Effect of Modern Agricultural Techniques on Sustainability of Groundwater and Enhancing Field Crops Production in Dhamar

Dr. Adel Al Washali[1], Dr. AbdulRahman Al Eriany[2] Dr. Samer Al Mashreqy[3] and Eng. Gamal Mangazi[4]

Introduction

In Yemen, water scarcity forms a major constraint in realizing the goals set in the national strategic development plans. Setting aside plans and goals, Yemen's dwindling water resources and increasing population threatens the future of the coming generations. The annual per capita share of water decreased to a record low of 115m^3/year which in the global context is considered as one of the lowest per capita, as the international average per capita is estimated at 1200m^3/year.

The gap between annual water resources (2.5BCM) and annual water consumption (3.4BCM) is estimated at 0.9BCM, a considerable shortfall that is 'remarkably' considered to be compensated by groundwater. This continuous shortfall has led to serious decline in groundwater tables in most basins in Yemen. Points of no return have been spoken of, where aquifers have almost entirely dried up, however the local (social and aquifer) dynamics are often overlooked and opportunities for replenishment particularly in the agricultural sector may be more proximate than the generally assumed.

In Yemen, irrigated agriculture consumes more than 80% of the total annual groundwater that is abstracted through more than 70,000 wells throughout Yemen. In addition, most of the irrigated areas still depend on traditional irrigation methods with low efficiencies (35%).

With these two matters in mind, Yemen's main governmental water organisations including the Ministry of Agriculture and Irrigation (MAI) and the Ministry of Water and Environment (MWE) made great efforts to reduce groundwater consumption in the agricultural sector. A roll-out example of these efforts was the National Irrigation Program (NIP-MAI) which targeted to cover total area of 1250 hectares by subsidizing the retail of drip irrigation systems in Amran, Dhamar and Sana'a.

Agricultural water users however face many obstacles in adapting Agricultural irrigation water saving techniques such as the limited financial capacity of small farmers. Most agricultural land in Yemen is cultivated by smallholder farmers and the potential benefits that are portrayed by the government with regards to reduced water usage and the attainment of the same crop yields, are outweighed by farmers' precarious cashbook balance and the lack of collateral and financing mechanisms.
The impact however that improved irrigation practices, coupled with reduced cropping intensity and cropping area is still seen as the best means to reduce agricultures consumptive share of water. Hence, the expansion of area covered with Agricultural irrigation water saving techniques are still a top priority to reduce annual abstraction and conserve Yemen's groundwater resources.

Research Objectives

Main research objective is to assess impact of applying Agricultural irrigation water saving techniques on: groundwater abstraction and crop yield. This research's sub-objectives are to predict the amount of irrigation water that could be conserved when applying Agricultural irrigation water saving techniques for cultivation of tomatoes and potatoes crops; and the effect of applying Agricultural irrigation water saving techniques on the declining groundwater level of the Dhamar aquifer.

Besides these research objectives, this practical action research aims to support the efforts of Yemens' governmental water organisations' to monitor the impact of applying Agricultural irrigation water saving techniques. The results of this research can contribute to raising the awareness of the agricultural community and help mobilise farmers towards adoption of Agricultural irrigation water saving techniques. Realizing that with less irrigation water, crop yields can still increase in a manner that can help in sustaining groundwater resources.

Literatures Review

Sustainable agriculture is used as term to describe novel agricultural techniques that are being innovated or adopted from past practices. Sustainable agriculture intends to capture on-farm practices that sustain the basic environmental elements such as soil and water required for increasing the agriculture production and to guarantee farmers livelihoods.

Sustainable agriculture could be define as one that, over the long term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable; and enhances the quality of life for farmers and society as a whole."

The United States Congress also defined sustainable agriculture in the 1990 Farm Bill [US Government, 1990]. Under that law, the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that over the long term will:

- Satisfy human food and fiber needs.
- Enhance environmental quality and the natural resource base upon which the agricultural economy depends.
- Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
- Sustain the economic viability of farm operations.
- Enhance the quality of life for farmers and society as a whole.

Sustainable agriculture can argue that the current excessive use of non-renewable resources that will not be available for future generations inhibits the attainment of sustainability. Sustainable agriculture means less emphasis on extractive methods (and the use of non-renewable resources) and greater reliance on renewable methods and enhancing the resource base for future generations (that is, exploiting useful biological cycles, thereby saving money on externally purchased inputs). This goes against the conventional move towards specialization and economies of scale, which is encouraged by the current economic/pricing system. Sustainable agriculture can survive in the current economic climate by working with nature’s biological cycles (usually through diversification); reducing expenditure for purchased inputs, relying on what Savory [1988] calls solar dollars (income generated through human creativity, labour, and constant sources Oenergy, especially the sun); and finding niche markets for the products produced. However, given the overwhelming power/influence of the prevailing economic system, popular acceptance of sustainable agriculture in its widest sense will require governmental policies that support farmers not only in the transition to sustainability but in maintaining that commitment once it has been attained. This does not necessarily mean subsidizing of farmers per se but rather implementation of policies that are important to ensuring the vitality and viability of society (i.e., families and communities) today and in the future.

There are many sustainable agricultural systems and techniques with different aims for each. Their objectives could be for reducing the consumption of water in agriculture sector, increasing crop yield production, reducing energy requirements in controlled out of season cropping systems, or increasing the usage of renewable energy. Therefore, any sustainable technique should be productive, resource conserving, socially supportive, commercially competitive and environmentally sounds.

Modern irrigation systems, greenhouses and mulching are considered as sustainable agricultural techniques that by using one or a combination of the two (greenhouse or mulch with drip) a positive effect on growth and yield of planted crops can be achieved and a reduction in water use.

Considering various improved irrigation systems, sprinkler irrigation has been able to guarantee water savings in a lot of different applications, however drip irrigation is more widely used since the mid of last century. Kadyampakeni (2004) considers the advantages of drip irrigation systems as follows:

1 ***More efficient use of water***: Compared to surface irrigation and sprinkler methods (with efficiencies of 50–75% in high-management systems), drip irrigation can achieve 90–95% efficiency. This is because percolation losses are minimal and direct evaporation from the soil surface and water uptake by weeds are reduced by not wetting the entire soil surface between plants (Polak et al. 1997a, b; Narayanamoorthy and Deshpande 1998; Narayanamoorthy 1999).

2 ***Reduced cost for fertilizers***: Precise application of nutrients is possible using drip irrigation. Fertilizer costs and nitrate losses can be reduced considerably when the fertilizers are applied through the irrigation water (termed fertigation). Nutrient applications can be better timed to coincide with plant needs since dressing can be carried out frequently in small amounts and fertilizers are brought to the immediate vicinity of the active roots.

