirement of vegetables, which can obviously reduce the humidity in greenhouse, save water, fertilizer, labour and improve the yield and quality of vegetables. In recent years, drip irrigation has been applied in protected vegetable cultivation in China. However, due to the lack of drip irrigation management techniques which are suitable for the characteristics of greenhouses and users' education level, the economic benefit of drip irrigation is not obvious, which affects the enthusiasm of users to adopt drip irrigation technology in greenhouse.

Controlling the soil water potential (SWP) (or soil matric potential, SMP) threshold in the root zone of crops is one of the commonly used methods in drip irrigation management. Kang et al. found that under the condition of non-saline sodic land and non-saline water irrigation, controlling the soil matric potential (SMP) at 20 cm depth directly below the drippers can well control the water status in the root zone, and most crops can achieve high yield and high water use efficiency when the thresholds were in the range of -35 to -25 kPa (Kang et al. 2004; Kang & Wan 2005; Wang D. et al. 2007; Wang F. et al. 2007). Marouelli & Silva (2007) found that in the dry and cool seasons from May to September in central Brazil, maximum tomato fruit yield was reached when irrigations were performed at SMP thresholds of -35, -12, and -15 kPa in the effective root system depth, that is, at 10 cm during the vegetative growth stage, at 15 cm in the fruit development stage, and at 20 cm in maturation growth stage. Hartz & Hanson (2009) recommended the drip irrigation schedule for high yield and good quality tomato in California, USA, with the SMP threshold at 30 cm depth of -35 kPa to -20 kPa before tomato fruit begin to ripen, and SMP threshold of -50 kPa to -40 kPa from thereon until the irrigations were ceased.

Different from the field experiment, irrigation in greenhouse production is basically the only source of soil moisture. Studies on the spatial and temporal distribution of soil moisture, and the responses of tomato yield, fruit quality, water consumption, and water use efficiency under drip irrigation with SMP controlled, are of great significance to the scientific and rational use of drip irrigation in facility vegetable production.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was carried out in greenhouse in Haizetian Agricultural Demonstration Park, Yongqing County, Langfang City, Hebei Province from 2015 to 2016. The test soil was sandy loam soil, the soil bulk density was 1.29 g/cm^3 at 0-20 cm depth, was 1.42 g/cm^3 at 20-50 cm depth, and increased to 1.52 g/cm^3 at 50-100 cm depth. The soil available phosphorus and available potassium in 0-30 cm soil layer was abundant, with an average of 46.2 mg/kg and 280.0 mg/kg, respectively, and decreased rapidly to deficient levels in 40-100 cm soil layer, with an average of 4.5 mg/kg and 56.1 mg/kg, respectively. The irrigation water came from local groundwater with total dissolved solid of 0.5 g/L. The groundwater was greater than 5 m.

2.2 Materials and Agronomy Management

Tomato was taken as the research object and the variety was Kate No. 1. Tomato seedlings were transplanted on September 9, 2015, and harvested on May 11, 2016. According to the local tomato agronomy management, 5 layers of spikes were kept.

Tomatoes were cultivated in ridge with plastic film mulching. The height of the ridge was 15 cm, the surface width was 80 cm, and the center distance between ridges was 120 cm. Two rows of tomato with two drip tapes were arranged, and the row spacing was 40 cm and the plant spacing was 33 cm on the ridge.

2.3 Experimental Design

Table 1. The SMP thresholds for each treatment

Stages	Date	SMP thresholds /kPa						
		S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
The seedling stage	9 September-25 September 2015	-15	-15	-15	-15	-15	-15	-15
The flowering and fruit setting period	26 September 2015-26 January 2016	-15	-15	-15	-25	-30	-30	-30
The fruiting period	27 January-11 May 2016	-15	-30	-45	-25	-15	-30	-45

The experiment consisted of seven irrigation management treatments (Table 1) resulting from the combination of four levels during two timings: (1) SMP irrigation thresholds (-15, -25, and -30 kPa) applied during the flowering and fruit setting period, and (2) SMP irrigation thresholds (-15, -25, -30 and -45 kPa) applied during the fruiting period. During seedling stage, no treatments were applied and irrigations were scheduled uniformly at SMP threshold values of -15 kPa. The area of each treatment plot was 7.2 m × 8 m, including 12 drip tapes and 12 rows of tomatoes.

The first irrigation was applied immediately after tomato seedlings were transplanted, and the irrigation amount was about 45 mm, so as to make the soil reservoir within the planned root range could reach or approach the maximum storage capacity. And then, about 6 mm water was applied per irrigation event, one or two additional irrigation events would be applied if the SMP value was still below the set threshold.

Organic fertilizer 2680 kg/hm^2, urea (46.4% N) 1430 kg/hm^2 was applied as base fertilizer before planting, and soluble fertilizer was added into fertilizer tanks and applied with fertigation as topdressing fertilizer after seedling stage. In the flowering and fruit setting period, compound fertilizer (N-P-K:18-18-18) was applied, and the total topdressing was 300 kg/hm^2; in the fruiting period, compound fertilizer (N-P-K:12-8-40) was applied, and the total topdressing was 415 kg/hm^2.

2.4 Observation and Equipment

Soil matric potential (SMP): for each treatment, one tensiometer was installed at 20 cm depth directly under the emitter in the center of the plot. The tensiometers were observed twice daily at 8:00 and 14:00 to schedule irrigation. In order to study the depth affected by controlling the SMP at a depth of 20 cm, tensiometers were embedded at the depth of 70 cm and 90 cm soil layer at three places, that is, under the drippers, 20 cm away (horizontal distance) from the drippers, and directly below the furrow. The tensiometers were observed at 8:00 every day.

Tomato yield and fruit quality: fruits were harvested manually once or twice a week when the proportion of red fruit reached about 95%. Tomato number and weight, and the abnormal fruit number and weight were measured for each plot at each harvest. In the fruiting period, 25 fruits were randomly selected from each plot, and the soluble solids content was measured by the Abbe refractometer method.

Water consumption (ET): the total ET for each treatment was estimated using the water balance method as follows:

$$ET=I+P+\Delta S-D-R \quad (1)$$

where I is irrigation amount (mm); P is precipitation (mm), there is no rainfall in greenhouse, so P=0; R is surface runoff (mm), there is no runoff in greenhouse, so R=0; D is water flux below the 80 cm soil profile, and were calculated by positioning flux method; ΔS is the change of soil water storage in the 0-100 cm soil profile (mm); soil water contents in the soil profile were determined by gravimetric method, and was converted to volumetric soil moisture content multiplying by soil bulk density.

Water use efficiency (WUE): was calculated as tomato fruit yield per unit land area (t/hm^2) divided by water consumed by tomato per unit land area (mm) to produce that yield.

Irrigation water use efficiency (IWUE): was calculated as tomato fruit yield per unit land area (t/hm^2) divided by irrigation amount per unit land area (mm) to produce that yield.

3. RESULTS AND DISCUSSION

3.1 The Temporal Variation of SMP at 20 Cm Depth

The range over where SMP fluctuated increased with the decrease in SMP threshold. Generally, the SMP value for each treatment was basically kept within the threshold during the irrigation period. In the flowering and fruit setting period, the average SMP value was -12.6, -14.6, -12.6, -21.2, -23.5, -22.9 and -24.7 kPa for S1-S7 treatments, respectively. In the fruiting period, the average SMP value was-17.3, -21.8, -34.4, -23.1, -15.2, -25.4 and -33.2 kPa for S1-S7 treatments, respectively (Figure 1).

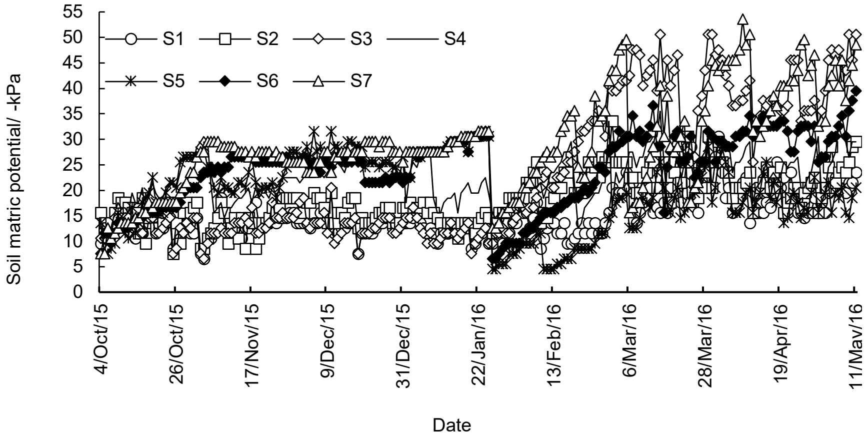


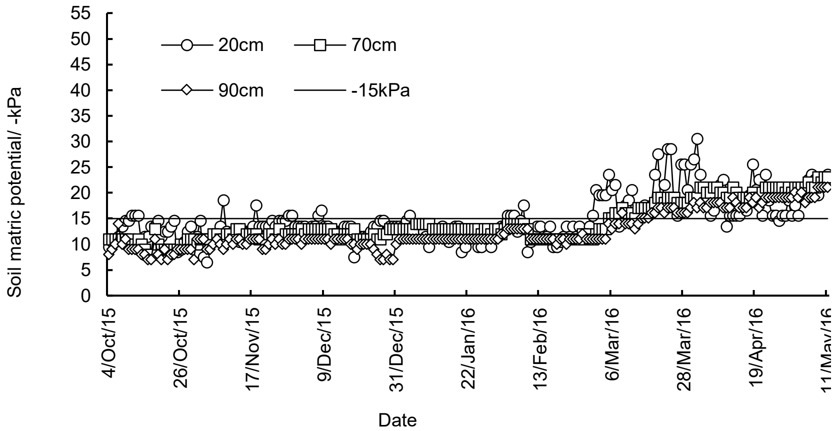
Figure 1. The temporal variation of the SMP at 20 cm depth for each treatment.

3.2 The Temporal Variation of SMP at 70 Cm and 90 cm Depth

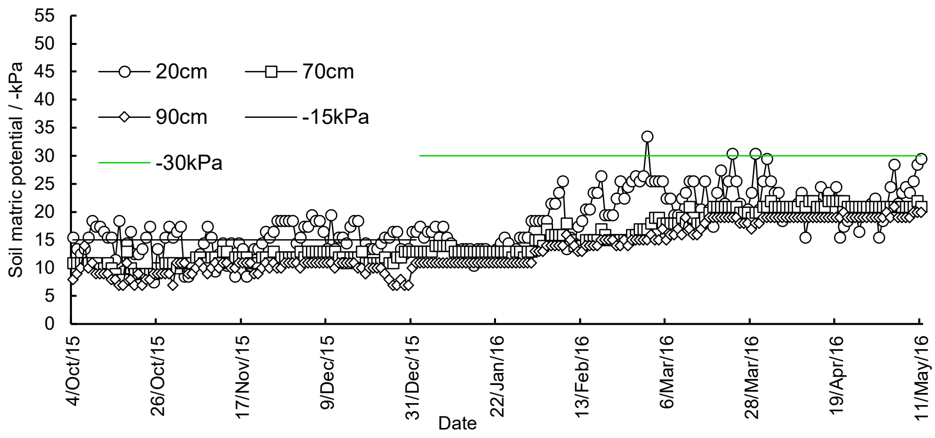
At the beginning of tomato flowering and fruit setting period, the SMP at 70 cm and 90 cm depth were high, ranging from -13.0 to -7.0 kPa (Figure 2). As tomato entered the growth peak period, the SMP of 70 cm and 90 cm depth decreased gradually, and its decrease was obviously affected by the SMP threshold at 20 cm depth.

For treatments with high SMP threshold during the whole growth period, such as S1, S2, S4 and S5 treatment (Figure 2(a), Figure 2(b), Figure 2(d) and Figure 2(e)), the SMP at 70 cm and 90 cm depth decreased slowly, and the range of decrease was basically the same, with the SMP values gradually decreasing from -10.0- -7.0 kPa to -23.0- -20.0 kPa. This means that the soil moisture above 70 cm was mainly consumed.

