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Research Article

Environmental and economic returns for the development and management of innovations in modern irrigation systems in Egypt

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Abstract

The pottery irrigation system is an ancient method to transport water drops slowly during porous pottery pitches, and it is filled manually. It is used in many countries and called with many names such as pitches, olla, clay, pours and ceramic irrigation systems. The present study aimed to analyze environmental and economic returns for developing and managing innovations in modern irrigation systems during the winter seasons (2020 and 2021) in AlSharqia, Egypt. Garlic was planted in one hectare under two irrigation systems, 1) The drippers were belt-in, the flow was 4 liter per second, with a operating pressure of 1 bar and two drippers in one meter on the hose, dripper known in Egypt as (Gr), used in the experiment as a surface drip (SD) and sub-surface drip (SSD) irrigation system, 2) The Innovative Follicular Drippers (IFD) had ultra-low flow (0.1 l/h and 0.2 low-head operating pressure), three IFD in one meter on the hose. The plant row had three hoses located under the soil surface by 20 cm. The soil texture was sandy loam and water salinity was 400 ppm. Soil, water, and yield measurements were conducted using more than applied energy analysis and economic feasibility. The results showed that water savings by using IFD were 45%. The highest yields were 21.6, 15.8, and 11.7 tons/ha for IFD, SD, and SSD, respectively. The highest water productivity was 8.4, 3.4 and 2.5 kg.m-3 for IFD, SD and SSD, respectively. Green house gases (GHG) of IFD system were lower than SD and SSD by 67%. Where the novelty and utility of IFD is the collecting of the feature of irrigation net and pottery media in one system, where the IFD irrigation is controlled like common drip irrigation and pottery media did not required to refill by water manuuly follow-stop.

Keywords: Climate changes, Dripper, Economic, Ecosystem, Energy, Garlic, Green house gases GHG, Innovation, water

INTRODUCTION

Pitcher irrigation system is economical and familiar. The natural pores in the pots allow the water to spread into the soil, creating moisture for crop growth. The pots were filled as and when required, thus maintaining a continuous water supply to the plants (Adhikary *et al.*, 2020).

Both mulching and pitcher pot irrigation system saves around 50–70 % of water compare than traditional methods of irrigation (Reddy *et al.* 2021).

The most essential factor in the agricultural development is the irrigation. More than 80% of obtainable water resources in the world, including India, are presently being used for irrigation (Bhalage *et al.*, 2015). The significantly decreasing minimum compensating inlet pressure (MCIP) of pressure-compensating emitters reduces the pump capacity and power requirement, leading to lower capital and operational costs for the pump (Sokol *et al.*, 2019 and El-Hagarey *et al.* 2015).

Saving water and nutrients in sandy soil is conducted by saving about 40% from irrigation-applied water and gaining better quantity and yield quality, increasing revenues under good management and using ultra-low flow drip (El-Sayed and El-Hagarey, 2015). Pottery dripper is innovative for saline water where water salinity is lower by 750 ppm. PD is suitable for using saline water. This investigation underscores the advantages of pottery media and irrigation systems for transporting water to plants. An innovative pottery dripper is used as a small filter. Pottery porosity is a main factor for the reduction of water salinity and flow (El-Hagarey 2015).

Pitcher irrigation is a conventional irrigation system and is considered several times more efficient than a traditional surface irrigation system. This type of irrigation is common in arid and semi-arid areas with acute water scarcity and extreme temperature; water and soil salinity challenges must be resolved (Bainbridge, 2001). Clay irrigation can provide available water directly in the root zones. In the root zones, infiltrated water accumulates with the maximum diameter and depth of the dripper wetting front, less than 60 cm and 40 cm, respectively, when the pitcher permeability is lower than the surrounding soil. Pitcher controls an infiltration rate at this case, Different depths of pitcher placement. (Mondal, 1974). water moves slowly with low flow into the plant root zones to produce partly wetted soil using clay pitcher irrigation system is a local irrigation system where (Stein, 1990), two types of pitcher which has two different saturated hydraulic conductivity of 3.9×10^{-7} and 3.6×10^{-4} cm per second (Stein 1994). Buried clay pot irrigation is cost-effective (Vasudevan *et al.* 2007). To irrigate tomatoes and chillies, Irrigation methods have been enhanced to reduce water loss due to high evaporation gain and increase water use efficiency using pitcher irrigation (Setiawan *et al.*, 1998; Setiawan, 2000).