3 ***Reduced labour demand***: Water application is less labour demanding compared to surface or bucket irrigation. Cultural practices such as weeding can be performed when the plants are being irrigated (Polak et al. 1997a, b; Narayanamoorthy and Deshpande 1998).

4. ***Low energy requirement***: A drip irrigation system requires less energy than a conventional pressurized system as it increases irrigation efficiency and therefore requires less water to be pumped. Compared to other pressurized systems, savings are also made because of the lower operational water pressure required for drip systems.
5. ***Reduced salinity risk***: The drip lines are placed close to a row of plants and the root zone tends to be relatively free of salt accumulations as the salts always accumulate towards the edge of the wetted soil bulb. The accumulation of salts on a surface-irrigated field tends to be right in the middle of the root zone.

A greenhouse is an enclosed space that creates a different environment to that found outside due to the confinement of the air and to the absorption of shortwave solar radiation through a plastic or glass covers (El Ghoumari *et al.*, 2005). The greenhouse microclimate can be manipulated by control actions, such as heating, ventilation, CO_2 enrichment to name a few; in order to provide appropriate environmental conditions (Bennis *et al.*, 2008).

Mulch is a protective layer of either organic or inorganic material that is spread on the top soil to guarantee:

1. Earlier production: raises the soil temperature, which helps plants grow more quickly and mature earlier
2. Reduce leaching of fertilizer: prevents rainfall from percolating through the soil and moving nutrients beyond the reach of plant roots.
3. Fewer weeds: black plastic mulch prevents the growth of most weeds except.
4. Increased plant growth: when plants are grown on plastic, the CO, released from roots accumulates under the plastic and eventually escapes through the holes in which the plants are growing. This "chimney effect" increases the concentration of CO, to the leaves and enhances plant growth.
5. Reduce evaporation: less water evaporates from soil under plastic mulch, and soil moisture is maintained more uniformly. Therefore, you actually need less water per unit of production (USDA, FAQ, Elevitch, C.R. and Wikinson, K.M.).

Shaghleb et al (2006) assessed the effect of irrigation methods (drip, sprinkler, and furrow) on maize production. The grain yield recorded 6.48, 6.065 and 7.905 t/ha for drip, sprinkler and furrow irrigation respectively. The values of maize water requirement were 4392.87, 5565 and 9011.92m^3/ha for drip, sprinkler and furrow irrigation systems respectively.

Al-Ghobari and El Marazky (2014) studied the effect of smart sprinkler irrigation systems (SIS i.e. computing applied water and evapotranspiration (*ETc*) based on climatic conditions) on water use efficiency for wheat crops in Saudi Arabia, using three levels of irrigation regimes by using schedule SIS on wheat *ET*, yield, *WUE* and *IWUE* in arid climatic conditions. The three irrigation levels were 100%, 80% and 60% of full irrigation. Results of ANOVA showed that SIS had significant effects on *WUE* and *IWUE*. Maximal yield was obtained when the optimal amount of irrigation was 600.35 mm and *ETc* was 466.75 mm. The results showed that, with the increase in irrigation, *ETc* increased and *WUE* decreased. The SIS technique conserved irrigation water by 12% less than that provided by conventional irrigation system CIS.

Mansour et al (2014) investigated the influence of bubbler and drip irrigation systems and treated agricultural wastewater on distribution uniformities, potato growth, tuber yield and water use efficiency. From his results on . WUE values were the highest by using treated agricultural wastewater with drip irrigation system (0.24, 0.19; 0.14 ton/m^3). Whereas the lowest values of WUE were by using fresh water with bubbler irrigation system (0.21, 0.18; 0.14 ton/m^3) under applied water treatments of (50, 75 and 100%) from ETo respectively.

Water use efficiency increased under shady conditions (Jifon and Syvertsen, 2003). Lorenzo et al. (2006) found that greenhouse shading improved the quality of tomato and increased yield of cucumber.

Hashem et al (2011) studied the effect of three green-house covers (polyethylene sheet, white and black net) and three irrigation levels [80%, 100% and 120% of the potential evapotranspiration estimated according to class A pan equation (ET_o)], applied by drip irrigation system, on plant growth and crop yield of cucumber. The highest irrigation water use efficiency was obtained by white net treatment combined with 80% ET. The level of 120% ET_o combined with black net treatment had the lowest irrigation water use efficiency.

Abdullah et al (2014) used four water level (40, 60, 80 and 100%) with total water applied amounts of (1440, 2160, 2880 and 3600 m^3/ha) for irrigation of tomato through drip irrigation under greenhouse. The irrigation scheduling was based upon the pan evaporation. The results recommended that grafted tomato plants under a moderate irrigation level (80% ETc) can conserve about 20% of irrigation water applied, but accepted with slight reduction in the total yield (0.7-1.3%) under greenhouse conditions.

Abdrabbo et al (2013) investigated the effects of different net colour on the growth and production of potato in terms of light intensity, air temperature, relative humidity and plant growth. Potato cultivated in-between orange trees under different five net colours for covering greenhouses and open field to increase the soil use efficiency. White netting increased the potato tuber yield per plant compared to the other net colour. The white nets allow proper light distribution for potato, which creates favourable conditions for plant growth, photosynthesis and metabolites translocation. The yellow net came in the second order followed open field treatment, while the black and blue cover gave the lowest tuber yield.

Eid et al (2013) studied the effect of pulse drip irrigation and mulching systems for saving water, increasing and improving yield of soybean, the control treatment was soil surface without mulch, one of the parameters was the irrigation water use efficiency. The results shows that pulsing irrigation technique effect was positive on Soybean irrigation water use efficiency (0.478Kg_{seeds}/m^3). While using mulching was positive on the value of Soybean irrigation water use efficiency (0.492Kg_{seeds}/m^3). The combination application of both pulsing technique and mulching system increased the irrigation water use efficiency of soybean to reach ($0.633Kg_{seeds}/m^3$).

Dalorima et al (2014) investigated the effects of different mulching materials on the growth performance of okra (ladies' finger). The treatment include plastic mulch, sorghum straw mulch and sawdust mulch and control (No mulch). Soil moisture conservation was observed under polythene and sorghum straw. The higher moisture conversion under the polythene mulch was mostly due to prevention of evaporation from the soil surface. Soil temperature was significantly higher under the plastic mulches than the other treatments, plastic mulches absorb comparatively large amount of the incoming radiation and transmit a considerable part of it to the soil underneath while soil temperature was lowest with the use of sorghum straw mulch.