For treatments with low SMP threshold in the fruiting period, such as S3, S6 and S7 treatment (Figure 2(c), Figure 2(f) and Figure 2(g)), the SMP at 70 cm and 90 cm depth reduced significantly, and particularly the SMP at 70 cm depth. For example, the S3 and S7 treatment, the SMP of 70 cm depth gradually reduced from -10.0 - -8.0 kPa to -41.0 - -36.0 kPa, and the SMP of 90 cm depth was reduced from -10.0 - -7.0 kPa to -29.0 - -22.0 kPa. This means that the soil moisture above 90 cm was mainly consumed.

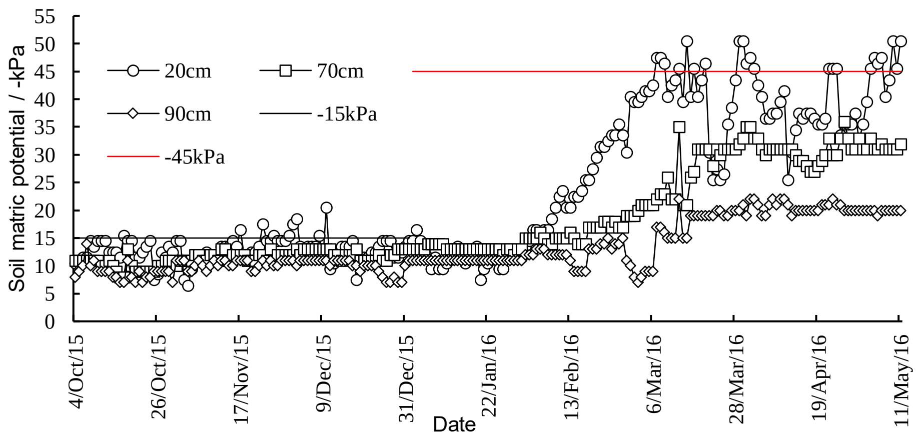


（a）S1 Treatment

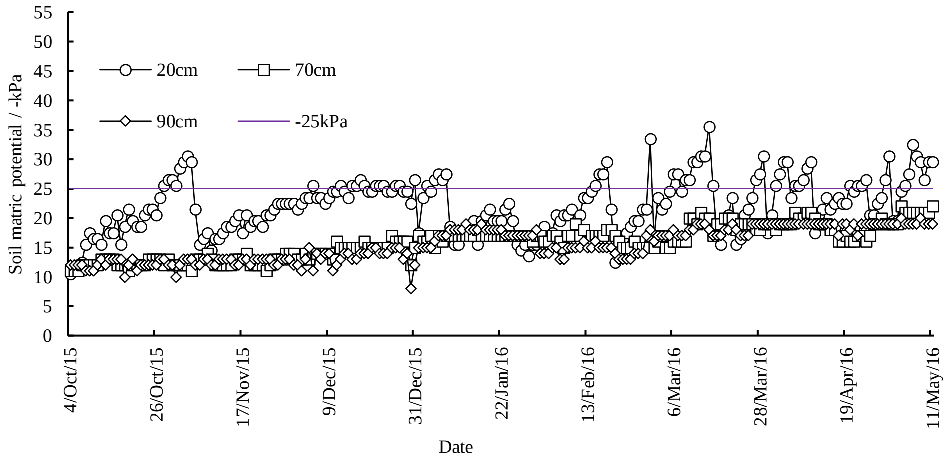


（b）

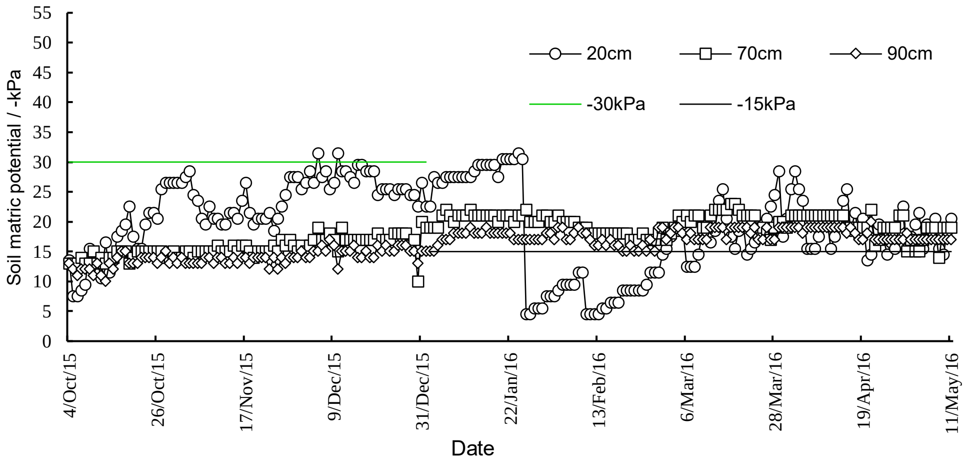
S2 Treatment



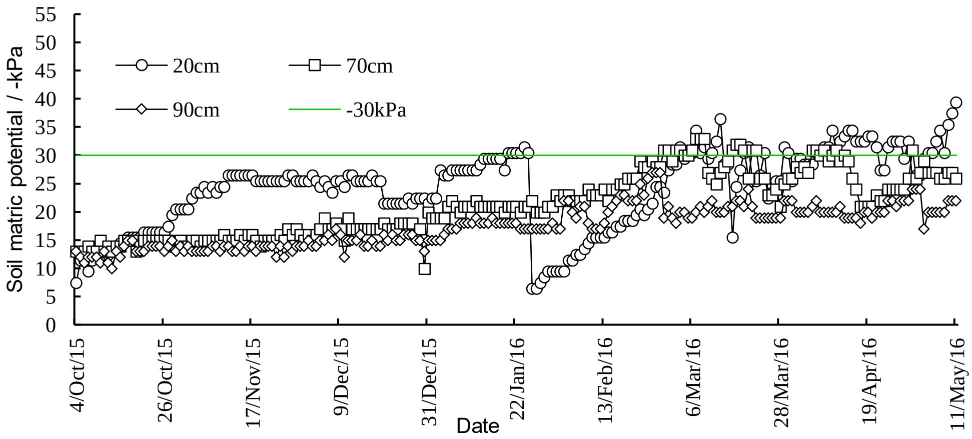
（c）S3 Treatment



（d）S4 Treatment

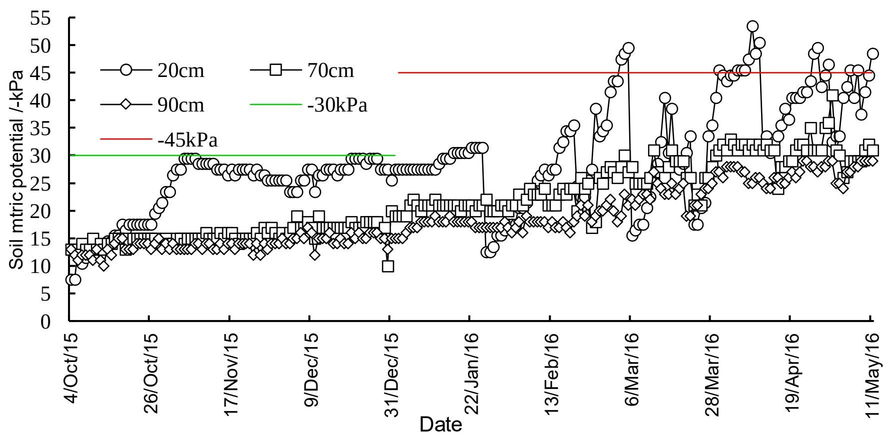


（e）S5 Treatment



（f）

S6 Treatment



（g）S7 Treatment

Figure 3. The temporal variation of SMP at 70 cm and 90 cm depth for each treatment.

This was mainly because under the high SMP threshold, the irrigation frequency was high, and the soil moisture, especially that at upper layer, was good, so most of tomato roots were distributed within the upper 60 cm soil layer; while under the low SMP threshold, the irrigation frequency was low, and the tomato root system continued to grow to form a relatively large root system so as to absorb and utilize soil moisture below 70 cm depth.

3.3 Yield and Quality of Tomato

There were significant differences in tomato yield among different SMP treatments. S3 and S7 treatments with the lowest SMP threshold of -45 kPa in the fruiting period had the highest tomato yield, with an average of 132.0 t/hm^2. The tomato yield of S5 treatment was the lowest, which was 103.8 t/hm^2, and was 78.6% of the average yield of S3 and S7 treatment (Table 2). For S5 treatment, the SMP threshold was -30 kPa in the flowering and fruit setting period, and increased to -15 kPa in the fruiting period, so it can be inferred that the sharp change of soil moisture was not conducive to the high yield of tomato.

There were significant differences in abnormal fruit rate among different SMP treatments. The S5, 56 and S7 treatments with the low SMP threshold of -30 kPa during the flowering and fruit setting period had the low abnormal fruit rate, with an average of 8.2%, and there was a tendency for the abnormal fruit rate to decrease with the SMP threshold decreased from -15 kPa to -45 kPa in the fruiting period.

There were significant differences in fruit soluble solids content among different SMP treatments. The S5, 56 and S7 treatments with the low SMP threshold of -30 kPa during the flowering and fruit setting period had the high soluble solids content, and the soluble solids content increased with the decrease of SMP threshold in the fruiting period.

Table 2. Yield and related quality indexes of tomato under different treatments

Treatment	S1	S2	S3	S4	S5	S6	S7
Yield/（t·hm^{-2}）	115.9b	115.1b	134.5a	118.5ab	103.8b	118.2b	129.5ab
Abnormal fruit rate/ %	25.7a	16.3ab	26.6a	26.5a	9.6bc	7.7c	7.4c
Soluble solids content / %	4.7cd	4.0de	4.1de	3.3e	5.2bc	5.8ab	6.4a

Note: Different lowercase letters in the row indicate that the difference was significant at the P<5% level, and the same lowercase letters indicated no significant difference at the P<5% level. It was the same below.

The high soil moisture content in the early growth stage of tomato tends to cause the growth of branches and leaves. Lots of nutrients are concentrated in stems and leaves, resulting in less nutrients supplied to flowers and fruits, which lead to the fall of flowers and fruit, and the formation of abnormal fruit.

In this study, the S1 and S4 treatment with the high SMP threshold of -25 - -15 kPa had the low yield and the high abnormal fruit rate, while the S7 treatment with the low SMP threshold of -45 - -30 kPa had the high yield and the lowest abnormal fruit rate. Liu et al (2009), Wang (2011) also found that the high soil moisture (higher than 80% of the field capacity) in the fruiting period reduced tomato yield and increased the formation of abnormal fruit and small fruit.

The soluble solids of tomato are mainly composed of soluble sugar and organic acid. Many studies had shown that water would dilute the soluble solids in fruits, and appropriate water stress would reduce the fruit water content, which in turn increase the amount of dry matter in fruit and increase the soluble solid content (Mohmed et al. 2016; Wu et al. 2016). The result of this study was consistent with these findings.

3.4 Tomato Water Consumption and Daily Water use

The ΔS value for S1 and S2 treatment was positive, which denoted soil water gain, and that for S3-S7 treatments was negative, which implied depletion of soil water by tomato. For S1, S2 and S4 treatments, the D at the 80 cm soil profile was negative, which implied the seasonal soil water flux percolated downward out of the soil profile of 80 cm depth. Because tomato root below 80 cm depth was very few, so the deep percolation belonged to the ineffective water. For S3, S6 and S7 treatments, the D at the 80 cm soil profile was positive, that is to say, the water below 80 cm depth replenished the soil water above 80 cm depth in the form of capillary rise.

So, it can be known that the SMP threshold of -15 kPa in flowering and fruit setting period was too high for tomato growth, and would cause deep leakage, and resulted in the waste of water resources. The SMP threshold of - 45 kPa - -30kPa during tomato growing period was beneficial to tomato to fully utilize the water stored in the soil reservoir.