The new irrigation and water management technologies have saved time, water, and money, with a potential net return of increased yields from the water. This is because the optimum moisture distribution improved the water use efficiency (Mengjie *et al.*, 2023). Garlic (*Allium sativum* L.) is a highland cultivated vegetable with high economic value. It is the 14th-ranked vegetable crop worldwide (FAO, 2016). The present study aimed to determine environmental and economic returns for developing and managing innovations in modern irrigation systems.

MATERIALS AND METHODS

The drip systems field evaluation trials were conducted in two successful seasons, from 1 September to 10 March (2020 and 2021), in Bilbeis restricted, Al-Sharqia government, Egypt. Garlics (*Allium sativum L.*) were planted in a hectare, the space of cultivation was 7 (plants) x 50 (rows) cm, used two irrigation systems, surface and subsurface drip irrigation system (SD and SSD), belt-in dripper known Gr in Egypt . The flow of water was 4 liter/second, with the operating pressure of 1 bar and 2 drippers per meter on the hose. For the plant row, there were two Gr hoses on surface. The last system was the control treatment; the second was the Innovative Follicular Drippers (IFD), which was innovated from maturing follicular earth material and engineering design and tested in the hydraulics lab. The ultra-low flow was 0.1 $l.h^{-1}$, and 0.2 low-head, and the space between drippers was 30 cm. (Fig. 1). there were three hoses all-round for the plant row. IFD was located under the soil surface (20 cm). Soil texture was Sandy loam and the water source was Ismailia Canal (Salinity of water: 400 ppm). In addition to the applied energy analysis and economic feasibility, soil, yield, and water measurements were taken. The statistical design of experiments was completely random blocks.

Fig. 1. *Innovative follicular dripper (IFD), 2 l/h and 2 M operating head for IFD drip irrigation systems*

Fertilization scheme

Amounts and doses of fertilizers were applied according to the Extension bulletins of Field Crop Institute, Agricultural Research Center (ARC) Egypt, Ministry of Agricultural and Land Reclamation for garlic plant, 300-400 kg of superphosphate with the addition of 50 kg of potassium sulphate 48% during service, in addition to 150 kg of nitrogen fertilizer in doses every three days.

Irrigation system

The irrigation system consisted of the following components:

Control head

Control head unit consisted of a centrifugal pump 5/5 inches, 2 bar, 80 m^3/h discharge, diesel engine, 50 hp, control valves, pressure gauges and inflow gauges. The source was an aquifer water, drip irrigation systems, surface and subsurface drip irrigation system (SD and SSD), belt-in cylinder dripper (Gr), the dripper flow is 4 l/s, 1 bar pressure and two drippers per one meter on the hose, there were two Gr (control treatment) hoses all-round the garlic plant row on the soil surface. And other system was the Innovative Follicular Drippers (IFD), which innovated from follicular earth material and was exposed to engineering designing tests in the hydraulics Lab. The ultra-low flow was 0.1 l/h, 0.2 low-head pressure, and three drippers in meter on hose. All -round the plant row, there were three hoses.

Water irrigation requirements:

Garlic irrigation water requirements were calculated with Belbeis weather station. Irrigation operating was according to tensiometer reading. Irrigation scheduling was done according to, Doorenbos and Pruitt (1977) and Keller and Karmeli (1975).

Where:

IR = Irrigation water requirements, m^3ha^{-1} day^{-1},

Sp = Distance between plants in the same drip line, =0.07 m,

Sl = Distance between drip lines, = 0.5 m,

Kc = Crop factor of garlic, according to FAO, 1984,

Eto = Potential evapotranspiration, mm day^{-1},

A = Area irrigated, m^2,

Interval Irrigation interval (3 days under experimental conditions),

Kr = Reduction factor that depends on ground cover, %,

LR = Leaching requirements, %,

Ea = Application efficiency, %, where 90% drip irrigation,

Measurements and calculations

First economic analysis

Analysis of costs:

The evaluation of drip irrigation systems was conducted by calculating Worth and Xin (1983).

The market price level 2021 for equipment and operating irrigation process was approved to calculate the fixed costs based on one hectare (48m× 200m).

Total annual fixed costs (F)

Analysis of costs:

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The market price level 2021 for equipment and operating irrigation process was approved to calculate the fixed costs based on one hectare (48m× 200m).