Yaya and Al-Weshali (2006), studied the optimum agricultural map for different zone areas in Yemen from water situation vision. Results indicate that preferable crops for Dhamar to be cultivated according to its water situation are at following seasons; pulses.15/2, Barley.15/2, Barley.15/7, Barley.15/12, Potato.1/2, Potato.1/7, Tomato.1/7, Vegetable 1/2, pulses.1/1, Vegetable.1/7, Wheat.15/6, pulses.1/7 and Tomato.1/2 (day/month).

Yaghia et al (2013) studied the effect of two types of plastic mulch (transparent TM and black BM) with drip irrigation (DI) on water requirement and Cucumber yield. They found that (DI + TM) treatment excelled all other treatments at yield and water use efficiency (WUE), where its yield was 63.9 t ha^{-1}, and (WUE) was 0.262 t $ha^{-1}mm^{-1}$. While (DI + BM) treatment produced 57.9 t ha^{-1}, with a (WUE) of 0.238 t $ha^{-1}mm^{-1}$. However, cucumber yield and WUE declined in the remaining treatments of no mulch (DI) and (SI) to reach 44.1 t ha^{-1} with 0.153 t $ha^{-1}mm^{-1}$ and 37.7 t ha^{-1} with 0.056 t $ha^{-1}mm^{-1}$, respectively.

Darouich et al (2014) explores the use of drip and surface irrigation decision support systems to select among furrow, border and drip irrigation systems for cotton, considering water saving and economic priorities. Comparing surface and drip irrigation systems, despite low cost, drip alternatives may lead to 28-35% water saving relative to improved graded furrows, and increase water productivity from 0.43 kg m^{-3} to 0.61 kg m^{-3}.

The National Irrigation Program (NIP) started in Yemen in 2009 is designed to improve farmers' livelihood and ensure resource sustainability both in quantity and quality through the provision of modern on-farm irrigation technologies throughout Yemen.

As shown in tables (1 and 2), the initial plan of the NIP for the distribution of improved irrigation conveyance systems was to have 10,171 ha served, in September 2012 however only a total covered area of 2,793 ha had been served. In addition the goal of covering 1,250 ha by modern irrigation systems in the three basins was by far not met as 109ha, 3ha and 1.4ha had been realized in Sana'a, Dhamar and Amran respectively until September 2012.

Table (1): Distribution of targeted areas to be covered in the three critical basins

Basin	Improved Conveyance Irrigation System	Modern Irrigation Systems
Sana'a	3,640	495
Dhamar	3,114	380
Amran	3,417	375
Total	10,171	1,250

Table (2): Distribution of areas that had been realized in the three critical basins, 2012

Basin	Improved Conveyance Irrigation System	Modern Irrigation Systems
Sana'a	1,211	109
Dhamar	734	1.4
Amran	848	3
Total	2,793	113.4

Location Background

This research is carried out in Jahran basin in Dhamar governorate. the city of Dhamar is located at 14°33′0″N 44°24′6″E, 2700 m above sea level, 100km south of Sana'a. Jahran district is situated near the central of Dhamar Governorate as shown in figure (1).
The south-west of the study area is connected more closely to the central highlands of Yemen and receives slightly more rainfall than the north-eastern part of the study area. The average annual rainfall for 2010 is 395 mm for Dhamar. The rainfall variability is bi-modal. June is a dry month in between two consecutive periods of rain. In 2006 the amount of rain is estimated to be 448 mm. The difference between both years is quite large (12%). The first rainfall period (March, April, May) yielded more rainfall in 2010 than in 2006, but the second rainfall period (July, August, September) as well as the end of the year were drier in 2010 than in 2006.

A satellite imagery analysis carried out by Water Watch and Hydro Yemen found that a large proportion (80%) of agricultural land in Dhamar is not-cropped. Of the land under cultivation approximately 2/3 is used to grow irrigated single season crops which estimated at a total area of 18,694 ha. Also, a study carried out as part of the GSCP found that the total groundwater abstraction is estimated of (204 mcm/yr), out of which an amount of 185 mcm is withdrawn for single season crops as shown table (3) (GSCP 2012).

Table (3): Total irrigation supply to the land use classes in Dhamar.

	Area	Actual Evapo-transpiration	Incremental ET	Gross irrigation supply [mcm/yr]		
	[hectare]	[mm/year]	[mm/year]	Surface	Ground	Total
Total study area	143 810			30	204	233
Non-cropped	116102	630				
Rainfed	7 573	316				
Irrigated						
Single Season	18 694	922	606	28	185	214
Double Season	923	1 079	763	1	12	13
Perennial	518	1 174	858	1	6	7

Jahran basin is considered as the biggest basin in Dhamar governorate with an area of 195km^2 (19500ha) and a groundwater table varying at a depth of 400-1000m with average annual declining rate of (3m).