Table 3. ΔS, I, D and ET for different treatments

Treatments	ΔS/ mm	I/ mm	D/ mm	ET/ mm
S1	67.3	526.0	-15.9	442.9
S2	63.6	484.4	-11.0	409.8
S3	-37.3	340.3	23.0	400.5
S4	-90.2	192.7	-22.1	260.8
S5	-4.0	251.9	9.2	265.1
S6	-39.0	170.8	40.5	250.3
S7	-57.8	140.6	23.5	221.9

The daily water use of tomato at different growth stages was significantly different. In the seedling stage, the plant and the leaf area was small, and the water use was low, averaged 0.4 mm at this stage; in the flowering and fruit setting period, tomato was in flourishing growth time, and the daily water use increased rapidly, and averaged 2.0 mm; at about 125 days after tomato transplanting, around the end of the flowering and fruit setting period, the temperature was low and the light was low in the greenhouse, so the daily water use was obviously reduced, and averaged 1.3 mm. In tomato fruiting period, the temperature and the light in the greenhouse gradually increased, a large number of fruits tended to mature, and the daily water use increased, but the values were relatively lower than that in the flowering and fruit setting period. As the fruits were continuously picked, the plant gradually turned to aging, and the daily water use was gradually reduced (Figure 3).

The daily water use for different treatments was significantly different. During the flowering and fruit setting period, the daily water use was obviously affected by the SMP threshold. For the S1, S2 and S3 treatments with high SMP threshold of -15 kPa, the daily water use was high, averaged 3.1 mm; for the S5, S6 and S7 treatments with low SMP threshold of -35 kPa, the daily water use was low, averaged

0.8 mm. For the high SMP threshold treatments, the irrigation frequency and total irrigation amount was high, the soil moisture content was high, so the plants grew vigorously, but this would easily lead to excessive growth of stems and leaves, and produce the luxury water consumption. In the fruiting period, the daily water use was not significantly related to the SMP thresholds, and the average daily water use for S1, S2, S3, S4, S5, S6 and S7 treatments was1.7, 1.3, 1.5, 0.8, 1.4, 1.2 and 1.2 mm, respectively.

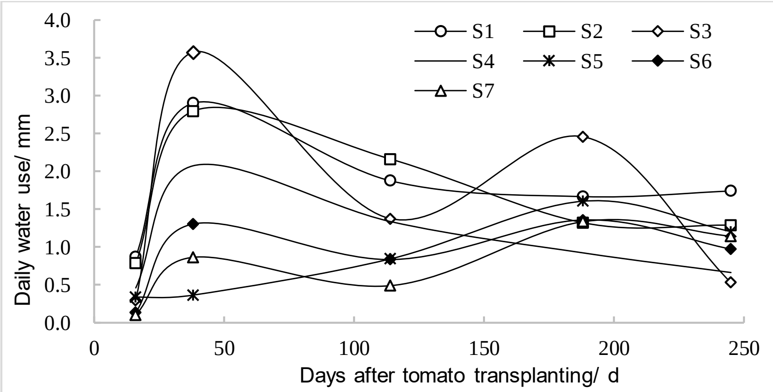


Figure 3. The daily water use of tomato for each treatment.

3.5 Irrigation Water use Efficiency (IWUE) and Water use Efficiency (WUE)

With the increase of SMP, the irrigation amount and water consumption increased obviously, while the IWUE and WUE decreased significantly. For S1 treatment, the SMP threshold was the highest, and the cumulative irrigation amount and water use were the highest, and the IWUE and WUE were the lowest; for S7 treatment, the SMP threshold was the lowest, and the cumulative irrigation amount and water use was the least, which was 0.3 times and 0.5 times of that of S1, and the IWUE and WUE were the highest, which was 4.2 times and 2.2 times of that of S1 (Table 4).

Table 4. Irrigation amount, water use, IWUE and WUE for different treatments

Treatments	S1	S2	S3	S4	S5	S6	S7
Irrigation amount/ mm	526.0	484.4	340.3	192.7	251.7	170.1	140.6
Water use/ mm	442.9	409.8	400.5	260.8	265.1	250.3	221.9
IWUE / （$t \cdot hm^{-2} \cdot mm^{-1}$）	0.22d	0.24d	0.40c	0.62b	0.41c	0.69b	0.92a
WUE / （$t \cdot hm^{-2} \cdot mm^{-1}$）	0.26e	0.28e	0.34d	0.45bc	0.39cd	0.47b	0.58a

3.6 Benefit Analysis and WFE Nexus Approach

Tomato variety "Kate No. 1" is a common planting variety in Hebei Province, which is suitable for greenhouse cultivation, and the growth period in greenhouse is about 250 days. In Haizetian Agricultural Demonstration Park, tomatoes are drip irrigation, but the irrigation management is according to the manager’s experience. The average tomato yield can reach 75 t/hm^2 and the irrigation water amount is about 450 mm.

In 2015-2016, after adopting the irrigation regime of regulating SMP threshold at 20 cm depth, the greenhouse tomato yield was 103.8-134.5 t/hm^2, with an average of 119.4 t/hm^2, and the total irrigation amount was 140.6-526.0 mm, with an average of 300.8 mm. For S7 treatment, the tomato yield was 129.5 t/hm^2 and the total irrigation amount was 140.6 mm, and tomato yield increased by 72.7%, water saved by 68.8%, IWUE increased by 5.5 times, and energy saved at least 60% compared with the local level. Therefore, the application of 20 cm SMP threshold in solar greenhouse to schedule drip irrigation can achieve obvious effects of yield increasing, water and energy saving.

The water, food and energy (WFE) Nexus is an approach that integrates management and governance across the multiple sectors of water, food and energy. Globally as well as locally, there is a growing realization of the interconnectedness between the securities of all these sectors (Carmona-Moreno et al, 2018). Agriculture is the biggest consumer of water resources and remains important in terms of share of the gross domestic product, employment forecasts and so on. In fact, the largest user of water at global level is agriculture. It accounts for 70 percent of total water withdrawal (CFS, 2015). Energy, on the other hand, is required to produce and distribute water and food. Any limitation in one of the inputs would disturb the availability of one of the others. Applying the WEF Nexus approach helps to improve understanding of the interdependencies across sectors with a view to improving integrated solutions in the field that improve achievement of sustainable development goals (Carmona-Moreno et al, 2018).

Drought and fresh water shortage are the main limiting factors for sustainable development of agriculture in North China. Using drip irrigation plays important role for overcoming the constraints and increasing crops yields. In this study drip irrigation by SMP regulation were utilized to increase the production of tomato yield by 72.7%, and at the same time to save about 68.8% of irrigation water and about 60% of energy compared with the local level. From the point view of nexus approach any saving in one item will be useful for the other items of nexus and the applied tool was very successful in saving in both water and energy and at the same time increased tomato crop production. So, it could be proved that managing drip irrigation by SMP regulation for tomato production was an excellent tool for achieving the water, food, energy nexus approach. The study provided valuable example to help the decision makers make informed decisions when operationalizing the WEF Nexus.

4. CONCLUSIONS

In greenhouse under drip irrigation, the soil moisture at the depth of 0-100 cm was significantly affected when irrigation was applied by the SMP thresholds at 20 cm depth. During the flowering and fruit setting period, when the SMP was controlled at -30 kPa or higher, only the soil moisture in the depth of 0-60 cm was consumed; the soil moisture to a depth of 80-100 cm could be utilized when the SMP threshold was reduced to -45 kPa or lower during the fruiting period.

For the treatments with low SMP thresholds in the flowering and fruit setting period, the abnormal fruit rate was low and the soluble solids content of fruit was high, and there was a trend for the abnormal fruit rate to decrease, and the soluble solids content of fruit to increase with the decrease of SMP in the fruiting stage. The tomato yield was the highest when the SMP threshold was -45 kPa in the fruiting stage. With the increase of SMP, the irrigation amount and water consumption increased obviously, while the IWUE and WUE decreased significantly.

The SMP threshold of -15 kPa in flowering and fruit setting period was relatively high for tomato growth, and caused deep leakage below the 80 cm depth. The SMP threshold of - 45 kPa - -30kPa during tomato growing period was beneficial to tomato to fully utilize the water stored in the soil reservoir. Considering tomato yield, fruit quality, and water consumption, the SMP threshold at -30 kPa in the flowering and fruit setting, and at -45 kPa in the fruiting period was recommended to trigger drip irrigation for tomato production in greenhouse in North China. Compared with the local drip irrigation water and fertilizer management method, tomato yield increased by 72.7%, and water saved by 68.8%, IWUE increased by 5.5 times, and energy saved at least 60%.

So, it can be known that managing drip irrigation by SMP regulation for tomato production was an excellent tool for achieving the water, food, energy nexus approach.

5. ACKNOWLEDGEMENTS

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EFFECT OF SUPERVISING THE OPERATION OF DRIP IRRIGATION SYSTEMS ON WATER PRICE, WATER USE EFFICIENCY AND WATER PRODUCTIVITY, CASE STUDY: KERMAN PROVINCE, IRAN

Farimah Omidi[1], Rahimeh Dehghani Dashtabi[2]

ABSTRACT

Water scarcity is the most important challenge facing the majority of the farmers in Iran. Deficiency of available water resources in agriculture shed more light on the importance of irrigation efficiency and water productivity enhancement. In this regard, farmers are being encouraged to use modern irrigation technologies such as pressurized irrigation. Designing and implementation of these irrigation systems by experts, consumes a great deal of time, cost and energy. The fact is that, lack of knowledge prevents farmers to achieve maximum irrigation efficiency and productivity by using modern irrigation systems. Therefore, the objectives of this research were to monitor the well-trained supervision on operation and maintenance of pressurized irrigation systems and to determine the effect of it on irrigation efficiency, water use efficiency and irrigation water price. This research was implemented from 2017 to 2018 on the farms equipped with drip tape irrigation system. Dominant products of the studied area which have been monitored were Corn (*Zea Mays*) and Wheat (*Triticum*). In order to study the effect of supervision on efficiency and productivity, the projects were categorized in two comparative groups which were: 1.The projects implemented without supervision on operation and maintenance until the research was started; 2. The projects which were chosen and introduced by Kerman Province Agriculture-Jihad Organization in order to start supervision on operation and maintenance. These two categories were managed based on The Handbook of Drip Irrigation Systems Operation and Maintenance Supervision for one year. Also, in order to perform operation and maintenance and manage irrigation schedule properly and to introduce technical equipment to the farmers, they were fully educated and instructed. At the end, irrigation water volume, crop yield and operation and maintenance costs were measured and calculated respectively and each crop was assessed separately. The results indicated that although pricing irrigation water increased operation and maintenance costs, it encouraged the farmers to apply water saving approaches. Also, the results showed that the volumetric amount of water decreased considerably after supervising the operation and maintenance and educating the farmers for each crop. The maximum amount of saved water was achieved for corn (*Zea Mays*). In addition, the results indicated that implementing operation and maintenance supervising increased irrigation efficiency, water productivity and water use efficiency. It can be concluded that educating the farmers and managing operation and maintenance of pressurized irrigation on a scientific regular basis not only would save more water but also could increase water productivity in a leaping pattern.

Keywords: Crop production function; Operation and maintenance; Pressurized irrigation systems, Corn, Rapeseed, Wheat, Watermelon

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1. INTRODUCTION

Considering the population growth and ever-increasing demand for food, production amplification is one of the most important objectives of agricultural sector. With the population of more than 80 million and counting, Iran is no exception. On the other hand, Iran which is located on the drought belt of planet earth, confronts challenges such as water scarcity, frequent droughts and devastating floods such as those happened in March 2019. Damages caused by population growth and the increasing need to agricultural products along with water and fertile soil scarcity have created a great challenge for this country (Pouran*et al.*, 2017).

In order to overcome water scarcity, farmers apply different solutions such as: Decreasing cultivated area, redesigning cropping pattern, applying new technologies, decreasing irrigation water amount and to change cropping time (Hargreaves and Samani, 1984; English, 1990; English and Raja, 1996; Geerts and Raes, 2009; Wada *et al.*, 2014; Manning *et al.*, 2018).

One of the effective solutions to confront water scarcity and to use water resources optimally is applying new irrigation systems such as pressurized irrigation (Piri, 2012; Zhang *et al.,* 2019; Alonso *et al.,* 2019; Sandhu, *et al.,* 2019). In this regard, Davis and Nelson (1970) implemented a research and concluded that applying surface and subsurface drip irrigation systems reduce water consumption by 22% for row plants and even more for citrus gardens. Also, as a result of a research, Fereidouni and Faraji (2017) concluded that applying drip tape irrigation along with deficit irrigation and plastic mulch can improve economic efficiency and produce maximum yield for sweet corn.