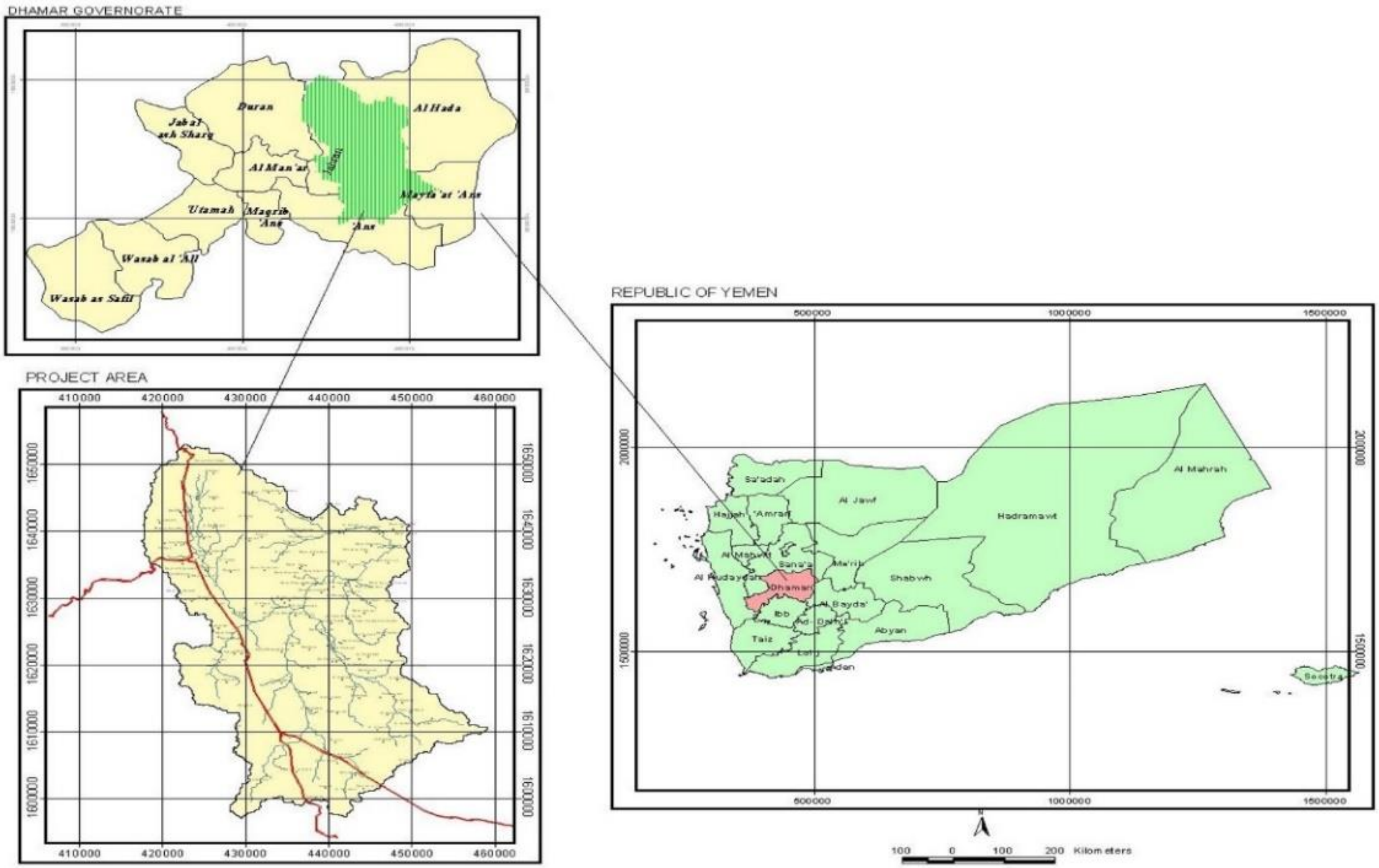

Fig (1): Location of Dhamar and Jahran in Yemen

Jahran basin represents 45% of the total area of Dhamar basin. It contains about 70% of total capacity of Dhamar groundwater aquifer storage from which the annual groundwater abstraction is estimated of 181.38 mcm with annual groundwater recharge of 86 mcm which mean that the deficit is equal to (113.38 mcm) annually, which be compensated from Dhamar aquifer strategic reserves of groundwater (NIP 2009).

Groundwater and Soil Conservation project (GSCP) of Yemen estimated average irrigation water requirements for tomatoes and potatoes crops under traditional irrigation systems in Dhamar of (6455 and 7662 m^3/hectare) respectively (GSCP Beneficiaries Book 2012).

As shown in table (4), the annual agricultural statistical book OF Central Statistical Organization (CSO) mentioned that the total cultivated areas in Dhamar by tomatoes and potatoes crops were (2776 and 7992 hectares), where the total yields for both crops were (35314 and 91313 ton) respectively. Thus, the average crop yield for both tomatoes and potatoes crops will equal to (12.72 and 11.42 ton/hectare) respectively (CSO 2013).

Table (4): Areas, yields and average crop production for tomatoes and potatoes in Dhamar.

Crop	Tomatoes	Potatoes
Total Area (hectare)	2776	7992
Total Yield (ton)	35314	91313
Average crop yield (ton/hectare)	12.72118	11.42555

Research Approach

The approach of this research is built upon calculating the amount of groundwater that could be saved by using modern irrigation techniques such as improved conveyance irrigation systems, drip irrigation systems, greenhouses, and mulching techniques. Comparing the obtained results with the traditional furrow irrigation system mostly used in Dhamar depending on its average irrigation water requirement and average crop yield per hectare.

The research was carried out at fields belonging to Jahran farmers who adopted chosen modern agricultural techniques. Monitoring of irrigation water used and crop yield were done depending on farmers experiences in managing their fields and irrigation schedules.

The most two important crops in Dhamar, i.e. tomatoes and potatoes, were determined to be cultivated under experimental treatments as follows and shown in table (5):

1- **Tomatoes under drip irrigation and in greenhouses (DG)**
Under a greenhouse of 42m length, 9m width and a plastic sheet cover of black colour, tomato crop had been planted during summer season. Crop plantation was on furrows of 40.5m length and with a separating distance between furrows of 0.6m. The drip irrigation systems used consisted of polyethylene laterals of 16mm

size and the emitters used were of GR type with a discharge of 4 l/h. The irrigation scheduling meant a daily irrigation duration of 0.31 hour.

2- **Tomatoes under drip irrigation system and plastic mulch (DP)**
In this trial tomatoes were planted during summer season under white plastic mulch. The cultivated area was estimated of 2860m^2, where the crop was planted on furrows with separating distance of 0.8m between each two furrows. The drip irrigation system used consisted of polyethylene laterals of 13mm inside diameter and spanned the entire furrow length. The emitter used was of GR type and 4 l/h discharge. The irrigation scheduling was 0.25 hour of irrigation duration for each operation time every day.

3- **Potatoes crop under drip irrigation system (DI)**
Potato crop was cultivated on open field during summer season. The plantation of potato crop was on furrows with 0.5m spacing length between each two furrows. The drip irrigation system used was of GR type of emitter that of 4 l/h discharge and 16mm size of lateral. The irrigation schedule was to irrigate during 0.3 hour for each operation time and the irrigation interval was one day between every two irrigation operation times.

4- **Potatoes crop under conveyance pipes irrigation system (SI)**
On open field area of 2400m^2, potato crop had been cultivated during summer season. The plantation was on furrows with separating distance of 0.5m. The irrigation system depend on conveyance PE pipe of 0.9m size that conveys the irrigation water from its source until the cultivated area to reduce water losses within the transferring length. The irrigation schedule was an irrigation operation duration of 12 hours each 10 days of interval.

Table (5): Experimental treatments information

Crop	Ag. Technique	Start date	end date	season Duration	Area
				Month	m2
Tomatoes	DG	1-Jun	27-Dec	7	378
	DP	1-Jun	14-Aug	2.5	2860
Potatoes	DI	6-Jan	9-Aug	3	1200
	SI	1-Jun	24-Aug	3	2400

Measurements and calculations

1- Crop production quantity
2- Amount of irrigation water use by each technique per crop/season/unit area
3- Estimated annual GW amounts that could be saved as a reduction in abstraction
4- Effect of groundwater conserved on annual declining rate of groundwater table

Results and Discussions

Data shown in table (6) for tomatoes indicate that under DG treatment that has an area of 378m^2 the amount of irrigation water used (IWU) was 222 m^3 during the season duration of 7 months and produced 10 ton. While, under DP treatment that has an area of 2860m^2 the IWU recorded 632m^3 during the season duration of 2.5 months and produced 6.9 ton.