A successful pressurized irrigation system is the one which is designed and operated well. In most situations, these two don’t happen fully and the operator cannot benefit the system at its full potentials. So, pressurized irrigation systems efficiency and productivity must be assessed. Also, this assessment can help finding solutions in order to improve system efficiency. In this regard, it is of vital importance to gather information and implement studies of these systems efficiency. Founding a national database can affect water consumption schedules deeply and will improve the percentage of success of irrigation projects (Sohrabi and Abbasi, 2009).

Since available water resources are scarce and water as an intermediate good in agriculture produces added value, it must be considered as an economic good and water consumption program must be scheduled economically (Hoekstra and Hung, 2005). So, it is of vital importance to determine the economic value of water especially in the regions facing water scarcity qualitatively and quantitatively. In order to determine the relationship between Abiotic stresses as inputs and crop yield as an output, crop production functions under different circumstances must be derived. These production functions are the basic foundation of all water pricing methods (Young, 2005; Young and Loomis, 2014).

The history of crop-water production functions goes back to more than 100 years ago. Researches accomplished by Cole and Mathews (1923), Mathews and Brown (1938), De Wit (1958), Arkley (1963), Jensen (1968), Hanks (1974), Minhas (1974), Stewart (1977), Doorenbos and Peruit (1977), Hexem and Heady (1978), Doorenbos and Kassam (1979), Hanks and Rasmussen (1982) all resulted of finding experimental crop production functions based on applied irrigation water, evapotranspiration or transpiration. Hexem and Heady (1978) presented a collection of useful concepts on agriculture and economics based on production functions. In this regard, Hargreaves and Samani (1984) assessed deficit irrigation economically. One of the major problems in economic evaluation of agricultural processes is that the relations being used in economic analysis are not in accordance with agronomic relations. Crop production functions can create a connection between these two fields. As for modality of this relation, many observations indicate that water price fluctuate through different stages of growth period (Geerts and Raes, 2009; Manning et al., 2018); whilst, some researchers believe that there is a linear relation between yield and water price through growth period (Stewart, 1977;English, 1990;Doorenbos and Kassam, 1979). Calculating irrigation water price is the first step to optimize irrigation water depth based on benefit over costs ratio with includes economic efficiency (Capra et al., 2008). In this regard, Omidi and Homaee (2015) implemented a research in order to determine the irrigation water price and estimate virtual water amount of wheat. In this research, crop production function was used as a tool. Dehghani and Jahani (2016) studied the economic value of water for corn in frames equipped with drip tape irrigation system. In another research, Mateos et al. (2018) assessed the performance of smallholder irrigation based on an energy-water-yield nexus approach.

They concluded that the adoption of foreign irrigation technology could be accelerated with the collaboration between local innovators and publicly supported irrigation advisory services using integrated performance assessment approaches like the one presented in the research. In another research, Delos Reyes and Schultz implemented a study on modernization on national irrigation systems in Philippines. They concluded that inconsistencies among the design philosophy, system and operational objectives, flow control structures and water supply of the irrigation systems are root causes of their suboptimal performance. Careful consideration of the logical coherence among the selected irrigation technologies, water distribution techniques and water supply availability would form a crucial part of a relevant irrigation modernization planning for the case study systems and other irrigation systems in similar situations.

Considering the importance of operation and maintenance management for pressurized irrigation systems, the objective of this research is to determine the irrigation water price based on crop production function and evaluate the irrigation efficiency and water use efficiency for Wheat (*Triticum*) and Corn (*Zea Mays*) before and after monitoring on operation management. Using the results, the effects of monitoring on operation and maintenance can be assessed and new solutions can be offered in order to improve management methods. The main objective of this research is to shed more light on the importance of monitoring the operation of modern irrigation systems.

2. MATERIALS AND METHODS

The project was conducted in Faryab County, south of Kerman Province with an area of 2564 (km^2). The average rainfall in Faryab is 160 (mm) annually. So the region is classified as a hot and arid climatic zone Figures 1 and 2 show the location of Kerman Province and Faryab County respectively.

Figure.1 The location of Kerman Province in Iran's country divisions

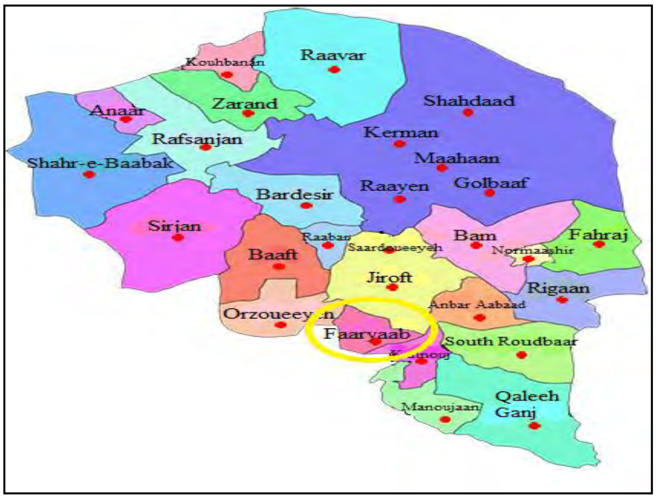

Figure.2 The location of Faryab County in Kerman Province, Iran

Farm Selection

In order to implement this research, two scenarios were defined:

The projects which were facing many problems in irrigation systems operation management till the beginning of this research were placed in first group. Important data such as irrigation water volume, yield production and costs were gathered from regional agriculture office, active experts and pioneer farmers and the irrigation water price, irrigation efficiency, water use efficiency and water productivity were calculated for wheat and corn in these projects.

The projects introduced by regional agriculture office were placed in second group. In this scenario, at first, 50 farms with an area of 1500 (ha) were selected. The farms were already under the supervision of pioneer farmers of the region. The farmers were selected in a way to represent the region's farms, irrigation management, typical agricultural practices farmers and agricultural population of the region. They included a range of low literacy to holder of a diploma or even an agricultural degree. The information of each farm included a booklet, a map of irrigation system design information and the information of the operators gathered from the agricultural department of the Faryab County. Between 50 farms, those which had better conditions from project implementation point of view were selected to be monitored. The number of the project is being indicated for each crop separately. A field identification card was prepared and completed to collect a comprehensive source of information from the farm. The required materials and forms for the project were prepared. Crop water requirement for all the studied crops was calculated by using climatic data and on farm examinations. The final amount of crop water requirement was calibrated by CROPWAT software.

Production Function

Crop-water production functions were derived from observed data with Excel and Sigmaplot 13.2 in order to be applied in calculating irrigation water price.
Irrigation water price

In this section, three methods were used to calculate irrigation water price in this research. The first method, calculates water price based on three percent of crop yield price which is brought in equation one:

$$P_w = 0.03 \times P_y (1)$$

Within which P_w is irrigation water price $(US\$/m^3)$ and P_y is yield price$(US\$/kg)$. As it can be seen this method has no scientific foundation and only represents an estimate of irrigation water price.

In second method, according to English (1990), English and Raja (1996), Young (2005) and Young and Loomis (2014), irrigation water price is a linear function of produced crop yield per consumed volumetric amount of water:

$$P_w = P_y \times \frac{Y}{W} \qquad (2)$$

Where P_w is irrigation water price$(US\$/m^3)$, P_y is yield price$(US\$/kg)$, Y is amount of crop yield (kg/ha) and W is amount of applied water(m^3/ha).

The third method is suggested for water limited regions:

$$P_w = P_y \times \left(\frac{\partial y}{\partial (w)}\right) (3)$$

Where P_w is water price$(US\$/m^3)$e, P_y is yield price$(US\$/kg)$ and $\frac{\partial y}{\partial (w)}$ is crop-water production function.

Afterwards, irrigation efficiency (IE) and water use efficiency (WUE) were calculated with equations 4 and 5 (Keller and Keller, 1995; Barker *et al.*, 2000; Seckler*et al.*, 2003):

$$IE = \frac{ET - ER}{AIW - DP - ReW} \qquad (4)$$

Where IE is irrigation efficiency, ET is actual evapotranspiration(mm), ER is effective rain(mm), AIW is applied irrigation water(mm), DP is deep percolation(mm) and ReW is re-entering water to its natural cycle(mm).

$$WUE = \frac{Y}{ET} \qquad (5)$$

Where WUE is water use efficiency(kg/m^3), Y is yield (kg/ha) and ET is actual evapotranspiration(m^3/ha).

Concept of water productivity (WP) is very wide. In general, water productivity is equal to output over inputs ratio. To conduct a better use of productivity concept, it can be divided to three categories which are: (1) Physical Productivity (PP); (2) Physical-Economical Productivity (PEP); (3) Economical Productivity (EP) (Barker *et. al.*, 2000; Seckler*et al.*, 2003).

In this research, physical productivity was calculated by equation six:

$$PP = \frac{Y}{AIW} \qquad (6)$$

Where, Y is crop yield (kg/ha) and AIW is applied irrigation water(m^3/ha).

Physical-economical productivity was calculated by equation seven:

$$PEP = \frac{P_y}{AIW} \qquad (7)$$

Where, P_y is yield price $(US\$/kg)$ and AIW is applied irrigation water(m^3/ha).

Economical productivity was calculated by equation eight:

$$EP = \frac{P_y}{P_w} \quad (8)$$

Where, P_y is yield price $(US\$/kg)$ and P_w is water price$(US\$/m^3)$.
Yield price was considered 0.89 $(US\$/kg)$ in this research.

3. RESULTS AND DISCUSSION

First, before applying management strategies and monitoring the operation, the information about volume of consumed water, total costs and yield production for each crop were collected as explained above. Table 1 presents the data collected from Agricultural Organization of the southern Kerman Province and active experts before the management project was implemented. Table 2 presents the same data after implementing the project.

Table 1. Data gathered from projects without monitoring irrigation systems operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop Type	Total applied water	Yield	Crop Price	Costs	Total Income	Total Net Benefit
	(m³/ha)	(kg/ha)	(US$/kg)	(US$/ha)	(US$/ha)	(US$/ha)
Wheat	5088	4000	0.31	754.8	1238.1	483.4
Corn	8500	6000	0.25	1059.52	1514.3	454.8

Table 2. Data gathered from projects under monitoring irrigation systems operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop Type	Number of projects	Cultivated area	Average applied water	Average crop yield	Crop price	Costs	Incomes	Net Benefit
		(ha)	**(m³/ha)**	**(kg/ha)**	**(US$/kg)**	**(US$/ha)**	**(US$/ha)**	**(US$/ha)**
Wheat	19	231	3876	5000	0.31	754.8	1547.62	792.9
Corn	15	345	6967	9400	0.25	1059.52	2383.6	1324.1

4. IRRIGATION WATER PRICE

The results of irrigation water price calculation are presented in tables 3 and 4 for before and after monitoring the operation management respectively.

Table 3. Irrigation water price for projects without monitoring the operation management for Wheat (Triticum) and Corn (Zea Mays)

Crop Type	Total applied water	Yield	Crop price	Total Income	Irrigation water price (First method)	Irrigation water price (Second method)
	(m³/ha)	(kg/ha)	(US$/kg)	(US$/ha)	(US$/m³)	(Rls/m³)
Wheat	5088	4000	0.31	1238.1	0.009	0.25
Corn	8500	6000	0.25	1514.3	0.008	0.18

As it can be seen in table 3, irrigation water price for wheat and corn was calculated based on two methods. In the first method, irrigation water price was calculated by Eq. 1. The difference between irrigation water prices of wheat and corn is because of their own price difference. This method has no scientific foundation and only calculates an estimate of irrigation water price which is not precise enough to be used in decision making. In second method, Eq. 2 was used in order to calculate irrigation water price. As it is clear, the irrigation water price in this method is higher than the one in first method. Since the amount of irrigation water, amount of yield and crop price are considered in second method, it is more reliable scientifically and can be applied when it is not possible to determine crop production function.

Having the data gathered from all selected project (Second group), wheat's crop water production function was derived as follows:

$$y = 9E - 07w^2 + 0.0015w + 0.0417 \quad (9)$$

Crop water production function for corn is presented as follows:

$$y = -0.0021w^2 + 6.6993w + 7266.1 \quad (10)$$

Within which, y is the amount of wheat yield (kg/ha) and w is the amount of applied water(m^3/ha).