Table (6): Irrigation water use and crop production results for cultivation of tomatoes under DG and DP treatments

Treatment	Area (m^2)	Season duration (month)	IWU (m^3)	Production (ton)
DG	378	7	222	10
DP	2860	2.5	632	6.9

Data shown in table (7) for potatoes crop indicate that under DI treatment that has an area of 1200m^2 the IWU recorded 599m^3 during the season duration of 3 months and produced 3.6 ton. While, under SI treatment that has an area of 2400m^2 the IWU was 2333m^3 during the season duration of 3 months and produced 6 ton.

Table (7): Irrigation water use and crop production results for cultivation of potatoes under DG and DP treatments

Treatment	Area (m^2)	Season duration (month)	IWU (m^3)	Production (ton)
DI	1200	3	599	3.6
SI	2400	3	2333	6

Impact of applying modern agriculture techniques on crop yield

Discussion of treatment's production results will depend on value of crop yield per square meter comparing with that of average crop yield per hectare in Jahran.

As shown in table (8), crop yield for tomatoes were (10.08 and 6.864 ton) with values per unit area production of (26.67 and 2.4 kg/m^2) under DG and DP systems respectively. These results indicate that DG technique produced higher crop yield more than that of DP, technique taking into account the long season of DG (7 months) comparing with the (3 months) of DP.

Table (8): Tomatoes and potatoes yield under agricultural techniques vs average yield in Dhamar

Crop	IT	Yt		Yav		Y icreasing	
		ton/area	kg/m2	ton/hect	kg/m2	k/m2	times
Tomatoes	DG	10.08126	26.67	12.72118156	1.272118156	25.39788184	20.9650337
	DP	6.864	2.4			1.127881844	1.886617206
Potatoes	DI	3.6	3	11.42555055	1.142555055	1.857444945	2.625694041
	SI	6	2.5			1.357444945	2.188078368

Comparing with average tomatoes yield (Y_{av}) in Jahran (12.721 ton/hectare) which has per unit area value of (1.272 kg/m^2) indicate that tomatoes production per unit area for both (Y_{DG}) and (Y_{DP}) were higher than that of (Y_{av}) with increasing amounts of (25.397 and 1.127 kg/m2) as shown in figure (3).

Regarding results of potatoes treatments (figure 4), (Y_{DI}) technique recorded higher yield per unit area of (3 kg/m2) which was more than that of (Y_{SI}) of (2.5 kg/m2) with an increasing yield of (0.5 kg/m2). Where, both DI and SI techniques realized higher amounts of potatoes yield comparing with that of average potatoes yield (Y_{av}) per unit area (1.1425 kg/m2) in Jahran with increasing yield amounts of (1.857 and 1.357 kg/m2) respectively.

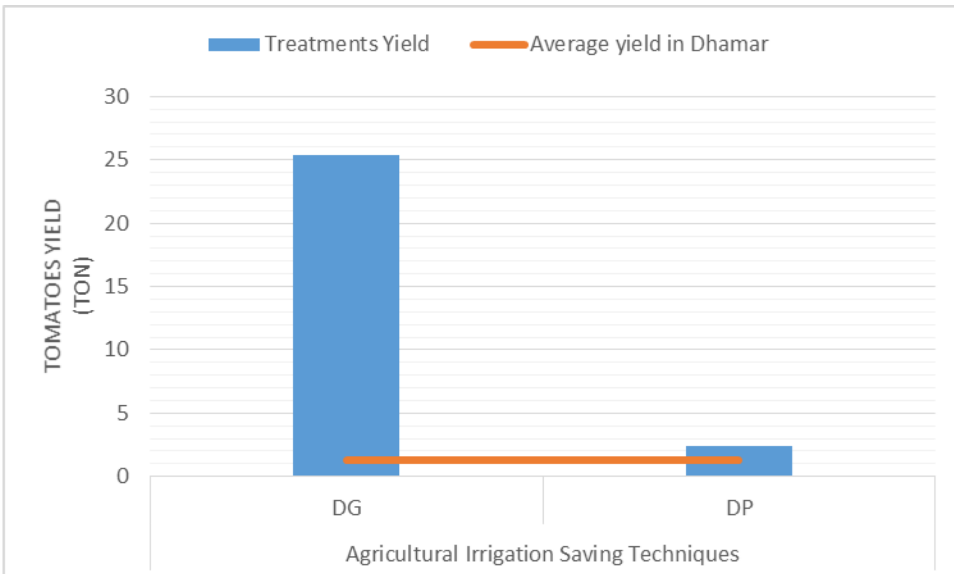

Fig (3): Impact of agricultural irrigation saving techniques on tomatoes yield comparing with average yield in Dhamar per m2

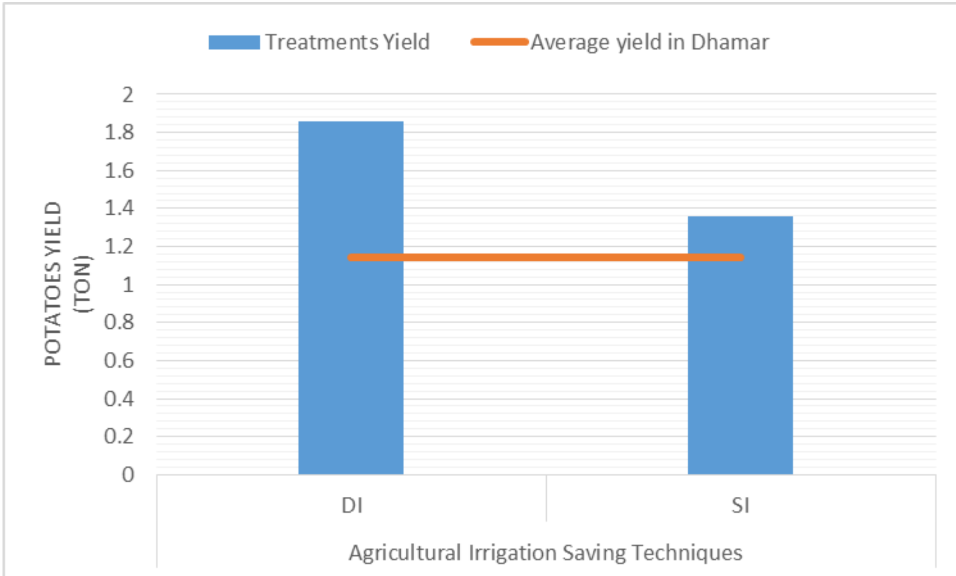

Fig (4): Impact of agricultural irrigation saving techniques on potatoes yield comparing with average yield in Dhamar per m2

Impact of applying modern agricultural techniques on reducing irrigation water requirements

Determine the effect of each treatment on saving of irrigation water requirement will be based on estimating the equivalent value of irrigation water required to produce the same quantity of the crop resulting from each treatment as part of the average irrigation water required to irrigate one hectare, depending on the average crop yield per hectare in Jahran.