After deriving crop water production functions for wheat and corn, the irrigation water price was calculated for each crop. The results are presented in table 4.

Table **4.** Irrigation water price for projects with monitoring the operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop Type	Number of projects	Average applied water	Average yield	Crop price	Irrigation water price (First method)	Irrigation water price (Second method)	Irrigation water price (Third method)
		(m³/ha)	(kg/ha)	(US$/kg)	(US$/m³)	(US$/m³)	(US$/m³)
Wheat	19	3876	5000	0.31	0.009	0.4	6
Corn	15	6967	9400	0.25	0.008	0.34	13.7

As it can be seen in table 4, in second method, irrigation water price after monitoring the operation management is higher than before monitoring implementation. This result included that although the amount of consumed water decreased and the amount of yield increased after monitoring operation management, the irrigation water price in second method did not increase significantly. This implies that the pricing method is of vital importance. In this regard, the third method is being suggested by the authors. Although the irrigation water price in third method is much higher than those in first and second methods, this method is based on scientific theories. In addition, considering the general national politics which aim to decrease water consumption, determining the exact value of water can encourage the farmers to reduce water application. The results concluded in table 5 show that although the irrigation water price in third method is apparently expensive, the produced benefit is considerably high and this can peruse the farmers to follow up monitoring operation management programs.

Table 5. Benefit cost calculations when pricing irrigation water after monitoring operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop Type	Income per cultivated area unit	Total income	Irrigation water price (Third method)	Water costs	Total costs	Total net benefit
	(US$/ha)	(US$)	(US$/m³)	(US$)	(US$)	(US$)
Wheat	1547.6	357500	6	23246.54	23247.3	334252.4
Corn	2383.6	822332.15	13.7	95262.14	95263.2	727069.1

Irrigation efficiency, water use efficiency and water productivity. In order to determine the irrigation efficiency, the amount of evapotranspiration was estimated by CROPWAT. The results are shown in tables 6 and 7 for before and after monitoring operation management respectively.

Table 6. Irrigation efficiency and water use efficiency without monitoring operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop type	Total applied water	Yield	Crop price	ET	IE	WUE
	(m³/ha)	(kg/ha)	(US$/kg)	(m³/ha)	-	(kg/m³)
Wheat	5088	4000	0.31	1750	0.34	2.29
Corn	8500	6000	0.25	6300	0.74	0.95

Table 7. Irrigation efficiency and water use efficiency with monitoring operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop type	Number of projects	Average applied water	Average yield	Crop price	ET	IE	WUE
		(m³/ha)	(kg/ha)	(US$/kg)	(m³/ha)	-	(kg/m³)
Wheat	19	3876	5000	0.31	1750	0.45	2.86
Corn	15	6967	9400	0.25	6300	0.9	1.49

The results indicated in table 7 shows that after the implementation of monitoring operation management of irrigation systems, irrigation efficiency increased to 45 % for wheat and 90% for corn. These efficiencies were considerably higher than those before the monitoring implementation. Also, water use efficiency increased by 0.49 for wheat and 0.54 for corn after the project started. The results indicated in tables 6 and 7 clearly show that implementing the project in order to monitor operation management had a positive, noticeable effect on irrigation efficiency and water use efficiency. This affirms the necessity of applying the same schedule for similar situations.

Water productivity calculations results are shown in tables 8 and 9 for before and after project implementation respectively.

Table 8. Water productivity before monitoring operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop type	Total applied water	Yield	Crop price	Physical productivity (PP)	Physical-Economical productivity (PEP)	Economical productivity (EP)
	(m³/ha)	(kg/ha)	(US$/kg)	(kg/m³)	(US$/m³)	-
Wheat	5088	4000	0.31	0.79	0.25	0.64
Corn	8500	6000	0.25	0.71	0.18	0.43

Table 9. Water productivity after monitoring operation management for Wheat (*Triticum*) and Corn (*Zea Mays*)

Crop type	Number of projects	Average applied water	Average yield	Crop price	Physical productivity (PP)	Physical-Economical productivity (PEP)	Economical productivity (EP)
		(m³/ha)	(kg/ha)	(US$/kg)	(kg/m³)	(US$/m³)	-
Wheat	19	3876	5000	0.31	1.29	0.4	1.05
Corn	15	6967	9400	0.25	1.35	0.34	1.25

As can be seen in tables 8 and 9, implementation of monitoring on operation management of irrigation systems increased water productivity and its components considerably.

5. CONCLUSIONS AND SUGGESTIONS

This research was conducted in order to assess the effects of monitoring the operation management of drip tape irrigation systems on water productivity, irrigation efficiency and water price in Faryab County, Kerman Province, Iran. To achieve the desired objectives, two scenarios were defined:

The projects which were facing many problems in irrigation systems operation management till the beginning of this research were placed in first group. Important data such as irrigation water volume, yield production and costs were gathered from regional agriculture office, active experts and pioneer farmers and the irrigation water price, irrigation efficiency, water use efficiency and water productivity were calculated for wheat and corn in these projects.

The projects introduced by regional agriculture office were placed in second group. In this scenario, at first, 50 farms with an area of 1500 (ha) were selected. The farms were already under the supervision of pioneer farmers of the region. The farmers were selected in a way to represent the region's farms, irrigation management, typical agricultural practices farmers and agricultural population of the region.

They included a range of low literacy to holder of a diploma or even an agricultural degree. The information of each farm included a booklet, a map of irrigation system design information and the information of the operators gathered from the agricultural department of the Faryab County. Between 50 farms, those which had better conditions from project implementation point of view were selected to be monitored. The number of the project is being indicated for each crop separately. A field identification card was prepared and completed to collect a comprehensive source of information from the farm.

The required materials and forms for the project were prepared. Crop water requirement for all the studied crops was calculated by using climatic data and on farm examinations. The final amount of crop water requirement was calibrated by CROPWAT software.

The results show that Irrigation systems must be designed considering the situations of each farm The applied materials to implement irrigation systems must have acceptable quality and technical characteristics; After implementation of irrigation systems, consultant experts must help the farmers by regular technical visits, educating them about services, operation and maintenance through the cropping year;

Operators must be benefited with technical knowledge by getting promotional education through justifying sessions.

The farmers and operators must be educated about the technical and scientific management of irrigation systems fully.

The pressurized irrigation systems will procure the ability to save water and increase agricultural production. So, considering the climatic conditions of Faryab County, technical management not only reduces the pressure on water resources but also provide a boosting bed to improve water productivity. Also, the authorities' attention to training the farmers and promoting recent scientific achievements can affect water productivity drastically.

Unfortunately, this issue has not been considered seriously. This is the reason of unsuccessful operation of pressurized irrigation systems till now.

As a conclusion, it can be said that monitoring the operation management of implemented irrigation systems in farms and orchards to increase the productivity and assessment of their effect is one of the most important solutions to improve water saving process which has been forgotten for many years. In order to achieve the ideal efficiency of irrigation systems on farms, the consultant experts must be present through the cropping year and must train the operators to get the best out of the systems. In addition, partial irrigation methods are suitable solutions to consume water resources optimally because of their high uniformity efficiency. But, if these systems are implemented by ignoring the quality of design and operation, they will not be able to present their nominal benefits.

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DROPS, WATTS AND CROPS – THE WATER PRODUCTIVITY CHALLENGES

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ABSTRACT

The Near East and North Africa (NENA) region will face increasing competition over scarce water resources. Climate change effects have already been felt in these regions, resulting in a growing dependence on groundwater and non-conventional resources. This comes at a growing cost in water (drops) and power (watts). Agriculture is expected to produce more crops per drop and more income per drop while reducing the energy cost. The relatively recent incentive to use renewable energy, particularly solar in irrigation, is providing a significant prospect for increasing productivity while posing simultaneously the risk of disrupting sustainable water resources management. The paper will review first the status of biophysical productivity from selected countries of the NENA region. Then will partially report on the opportunities offered by the introduction of solar energy, and finally will discuss some of the main trade-off, challenges, and emerging risks that may prevent the achievements of win-win results.

Keywords: Water productivity, water sustainability, solar energy

1. INTRODUCTION

In the arid and semi-arid areas of the world water limits agricultural production and the efficient use of the limited water resources becomes the focal point of efforts aimed at improving farmers' livelihoods. A concept termed water productivity (WP) has been coined to quantify such efforts, and is defined as the ratio of crop yield (biophysical WP) or income (economic WP) to consumed water (evapotranspiration, ET).

Nowhere on the Planet is water scarcity more acute than in the Near East-North Africa (NENA) Region. Therefore, improving agricultural water productivity becomes of paramount importance in this region. Despite the fact that high-quality soil resources are also quite limited in NENA, water scarcity has become so widespread that improving WP constitutes a challenge that must be tackled with urgency. Several factors such as increased water demand, periodic droughts, and the threats of desertification and climate change, all contribute to the perception of dwindling water resources in the NENA region, and to bring water scarcity to the top of the political agenda. The Food and Agriculture Organization of the United Nations has, in fact, developed, with several partners in the Region, an initiative dedicated to water scarcity and a recent concerted effort has been launched to implement the 2030 SDG Agenda for water efficiency/productivity and sustainability in NENA countries, with three basic pillars: water accounting, water productivity and water sustainability. Some of the concepts explored in the WP topic are covered here,

The popularity that WP improvement has enjoyed since the statement 'more crop per drop' was proposed by David Seckler in the early nineties, has been qualified a

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number of times(e.g., Molden et al., 2010), for many reasons, including the difficulties associated with WP being a ratio where the numerator and the denominator are governed by different processes. Yield, the numerator, has been increasing steadily in the last 60 years at the global level, while ET, the denominator, apparently has not varied much over the years, although there is scant information on ET trends while there is much more reliable information on yield trends. The panoply of measures to improve WP are primarily based on improving yield or income, while the efforts to reduce consumptive use are generally ill-directed and do not result in WP improvements, particularly at the economic and social levels.

The assessment of WP requires measurements of yield and of ET at scales that vary from the field plot to country and region. WP could be characterized with painstaking research observations at the field level or using remote sensing parameters associated with yield and ET, or even with broad country statistics. The goal would be to assess the trends in WP in the Region and to establish a baseline against which the impact of proposed improvement measures may be evaluated.

2. WATER PRODUCTIVITY TRENDS IN THE NENA REGION AT COUNTRY SCALE

Water productivity is determined by both yield and ET, but it is generally accepted that yield is the dominant factor in the determination of WP. It is therefore pertinent to evaluate the time course of yield over the years as an indirect assessment of WP. For comparative purposes, we have chosen wheat as a reference crop because it is grown in all countries of the region, although under diverse conditions, from fully irrigated to supplemental irrigation, and to rainfed, a factor partially responsible for the differences encountered among countries.

Figure 1 presents the time course of wheat yield since 1970 for eight countries in the NENA region. Inset in each country graph there is a value (N, kg/ha/year) of the slope of the regression line of yield against time, indicative of the rate of yield progress at the national level.

Wheat yield progress has been substantial in all countries, at rates which vary from 18 to 28 Kg/ha/yr, with the exception of Egypt, which has a rate of 93 kg/ha/yr, one of the highest in the World. Country average yields in recent years oscillate between 2 and 2.5 t/ha, again with the exception of Egypt where recent average annual yields have reached nearly 7 t/ha, and of Lebanon where it is approaching 4 t/ha. The observed variations in the slope (N) values among countries are probably related to differences in the frequency and severity of droughts that plague the region and caused large year to year fluctuations in yield which impacted the regression trends.

One feature of the yield trends of most countries is the big yield fluctuations reflecting the impact of periodic droughts. Only in the two countries where either wheat is irrigated (Egypt) or there is sufficient annual rainfall for high yields (Lebanon, Figure1), yields are very stable from year to year. In the other cases, wide yield oscillations may be observed despite the increasing trends.

To evaluate the corresponding WP, there are no simple solutions. The initial step would be to use for the denominator the annual precipitation as an indicator of water supply. The yield: rainfall ratio (YRR) is reported in Table 1. Values of YRR also increased steadily with time in all countries. Values for Egypt are not reported as the annual rainfall is not at all indicative of the crop water supply in this case.

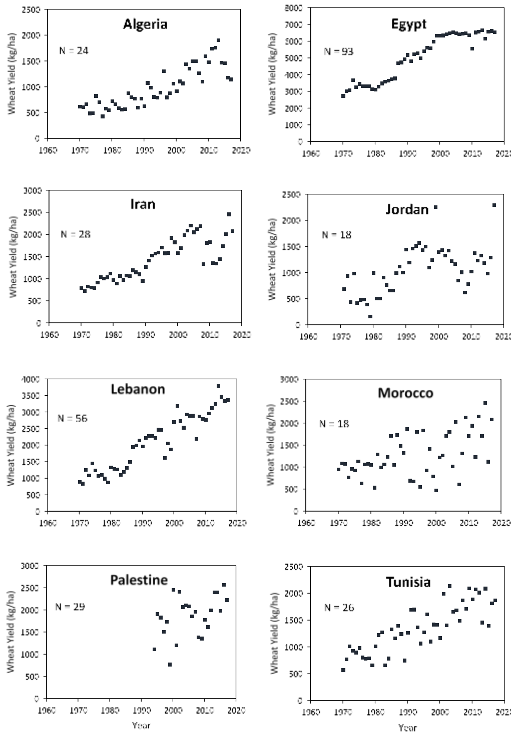

Figure 1. Time course of annual wheat yield for eight countries in the NENA region since 1970. The N value is the slope of the linear regression line in kg/ha/year. Source: FAOSTAT[4] (2019)

Country differences in YRR are mostly related to geographical and climatic differences, those countries with lower rainfall due to the presence of deserts in their territories have higher YRR values. In all cases, however, the YRRmore than doubled since 1970, which is indicative of substantial progress in WP even though the YRR represents a crude estimate of WP. Note that decadal averages of yield removed much of the fluctuations observed in the data of Figure 1, asin the Table 1 YRR values consistently increase with time.

Table 1. YRR: Yield (decadal average, kg/ha) divided by the long-term average annual precipitation in depth (mm/year)

Years	Algeria	Egypt	Iran	Jordan	Lebanon	Morocco	Palestine	Tunisia
1970-79	6.8	-	4.0	5.0	1.6	2.8	-	4.0
1980-89	7.9	-	4.6	7.4	2.3	3.5	-	5.3
1990-99	10.4	-	7.0	13.3	3.3	3.4	3.7	6.7
2000-09	14.5	-	8.4	10.2	4.2	3.9	4.7	8.3
2010-17	17.1	-	7.8	12.1	4.9	5.2	5.3	8.8

Sources : FAOSTAT (2019), AQUASTAT[5](2019).

[4] http://www.fao.org/faostat/en/

[5] http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en

To assess WP at the country scale in a more precise fashion would require a more detailed analysis focused on the wheat-growing regions of each country, such as that of Latiri et al., (2010), and that is not intended here. Nevertheless, it is possible to use the analysis of Sadras and Angus (2006), who compiled WP data from all over the World and divided it into four regions, one being the Mediterranean Region which is similar to NENA. The observed values of WP varied from 2 to 20 Kg/ha/mm and the average values for each region, in the case of the Mediterranean was 7.6 kg/ha/mm. Based on the average yield for each decade, using a value of attainable WP of 20 Kg/ha/mm (Sadras and Angus, 2006), and assuming that the evaporation (E) from the soil at zero yield is 60 mm (Sadras and Angus, 2006), the average decadal yield for 2010-17 was used to estimate a value of a theoretical, attainable wheat ET for that yield as: ET= E+ Y/WP. To calculate the attainable ET for earlier decades, we back calculated an average decline in WP in earlier decades, as the average slope of the decadal yield decline for four countries (for the records of Tunisia, Morocco, Iran and Jordan of Figure 1, an average slope of 1.162 was found).From that, we estimated that WP decreased 14 % per decade, giving the ET and the WP for each country and decade presented in Table 2.

Table 2. Estimated attainable Evapotranspiration (ET) and water productivity (WP) for each country based on the average yield and a maximum attainable WP of 20 kg/ha/mm.

Decade	Algeria		Egypt		Jordan		Iran		Lebanon		Morocco			Tunisia
	ET	WP	ET	WP	ET	WP	ET	WP	ET	WP	ET	WP	ET	WP
1970-79	114.6	5.2	355.2	9.1	110.8	5.0	142.8	6.4	159.0	6.9	148.3	6.6	134.9	6.1
1980-89	114.6	6.1	366.1	10.7	123.9	6.6	142.2	7.4	178.4	8.5	155.5	7.9	145.1	7.5
1990-99	122.4	7.6	427.1	12.8	159.4	9.3	168.1	9.6	204.8	10.5	140.3	8.5	153.9	9.1
2000-09	134.8	9.6	433.9	14.9	125.4	9.0	171.0	11.2	221.2	12.6	139.2	9.8	160.2	10.8
2010-17	136.1	11.2	380.7	16.8	127.2	10.6	149.4	12.0	223.2	14.6	150.4	12.0	151.5	12.1

The ET of Table 2 is the minimum ET_c needed to produce the average yield reported for that decade. The use of a constant value of E (60 mm) over the decades could be a source of error, as the ET_c for lower yields should have a higher E component (due to sparser crop canopies), although we could not find experimental data in the Region to support that hypothesis. Nevertheless, using a representative climate of the region, we conducted simulations with the model AquaCrop to estimate the changes in soil E as yield decreases from 2.5 down to 0.7 t/ha. While the E value for 2.5 t/ha was 58 mm for a particular year, a decrease in yield to 1.6 t/ha gave an E value of 75 mm, and a further decrease down to 0.7 t/ha increased the simulated E up to 88 mm. We propose that, for the range of yield values used to estimate ET of Table 2, E should probably be increased from 60 to about 90 mm going from the 2010 decade back to the 1970 decade.

ET values of Table 2represent the attainable ET values under the maximum WP observed for wheat (20 Kg/ha/mm). If one would use the average WP of Sadras and Angus (2006) for the Region of 7.6 kg/ha/mm, the ET values would be significantly higher and probably much closer to what may be the actual values. For instance, the ET of 151.5 mm of Tunisia for the decade 2010-2017 (Table 2) would be equivalent to an ET 300.9 mm calculated with an average WP. This approach to estimate ET at country level should be refined by comparing it to the actual ET measurements at lower scales. Also, for country comparisons, the varietal differences should be taken into account, although since the 1970’s, the work of CIMMYT in all of these countries has led to the development of high yielding varieties (HYV) adapted to local conditions. Such HYV have similar yield potential across the Region.

Notwithstanding the method used in estimating ET, the overall picture of Table 2 shows that wheat WP about doubled over the last 50 years in all eight countries, with higher values of WP in Egypt where wheat is irrigated, while in many of the other countries wheat is mainly grown under rainfed conditions. In fact, the estimated gains in WP were somewhat less than the gains in yield, because of the non-productive E losses from soil which are still important at the current average yields of 2-2.5 t/ha in wheat.

3. WATER PRODUCTIVITY AT THE FIELD SCALE

Measuring WP by determining yield and ET in experimental field plots or in farmers’ fields is not an easy task. Errors on such determinations are frequent, particularly related to ET measurements where other water balance components such as drainage interfere with the ET measurement. Therefore, it is not surprising that the WP values found in research reports vary widely, from too low to values that exceed the theoretical maximum.

A literature search was conducted to establish the baseline WP values in the region. Such values are composed of the ceiling or uppermost WP values found in the published studies, and the average of all reliable WP determinations that have been published. Both ceiling and average values determine the WP gap. In wheat, Sadras and Angus (2006) regional analyses proposed an attainable WP of 20 kg/ha/mm and an average WP of 7.6 kg/ha/mm, resulting in a theoretical WP gap of 12.4 kg/ha/mm.
Ceiling values actually measured in the field must be less than the theoretical value derived from regression/envelope analysis of Sadras and Angus (2006) because of the experimental errors involved in field measurements. In Morocco, wheat WP values as high as 19 kg/ha/mm were reported by Boutfirass*et al.*(2011) with an average of the highest values of 14.2 Kg/ha/mm for 3-4 farmers’ fields over three years. Other studies (Kharrou*et al,* 2011) indicate that a WP of about 15 kg/ha/mm has been achieved under good farming conditions. Farmers’ average WP values derived from the published studies oscillate between 5 and 11 Kg/ha/mm, suggesting a WP gap of 7 kg/ha/mm, or about 50% of the ceiling value.

Studies on wheat WP in other countries present somewhat lower WP values as ceiling values. For instance, in Jordan Al-Ghzawi*et al.* (2018) found a maximum WP of 10.3 kg/ha /mm under irrigation, although Zhang and Oweis (1999) measured a WP of 16 kg/ha/mm under supplemental irrigation in a similar environment in Syria. A five-year study in Algeria gave an average maximum WP of 10.4 under full irrigation(Bouthiba, Debaeke and Hamoudi, 2008), and a study in Iran raised the WP from 5.3 to 9.8 Kg/ha/mm by improved water management(Heydari*et al*., 2018). A WP value of 13.5 kg/ha/mm has been recently reported by Jovanovic et al.(2018), in Tunisia, and a study of the Bekaa Valley in Lebanon reported a value of 9.1(Karam*et al.,* 2009).

In conclusion, currently there is a wide WP gap for wheat in the region that may be estimated as 50-60% of the attainable WP value of 15-20 kg/ha/mm. Even though the gap is greater under rainfed conditions, research studies and yield records indicate that the WP gap under irrigated conditions is quite similar. Therefore, despite pressures emerging from the increased water scarcity, ample opportunities still remain for the improvement of water productivity.

4. SOLAR ENERGY – OPPORTUNITIES AND RISKS

Most Arab countries are part of the so-called ‘sun-belt’ region, consisting of countries that are situated between 35º N and 35º S and generally characterized by high solar irradiation. This Region benefits from solar insolation levels that are among the highest in the world (as high as 2370 kWh/m^2 per year).

Egypt in particular, with its 96 % of desert land, high frequency of clear sky days, and solar radiations ranging from 2000 kWh/m2 per year in the north and up to 2600 kWh/m^2 per year in the south, is one of the countries in the MENA region with the highest potential for solar energy adoption.

Thus, the renewable energy landscape is rapidly evolving in the Region and significant developments are taking place, providing large opportunity for its use in agriculture, including for water pumping, micro-desalination, wastewater treatment, supplementary irrigation from harvested rainfall water, which would increase water productivity.

In fact, as investment costs for solar-powered irrigation systems are decreasing, such technologies are becoming a viable option for many farmers in rural areas, and possibly for other users in rural areas that lack reliable access to electricity or where diesel fuel is expensive and/or non-sustainable and non-reliable.

The use of solar energy, to power irrigation pumps, provides a promising and reliable solution for sustainable agricultural production and is increasingly in demand in many countries in the NENA region, especially when the demand for water during the dry season is highest. Solar-powered irrigation technology has several advantages over fossil fuel powered systems since it is characterized by zero Greenhouse Gases (GHG) emissions and relatively low operation and maintenance costs, and its suitability for small-scale application and remote rural areas.

However, in water scarce countries, the provision of cheap energy for the pumping of groundwater for irrigated agriculture can result in problems of groundwater depletion and quality deterioration with severe consequences for those that have come to precariously depend upon groundwater irrigation. It poses a challenge on how to best regulate and ensure coherence between energy, land use and irrigation policies.

In conditions of limited or no surface water, groundwater is a particularly important source of water supply in the NENA region, on which it depends to meet their growing water demands. High water stresses in the region are met with varying degrees of depletion and mining of aquifer systems. As a result, many groundwater resources are at risk of being exhausted through over-pumping. This has been manifested by continuous water level declines and degradation of water quality due to salinization.

Thus, there is a trade-off in expanding the use of cheap/subsidized solar energy for pumping. On one side there is an increase in benefit due to low cost of irrigation, on the other side there is high risk of over abstraction with consequent problems of sustainability due to the increase irrigation.

5. CONCLUSIONS

An initial estimation of the water productivity at country level based on statistical data indicates that the WP of wheat has increased steadily since 1970 in all eight countries of the NENA region studied. A literature review of field-scale research results also shows progress in increasing WP. With the exception of Egypt, there is a wide WP gap in wheat production in all the countries due to being grown under rainfed conditions in areas of very limited rainfall. The introduction of solar energy for pumping is changing irrigation economics in many areas, although it poses a challenge for the sustainability of water-limited agriculture.