1) Estimating the equivalent area A_e that produce the same amount of each treatment crop yield (m^2)

   $Ae = \frac{10000 \times Yact}{Yav}$ (equ.1)

   Where;

   Yact is the actual crop yield produced from each treatment (ton/area of the treatment field)

   Yav is the average crop yield per hectare in Jahran under traditional irrigation system (ton/hectare)

2) Estimating the equivalent irrigation water used IWUe required to irrigate the equivalent area (m^3/Ae)

   $IWUe = \frac{Ae \times IWUa}{10000}$ (equ.2)

   Where;

   IWUa is the average irrigation water required to irrigate one hectare in Jahran (m^3/hectare)

3) Calculating the amount of irrigation water saving IWS (m^3/Ae)

   IWS = IWUe – IWUt (equ.3)

   Where;

   IWUt is the actual irrigation water used to irrigate the area of each treatment At (m^3/At)

4) Calculating the percentage of irrigation water saving IWSp (%)

$$IWSp = \frac{IWS}{IWUe} \times 100 \qquad \text{(equ.4)}$$

Table (9): Equivalent IWR for different agricultural techniques comparing with average IWR in Dhamar

Crop	IT	Yav	Yact	Ae	IWUa	IWUe	IWUt	IWS	IWSp
		ton/area	ton/area	m2	m3/hectare	m3/Ae	m3/At	m3	%
Tomatoes	DG	12.72118	10.08126	7924.78274	6455	5115.447257	221.518	4893.929	95.66963
	DP		6.864	5395.72521		3482.940622	631.8	2851.141	81.86016
Potatoes	DI	11.42555	3.6	3150.83285	7662	2414.168129	599.4	1814.768	75.17157
	SI		6	5251.38808		4023.613549	2332.8	1690.814	42.02227

Depending on the average tomatoes yield (Y_{Tav}) (12.721 ton/hectare) in Jahran and comparing with (Y_{DG}) result of tomatoes yield (10.08 ton), the equivalent portion of standard hectare (A_e) area that could produce the same amount of (Y_{DG}) tomatoes yield is (7924.78 m^2). Using the average irrigation water (IWR_{av}) required to irrigate one hectare of tomatoes under traditional irrigation system in Jahran (6455 m^3/hectare), the equivalent amount required (IWR_e) to irrigate the equivalent portion of standard hectare area (Ae) is (5115.447 m^3) this (IWR_e) value would produce the same amount tomatoes yield resulted from DG treatment. Comparing the last value with actual (IW_{DG}) result the saving amount of (IW_s) that equal to (4893.929 m^3) which represent a saving percentage of (95.669%). Following the same calculating steps resulting the saving amount (2851.141 m^3) and percentage (81.86%) WHEN applying DP irrigation saving technique as shown in figure (5).

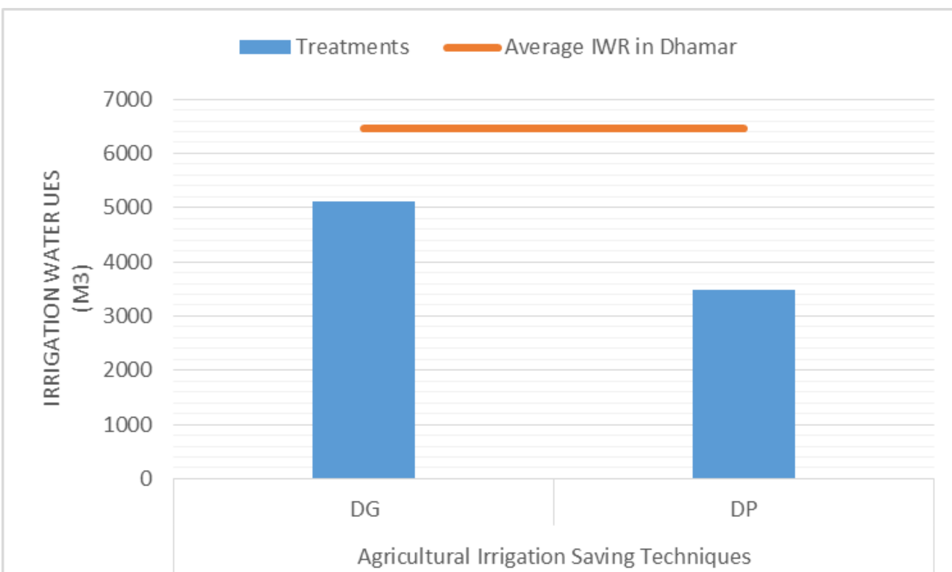

Fig (5): Impact of agricultural techniques on saving IW for tomatoes production comparing with average IWR in Dhamar

Comparing with average potatoes yield (Y_{Pav}) (11.425 ton/hectare) in Jahran, the equivalent area that produce the same amount of (Y_{DI} and Y_{SI}) yield are (3150.83 and

5251.38 m^2) respectively. Both equivalent areas required (2414.68 and 4023.61 m^3) respectively as equivalent irrigation water amount (IWR_e) as a part of average irrigation water required (IWR_{av}) (7662 m^3/hectare) in Jahran. This indicate that the amounts of irrigation water saving (IW_s) are (1814.76 and 1690.81 m^3) with saving percentages of (75.17 and 42.02 %) for both DI and SI treatments respectively as shown in figure (6).

Regarding comparison between irrigation water saving resulted from both crops treatments as shown in (table 9), DG technique realized a percentage of (95.66%) saving in irrigation water which is higher than that of DP technique of (81.86%) with an increasing saving percentage of (13.80%). Where, for potatoes treatments, DI technique has a capacity in saving irrigation water with a percentage of (75.17%) which is higher than that for SI technique of (42.02%) with an increasing percentage of (33.149%).