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BALANCING POWER AND PRESSURE - DEVELOPMENT OF AN IRRIGATION ENERGY CALCULATOR

Chris Nicholson[1], Nick O'Halloran[2], and Rabi Maskey[3]

ABSTRACT

Energy is a major operating cost for pressurised irrigation systems such as Centre Pivots and Linear Move Systems. Field assessments of systems within the Shepparton Irrigation Region highlighted that many irrigators do not have a good understanding of whether their system is using an appropriate amount of energy (electricity or diesel) relevant to the water applied and what improvements they could make to reduce their energy usage.

Existing literature showed that there are tools available for irrigators to assess the efficiency of their pressurised irrigation system. However, they all required a detailed understanding of the irrigation systems engineering or design specifications, making these existing tools very difficult to use. To overcome this barrier and assist irrigators to determine how energy efficient their irrigation system is, a simple Irrigation Energy Decision Support Tool (Energy Calculator) was developed. The Energy Calculator allows Irrigation Extension Officers to assist irrigators to identify their energy use and examine opportunities to economically improve energy efficiency of their systems.

This paper describes the basics features of the calculator and how it has been tested with two case study landowners. The learnings from these case studies helped to improve the calculator which is allowing Irrigation Extension Officers to assist other landowners to improve their irrigation efficiency.

1. INTRODUCTION

As water becomes scarcer and more expensive landowners within the Shepparton Irrigation Region in Northern Victoria, Australia, are seeking ways to use water more efficiently. Increasingly landowners are switching from gravity fed surface irrigation to pressurised irrigation systems such as Centre Pivot and Linear Move (CPLM) irrigators. This pursuit of Water Use Efficiency has led to the consumption of more energy (fuel or electricity), which is the major component of operating costs for pressurised irrigation systems.

Field assessments of irrigation systems within the Shepparton Irrigation Region have highlighted that many landowners do not have a good understanding of:

- Whether their system is using an appropriate amount of energy (electricity or diesel) for the water being applied; and
- Improvements they can make to reduce their energy usage.

When selecting an irrigation system, due consideration should be given to the system life cycle cost, including maintenance, energy and capital costs. Improvements in efficiency of irrigation systems can reduce energy costs, reduce maintenance

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requirements and more closely match irrigation system capacity to production requirements. A review of existing literature showed that there are tools available for landowners to assess the efficiency of their pressurised irrigation system (NSW Agriculture[1], 2003; NSW Agriculture[2], 2003; Sustainable Victoria, 2009 and Tallemenco Pty Ltd, 2011). However, they all required a detailed understanding of the irrigation systems engineering or design specifications. The field assessments showed that most landowner do not readily have access to this information, making these existing tools difficult to use.

To overcome this barrier and assist landowners to determine how energy efficient their irrigation systems are an irrigation energy decision support tool (Energy Calculator) was developed. The Energy Calculator allows an Irrigation Extension Officer to assist an irrigator to answer questions:

- How can I tell if my irrigation system is functioning efficiently?
- What is the likely cost benefit of improving the energy efficiency of my system?
- What parts of my system can be improved to operate more efficiently?

2. HOW DOES THE ENERGY CALCULATOR WORK?

For pressurised irrigation systems energy consumption per megalitre of water pumped, and therefore pumping costs, generally increases as system operating pressure increases. However, for a given system operating pressure energy consumption will also vary depending on the design, maintenance and operation of the system. The relationship between system operating pressure and energy consumption provides a bases on which to benchmark the energy efficiency of any irrigation system. Knowing the operating pressure of an irrigation system enables calculation of the theoretical energy consumption per megalitre of water pumped. Any deviation from this known relationship is a measure of inefficiency and can provide an insight into potential improvements that can be made to a system.
The Energy Calculator has two parts.

Part I – Energy Cost Assessment

This part of the calculator compares energy consumption of the landowner's irrigation systems to the energy consumption of a 'typical' system of the same type running at a standard pressure and energy efficiency. Reference for a "typical system have been obtained from previous studies conducted in the region (Department of Agriculture, 1994; Maskey R et.al, 2016; ISSDG, 2019) This can help determine if the landowner's system is:

- well designed (ie. is the system designed to run at a pressure typical of that system type, or is it undersigned and running a higher pressure than a typical system of that type)?
- operating efficiently compared to a typical system.

The Energy Cost Assessment provides an economic analysis of seasonal pumping costs and pumping costs for the life of the system (15 years) for both the landowner's system and the typical system. This gives an indication of the maximum economic benefit of improving the energy efficiency of the irrigation system and therefore whether improvements are likely to be cost effective. It requires limited information about the system specifications and an estimate of pumping costs which can be derived directly from power and water meters or from power and water bills. The information required is:

- Irrigation system type (see Table 1 for list of available irrigation systems)
- Area irrigated by the system (ha)

- Crop grown (indicates if crop water use is reasonable)
- Total annual water application (ML)
- Average energy unit costs ($/kWh for electric systems and $/litre for the diesel systems)
- Estimated pumping cost ($/ML), which is estimated from power bill and water use data.

Table 1. List of irrigation system included in the Energy Calculator and typical operating pressures.

System type	**System Total dynamic Head (m)**
Reuse system	4
Pipe and riser system	20
Centre Pivot and Linear Move Irrigator (low head)	21
Centre Pivot and Linear Move Irrigator (medium head)	30
Centre Pivot and Linear Move Irrigator (high head)	50
Sub Surface Drip	25
Specify Total Dynamic Head	User defined

Part 2 – System Energy Diagnostics

The second part of the Energy Calculator calculates the actual efficiency of the landowner's irrigation system and identifies opportunities to improve efficiency.

The landowner inputs system pressure (Figure 1) and an estimate of energy consumption per megalitre of water pumped. This energy consumption rate is compared to the energy consumption of an 'ideal' system operating at the same pressure to compare efficiency.

The landowner can input irrigation system pressure at various points along the system (Figure 1) to determine more specifically where energy losses are occurring. The information required:

- Energy source (electricity or diesel)
- Energy unit costs ($/kWh for electric systems and $/litre for the diesel systems) A combination of peak and off-peak energy price depending on the proportional use.
- Estimated energy use (kWh/ML or L diesel/ML) This is mostly obtained by measuring water use and energy use over a given period.
- System pressure:
    - Delivery line pressure
    - Suction line pressure
    - Total lift above the pump
    - Regulator pressure rating
    - Residual pressure (pressure at the end of the system)

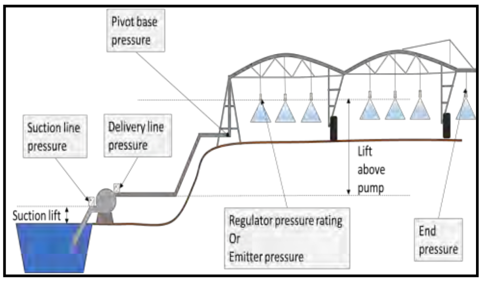

Figure 1. Diagram showing the locations where system pressure is measured to determine system efficiency and diagnose energy losses.

3. ESTIMATED PUMP EFFICICENY CALCULATION

The Energy Calculator uses the following equation to estimate pump efficiency for the landowners system:

$$\text{Estimated pump efficiency (\%)} = \frac{\text{(A) Theoretical energy use for 100\% efficient pump} \times \text{(B) Total dynamic head}}{\text{(C) Estimated energy use}}$$

(A) Theoretical energy use of 100% efficient pump calculation (Foley, 2015)

Electricty: $\frac{\text{2.725 kWh/ML/m head}}{\text{(pump efficinncy (1) x motor efficiency (0.9) x drive efficiency (0.95))}} = $ 3.19 kWh/ML/m head

Diesel: $\frac{\text{0.255 kWh/ML/m head}}{\text{(pump efficiency (1) x motor efficiency (0.35) x drive efficiency (0.95))}} = $ 0.77 L diesel/ML/m head

The landowner provides their own estimate of:

(B) Total dynamic head (m head), including suction line and delivery line pressure

(C) Estimated energy use kWh/ML (electricity) or L diesel/ML (diesel)

The Energy Calculator plots the landowners 'Estimated energy use' (C) against the Total dynamic head (B) of the system on a graph with pump efficiency isolines of 40%, 50%, 70% and 90% (Figure 2). Ideally the landowners irrigation systems will be operating between the 70% and 90% pump efficiency lines. Any system that has a pumping efficiency less than 65 % can be improved. The degree of red shading on the graph indicates the level of inefficiency of the system. The darker the red shading the more inefficient the system.

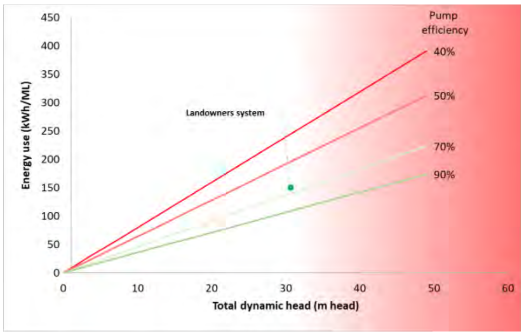

Figure 2. Graphical output from the Energy Calculator showing the Total dynamic head and Energy use of the landowners irrigation system plotted against pump efficiency isolines.

The layout of the Energy Calculator, Part I – Energy cost assessment is shown in Figure 3. and Part 2 - System energy diagnostics is shown in Figure 4. In both parts the blue cells are populated with the landowner's data.

4. TRIALING THE ENERGY CALCULATOR

The Energy Calculator has been tested with two landowners to determine if famers have access to the necessary data to populate the calculator and to verify the appropriateness and usefulness of the outputs. Of the two landowners, one was sufficiently aware on the performance of his systems and regularly recorded data to assess the performance of his irrigation systems. The second landowner was less aware of the energy performance of his system.

Case Study 1

For Part 1 of the Energy Calculator (Energy cost assessment) the following information was provided by the landowner.

- Irrigation system type – CPLM (medium head) 30m
- Area irrigated by the system – 37 ha
- Crop grown – maize
- Total annual water application – 218 ML (6 ML/ha)
- Average energy unit cost - $0.153 kWh (mostly operated during off-peak period)
- Estimated pumping cost - $22/ML

For Case Study 1 all data was readily available from the landowner's record. Estimated pumping cost was calculated from the landowner's records of water use and electricity use. The landowner estimated energy use was 144 kWh/ML of water pumped, and this was multiplied by the average energy unit cost ($0.153 kWh) to estimate an average pumping cost of $22/ML of water pumped. This figure is then compared with a 'typical' CPLM system operating at 30 m head. Pumping costs were $1.1 ML more than a 'typical' CPLM operating at 30 m head which would cost $20.9/ML. Over a growing season the landowner is spending a total of $4,796 on energy compared to $4,553 for a 'typical' medium head CPLM system to grow a maize crop. The use of this part of the calculator indicated that the system was operating efficiently and potential cost saving from improving the efficiency of the system were limited.

For Part 2 of the Energy Calculator (System energy diagnostics) measurements of system pressure, water flow rate and power consumption were undertaken to determine if the landowner's system was comparable to a typical medium head CPLM system operating at 30 m head, and also to determine the actual energy efficiency of the irrigation system.

The data obtained for Part 2 of the Energy Calculator was:

- Energy source: Electricity
- Energy cost: $ 0.153/kWh
- Estimated energy use: 137 kWh/ML of water pumped
- System pressure:
    - Delivery line pressure: 33.5 m
    - Suction line pressure: 0.5 m
    - Total lift above the pump: 3 m
    - Regulator pressure rating: 7 m
    - Residual pressure (pressure at the end of the system): 7 m

From this data it was evident that the landowner's system was operating a slightly higher pressure (total dynamic heads = 33.5 m) than a typical medium pressure CPLM irrigation system. However, this operating pressure was still within an acceptable operating range.

Estimated energy use to pump a megalitre of water (kWh/ML) was calculated from the power usage and the flow rate data. The figure derived this way was similar to the information provided by the landowner. The calculated kWh/ML was 137 which was slightly less than the data provided by the landowner which was 144 kWh/ML. Note that the landowner derived the figure by using his power bill and irrigation water flow rate data.

From the above information, the Energy Calculator estimated pumping efficiency. Pump efficiency calculated from the measured data was 78% compared to 74% from the data provided by the landowner. Both the figures were above 70% which is considered an acceptable efficiency for centrifugal irrigation pumps.

If available, we can also obtain flow rate versus system head characteristic curves from the pump manufacturers to assess the pumping system design and operating points and compare with the calculated pump efficiency.

The landowner was asked about the usefulness of the calculator – "How useful was the Energy Calculator?"

The landowner responded that the calculator was helpful in understanding energy use for growing the crop but believed that the calculator would best be used with the support of an Extension Officer. Despite the simplicity of the Energy Calculator, an Extension Officer should guide a landowner through the use of the calculator, explaining what data is needed and why. The Extension Officer can explain how results are generated and help in the interpretation of outputs and identification of changes that can be made to improve energy efficiency of the system if necessary.

5. OTHER LESSON LEARNT

This case study found that the landowner's system was sufficiently efficient in it's energy use, however during the farm assessment it was found that the system was not operating well in terms of water application uniformity. An assessment of irrigation uniformity found that pressure regulators on the pivot had deteriorated. This resulted in higher application depths towards the centre of the pivot and low pressure and reduced application depth on the outside of the pivot. Replacing the old pressure regulators would improve application uniformity but is also likely in increase system pressure and therefore energy consumption and operating costs. However, improving uniformity should improve productivity and water use efficiency, which would compensate for a slight increase in energy costs.

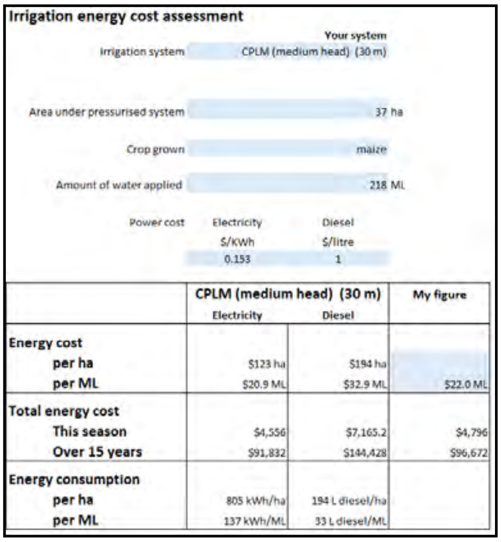

Figure 3. Energy cost assessment calculator for Case study 1. Blue cells are populated with the landowner's information.

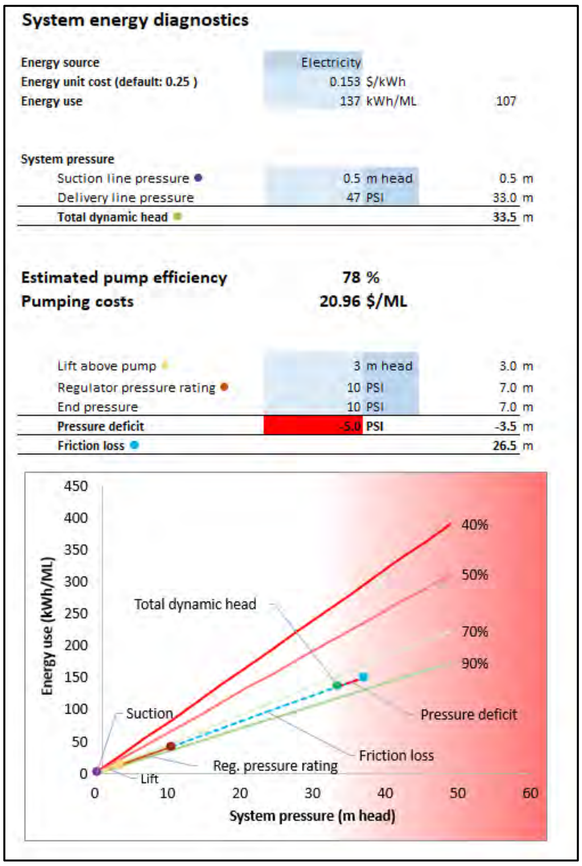

Figure 4. System energy diagnostics output used to assess pumping efficiency for Case study 1

Case Study 2

For Part 1 of the Energy Calculator (Energy cost assessment) the following information was provided by the landowner in Case Study 2.

- Irrigation system type – CPLM (medium head) 25.6 m
- Area irrigated by the system – 25 ha
- Crop grown – lucerne
- Total annual water application – 187 ML (7.5 ML/ha this figure was obtained through discussion between the landowner and Extension Officer)
- Average energy unit cost - $0.2 kWh (based on the proportion of off-peak and peak power used)
- Estimated pumping cost - $30/ML

In this case study the landowner did not have sufficient records to provide much of the data required. However, a separate irrigation system uniformity check had recently been undertaken which provided the data required. In the irrigation system uniformity check it had been estimated that this system was costing about $30/ML water pumped.

Initially the Energy Calculator was run assuming the system had an operating head of 30 m and the results indicated that the irrigation system was running at a reasonable efficiency. However, further discussion with the landowner revealed that the operating head was actually 25.6 m. For a system running at 25.6 m head the Energy Calculator indicated that pumping costs should be $23.30/ML. The system was therefore costing $7 ML more than it should. The Energy Calculator indicated that over a 15-year life of the system, the landowner would be spending an extra $25,000 to grow Lucerne. This indicates that with some improvements in the system, the landowner can save some or all of $25,000.

In order to explore where the improvements can be made, the second part of the calculator was used. The second part of the calculator uses measured data from the farm.

The data obtained for part 2 of the Energy Calculator was:

- Energy source: Electricity
- Energy cost: $ 0.2/kWh
- Estimated energy use: 150 kWh/ML of water pumped
- System pressure:
    - Delivery line pressure: 24.6 m
    - Suction line pressure: 1.0 m
    - Total lift above the pump: 3 m
    - Regulator pressure rating: 10.5 m
    - Residual pressure (pressure at the end of the system): 16.9 m

The Energy Calculator estimated a pump efficiency of 54 percent (Figure 6). This is below the acceptable efficiency for a centrifugal irrigation pump of 70 percent. The measured data showed that the power required to operate the system at 25.6 m head was 16kW assuming that the pump efficiency of 75 percent. The calculation showed that the power used is 24 kW and the pump motor kW at duty point is shown as 22 kW. This indicates that the pump motor is oversized for the system. The landowner suggested re-nozzling the system to increase application rate and utilise the extra motor capacity. This potential solution warrants further investigation.

When asked about – "How useful was the Energy Calculator?" – The landowner responded that the tool was helpful in understanding his energy usage but believed that the tool should be used with a help from an Extension Officer. The tool indicated that the landowner was spending extra $7/ML of water pumped. The landowner considered the $7/ML is a significant amount of money. "It is one wage for one person on farm" he commented.

Irrigation energy cost assessment

	Your system	
Irrigation system	Specify TDH	
	25.6	meter
Area under pressurised system	25	ha
Crop grown	lucerne	
Amount of water applied	187	ML

Power cost	Electricity	Diesel
	$/KWh	$/litre
	0.2	1

	Specify TDH		My figure
	Electricity	Diesel	
Energy cost			
per ha	$174 ha	$210 ha	
per ML	$23.3 ML	$28.0 ML	$30.0 ML
Total energy cost			
This season	$4,359	$5,244.8	$5,610
Over 15 years	$87,869	$105,720	$113,080
Energy consumption			
per ha	872 kWh/ha	210 L diesel/ha	
per ML	117 kWh/ML	28 L diesel/ML	

Figure 5. Energy cost assessment tool for Case study 2.

System energy diagnostics

Energy source	Electricity	
Energy unit cost (default: 0.25)	0.2 $/kWh	
Energy use	150 kWh/ML	82
System pressure		
Suction line pressure	1 m head	1.0 m
Delivery line pressure	35 PSI	24.6 m
Total dynamic head		25.6 m
Estimated pump efficiency	**54 %**	
Pumping costs	**30.00 $/ML**	
Lift above pump	3 m head	3.0 m
Regulator pressure rating	15 PSI	10.5 m
End pressure	24 PSI	16.9 m
Excess pressure	4.0 PSI	2.8 m
Friction loss		8.2 m

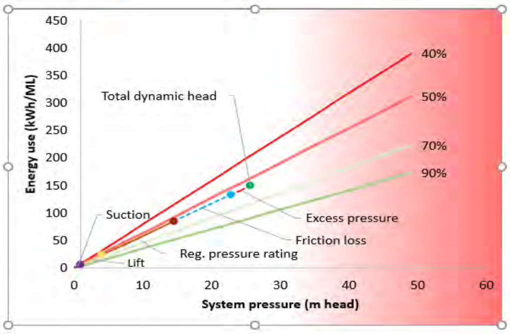

Figure 6. System energy diagnostics output used to assess pumping efficiency for Case study 2

6. LEARNINGS FROM THE CASE STUDIES

Both the landowners found the Energy Calculator to be useful for them to understand the energy use of their pressurised irrigation systems. Some of the learnings and suggested improvements from the case studies are to:

- Include an option for both peak and off-peak power in the calculator.

  Landowners use a combination of peak (7 am to 11 pm weekdays) and off-peak (11 pm to 7 am weekdays, Saturday, and Sunday) power. Both the landowners suggested to include an option in the calculator to have a combination of peak and off-peak power options. Such as a combination of 1/3 peak and 2/3 off-peak power.

- Revisit Part 1 of the calculator after generating precise figures from Part 2.

  After going through the whole process, landowners can revisit Part 1 with precise data from Part 2 which will provide them with more accurate information to look at the economics of making improvements. In most cases, at least some improvements can be identified that could pay for itself in energy savings alone. Very often as the case study demonstrated, the landowners who owned these inefficient systems were unaware of any problems.

- Use the calculator with the assistance of an Extension Officer.

  With both the case studies the landowners mentioned the importance of involving an Extension Officer to assist in going through the calculator. This not only helped landowners to understand what data they needed, but also gave them confidence in interpreting results to improve their systems.

- Water use and energy use nexus

  The first case study demonstrated that the landowner's irrigation system was sufficiently efficient in its energy use, however during the system uniformity check it was found that the system was not operating well in terms of water application uniformity. The assessment found that the pressure regulators on the irrigation system were not functioning correctly and needed replacement.

7. CONCLUSIONS

In times of high energy costs, energy efficient irrigation equipment is essential to the viability of irrigated farms. Assessments done in the region showed that most irrigation systems are not as efficient as they should be. Unfortunately, many landowners with inefficient systems are unaware of the problem. The Energy Calculator provides a useful tool to help landowners benchmark the energy efficiency of their irrigation systems and identify opportunities to economically improve energy efficiency. The Energy Calculator breaks this analysis into two parts. The first part of the calculator requires limited data to compare landowner's irrigation system with a 'typical' pressurised irrigation system. It provides information about energy consumption compared to a 'typical' system and an estimate of how much money could be saved by improving the system.

The second part of the calculator is used to estimate the actual energy efficiency of the landowner's irrigation system. This part also helps to identify which area of the system can be improved to make the system more energy efficient.

As the first case study demonstrated, energy efficiency does always equate to better water use efficiency. Problems like inadequate system pressure and poor application uniformity result in uneven and inefficient application of water. This can result in crop stress, reduced yields, wasted water, runoff and many other problems. Equipment that is poorly maintained and badly designed reduces the irrigator's degree of control over the way water is applied.

Common areas that could be considered for making your system energy efficient are:

- Maintain your system

  Worn sprinklers and regulators, plugged screens and leak systems are few of the problems that can be avoided with regular maintenance.

- Pump performance

  A pump that is oversized, undersized or just not right for the system will never operate efficiently. One of the places to begin looking at improving efficiency is at the pump. As the pump is a major energy consumer, any improvement in is efficiency reduces the cost of operating the system.

- Proper size pipes and fittings

  Every time that irrigation water passes through undersized pipes, valves and fittings at high velocity is operating in an inefficient manner. It would be preferable to replace undersized fittings with ones of the correct size.

- Negotiate energy cost

  Reduce cost per unit of energy by negotiating a better rate with the utility.

- Make your own energy

  Installation of solar system to generate electricity can reduce your energy bill.

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