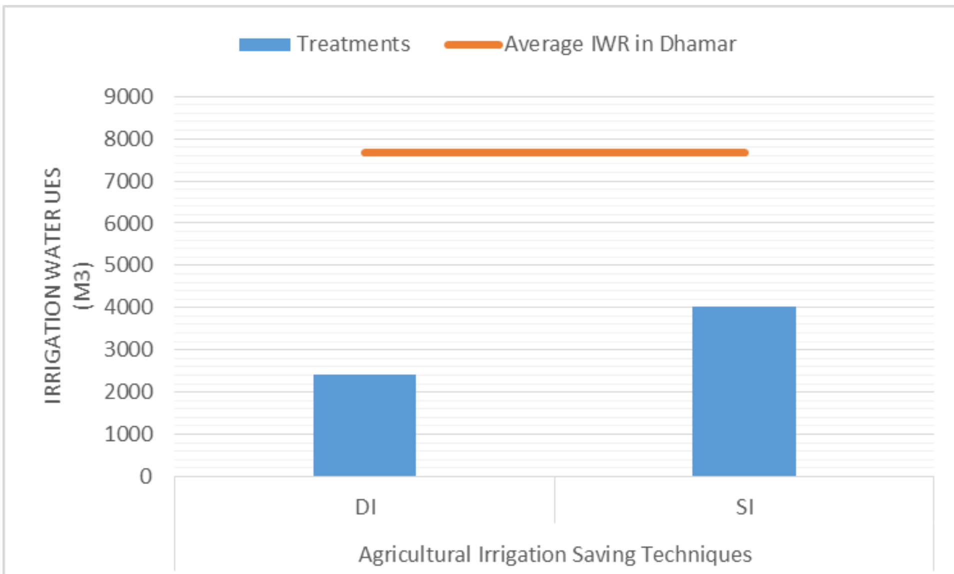

Fig (6): Impact of agricultural techniques on saving IW for potatoes production comparing with average IWR in Dhamar

Impact of applying modern agricultural techniques on Dhamar groundwater aquifer

Depending on total cultivated areas by tomatoes and potatoes (2776 and 7992 hectare) in Dhamar and average IWR for both crops (6455 and 7662 m^3/hectare), the total amount of IWR used annually in Dhamar are (17919080 and 61234704 m^3/annually) i.e. (18 and 61 mcm/year) as shown in (table 10). Regarding results of saving percentages in saving IWR for each sustainable irrigation saving technique, the total amounts of saving in irrigation water will equal to (17.1 or 14.6 mcm) if applying DG or DP for production of tomatoes crop respectively as shown in figure (7). Where, for potatoes crop (figure 8) the amount of saving irrigation water at level of Dhamar basin will equal to (46, or 25.7 mcm) if applying DI or SI irrigation technique respectively.

If the highest irrigation saving techniques for both tomatoes (DG) and potatoes (DI) crop production were applying in Dhamar, the total amount of saving irrigation water will be equal to (63.1 mcm) annually.

Table (10): Saving in groundwater abstracted from applying different agricultural techniques to produce same annual yield of tomatoes and potatoes in Dhamar.

Crop	IT	TA	IWUav	T IWUh	IWSt	T IWS
		hectare	m3/hect	m3	%	m3
Tomatoes	DG	2776	6455	17919080	95.66963	17143117
	DP				81.86016	14668587
Potatoes	DI	7992	7662	61234704	75.17157	46031090
	SI				42.02227	25732210

In addition to benefit of chosen DG technique in saving irrigation water, it benefits will cover also large areas of cultivated land that could be used to cultivate other crops and enrich the cropping pattern of Dhamar agricultural production. As area of DG greenhouse used in the experimental treatment was (378 m^2) which represent (3.78%) of standard hectare area, a total area of (2671 hectare) of agriculture land will be available for cultivation of other crops, where only (104.9 hectare) will be able to produce the actual Dhamar annual production of tomatoes crop using drip irrigation under greenhouses (DG).

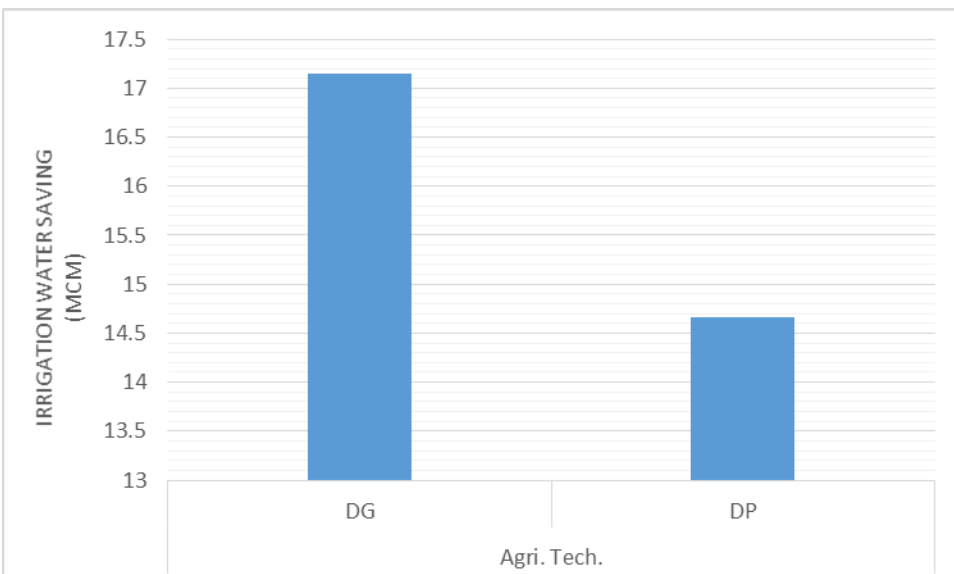

Fig (7): Impact of agricultural techniques on saving IW used at level of total tomatoes areas in Dhamar

Supposing that the strategic target is to depend on the most effective modern irrigation techniques for producing the actual annual crop yields of tomatoes and potatoes in Dhamar. Therefore, DG irrigation technique would be chosen for production of tomatoes crop and DI technique would be selected for production of potatoes crop. The ensemble reduction in IWR of both DG plus DI when applying to produce actual annual average yield is estimated of (63.17 mcm), where, the actual groundwater abstraction in Dhamar is estimated of (181,38 mcm). Thus the annual groundwater abstraction will equal to (118.21 mcm) with a reduction percentages is (34.83%) of total annual groundwater abstraction from Dhamar basin as indicated in table (11) and shown in figure (9).

Table (11): Reduction in annual groundwater abstraction (mcm) when applying both DG and DI techniques to produce both crops annual yield in Dhamar

Ensemble reduction in GW abstraction from depending on DG+DI	Actual GW abstraction In Dhamar	Annual GW abstraction after applying DG+DI
63.17420631	181.38	118.2058

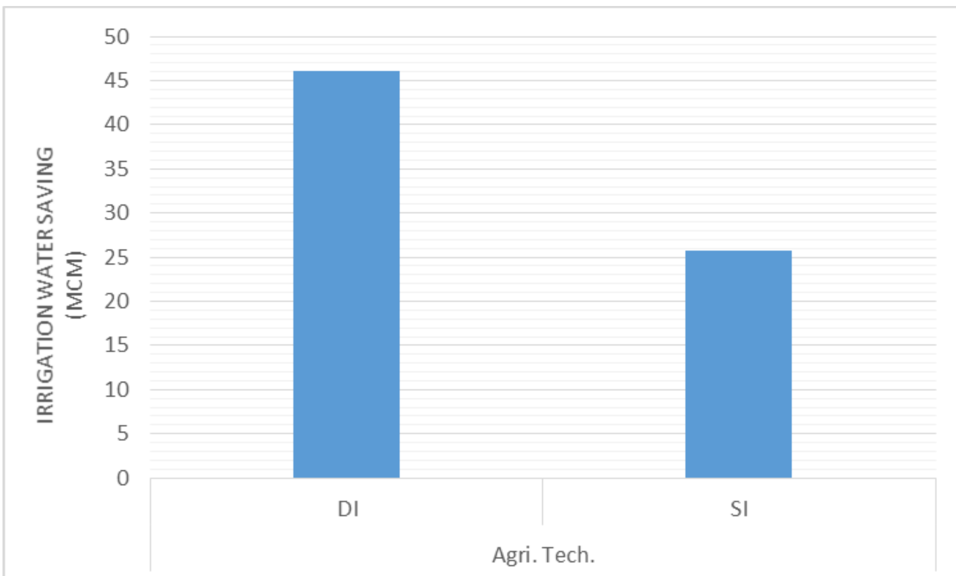

Fig (8): Impact of agricultural techniques on saving IW used at level of total potatoes areas in Dhamar

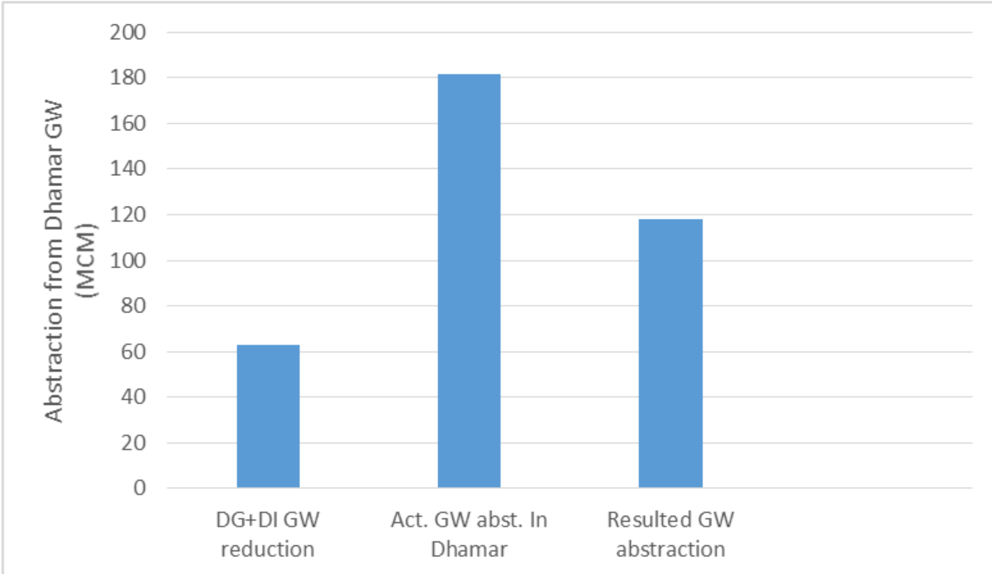

Fig (9): Estimating of the reduction in GW abstraction when applying DG+DI for tomatoes and potatoes to produce actual both yield in Dhamar

Conclusion

Results of the experimental treatments indicate that:

1. The actual irrigation efficiency applied in Dhamar that depend on traditional surface irrigation systems is so low which results in excessively consume groundwater. That is clear when compared between average IWR required for cultivation tomatoes and potatoes with that for irrigation saving techniques were under study in the research.
2. As NIP reported (2012) that only (734 hectare) from (3114 hectare) were covered by irrigation conveyance pipes and (1.4 hectare) from (380 hectare) were covered by drip irrigation systems during four years (from 2009 to 2012). It is clear that there is slowly movement in increasing coverage areas by modern agricultural techniques. In addition, it seem that governmental efforts concentrate on spreading both drip irrigation systems and conveyance pipes, where greenhouse and mulching techniques take lower place of interest.
3. DG technique recorded the highest saving percentage in IWR for production of tomatoes comparing with DP technique by (13.8%) and by (95.66%) when comparing with average IWR using traditional irrigation in Dhamar. Where DP technique was higher by (81.86%) than average IWR using traditional irrigation system in Dhamar.
4. DG technique increased per square meter tomatoes yield by (20.97 times) comparing with that for average yield of tomatoes under traditional irrigation in Dhamar. On the other side, DP increased per square meter tomatoes yield by (1.88 time) comparing with average tomatoes yield per unit area (m^2) in Dhamar.
5. DI technique recorded the highest saving percentage in IWR for production of potatoes comparing with SI by (33.15%) and by (75.17%) when comparing with average IWR using traditional irrigation system Dhamar. Where SI IWR saving

was higher by (42.02%) than that of average IWR using traditional irrigation system in Dhamar.

6. DI techniques augmented per square meter potatoes yield by (2.62 times) comparing with that of average potatoes yield in Dhamar. Where SI increased per unit area (m^2) potatoes yield by (2.18 times) comparing with that for average potatoes yield in Dhamar.
7. When depending on DG plus DI for producing their actual average annual yields, the predicted reduction in GW abstraction from Dhamar aquifer is estimated of (63.17 mcm) which represent saving percentages (34.83%) from total annual groundwater abstraction from Dhamar aquifer.

Recommendations

1. The low efficiency of actual irrigation methods applied in Dhamar need to be improved to control abstraction from groundwater and reduce its annual declining rate.
2. There is a highly request to investigate the reasons that constrain the movement towards increasing coverage areas with modern irrigation systems, from the water governmental sectors side as from agricultural water users sides, and at two levels the planning one and the implementation one.
3. As in combination application of greenhouse and mulching techniques with drip irrigation system proved their effectiveness in sustaining groundwater resources, it is extremely requested to put greenhouse and mulching techniques at the same level of interest in developing agricultural strategic and action plans.
4. Tackling from success of modern agricultural irrigation water saving techniques in increasing crop yields, awareness and mobilization plans should dedicated to water users using on results of this research by governmental water sectors in meaner to enhance their local groundwater management experiences.
5. The high impact of greenhouse with drip irrigation technique in both reducing IWR and increase tomatoes yield give an advantage for agricultural planner to depend mainly on it to guarantee the actual average tomatoes yield in Dhamar using the lowest irrigation water requirement.
6. There is a need for more research studies to cover the request for modification cropping pattern from water conservation vision in condition that aid in enclosing the food gab at level of Dhamar governorate.

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