Initial costs (IC):

(IC) (LE/ha.) = Price of drip irrigation (LE) * quantity for ha Eq.2

Total annual fixed costs (F):

Fixed costs (one year) ($LE.year^{-1}$) of the irrigation systems were calculated using the relationship:

F = D + I + T Eq.3

Where:

F = Total fixed costs (LE/year),

D = Depreciation rate (LE/year),

I = the interested (LE/year).

T = Taxes and overhead ratios (LE/year) taken 1.5% from initial cost..

Depreciation rate cost was calculated using the relationship:

D = (I.C – D.C) / E.L Eq.4

Interest on initial was calculated as follows:

I = (I.C + D.C) x 0.5 IR Eq.5

Where:

I.C = Initial cost (LE/ha)

D.C = Price after depreciation (LE)

E.L = Expected life (year)

IR = Interest rate per year (taken 14%).

Taxes and overhead ratios equal 1.5 % of initial price.

3– Operating cost (O):

Annual operating cost (LE/year) of the capital investment in the irrigation system was calculated as follows:

O = L + E + (R & M) + IS Eq.6

Where:

O = Operating cost

L = labor cost (LE/year).

E = Energy cost (LE / year).

R & M = Repair and maintenance cost (LE / year).R & M cost taken as 3 % of initial cost.

IS = Lateral installation cost (LE / year).

Where,

total annual cost (LE/year) = F + O ; Eq.7

Irrigation cost of Water units (LE/m^3) and Unit production irrigation cost (LE/kg)

Second Energy analysis

Total (sum) of irrigation system energy inputs

The total energy inputs into the irrigation system were determined annually based on applied water amounts and irrigated area. Seasonal energy was the summation of seasonal fixed installation energy and seasonal operation energy for irrigated crops (Down *et al.*,1986). Seasonal fixed installation energy is required to install the irrigation systems for a useful life of at least some evaluation period divided by the life span year's numbers. The life span was 20 years.

Calculation of total irrigation energy

The total irrigation energy (season) is the summation of both seasonal installation and operating (pumping and maintenance) in addition to human labor energies were computed as follows:

Installation energy (IE)

The energy of installation includes:

(a) The fixed energy (per year) to manufacture a limited number of irrigation materials and computed according to Batty and Keller (1980):

AFE = (ERM+ERC) (NTR) / (ESL) Eq.8

Where:

AFE = fixed energy (year), (MJ kg^{-1} yr^{-1}), Eq.9

ERM = Energy input to manufacture irrigation products from raw materials, MJ kg^{-1},

ERC = Energy input to manufacture irrigation and devices products from recycled materials, MJ kg^{-1},

NTR = Number of times product is replaced over the life span of the irrigation system, and

ESL = Life span of system, years.

The manufacturing energy for irrigation products, (Batty and Keller, I980),

(b) required energy of manufacturing equipment or machinery.

Manufacturing energy, ME used in soil excavation and land reformation, according to (Batty *et al.* 1975)

ME= [Hp,kW ×14.88 MJ/kW+Equip.Wt.×71.2 MJ/ton]×(job hours)/(life span,h) Eq.10

Where:

ME = Manufacture energy, and

Hp = Engine power, kW.

(c) Fuel consumption energy is calculated directly based on 4I.06 MJ liter^{-1}, Batty *et al.* (1975).

(d) Repairs and maintenance energy of the machinery was estimated as 5% energy inputs of machinery, Larson and (Fangmeier, I987).

(e) Human labor energy was estimated according to Kassem (1986):

EHL= CHL/Fc×NL Eq.11

Where:

EHL = Energy of human labor. MJ ha^{-1},

CHL = Energy input coefficient represented the human labor energy, 2.3, MJ man-1h^{-1},

NL = laborers number required for operation, and

Fc = Field capacity, ha h^{-1}.

Energy of operating process (OE)

Operation energy inputs of drip irrigation system, including pumping and maintenance and energies:

Maintenance energy per year of the drip irrigation system was assumed by 3% annual installation energy (Batty *et al.*, I975).

The pumping energy was computed by the next relationship (Israelsen and Hansen, 1962a) and (Batty *et al.*, I975):

PE=K. (A .D .H)/ (Ep.Ei) Eq.12

Where:

PE = Pumping energy, MJ ha^{-1},

K = Conversion factor,

A = Irrigated area, ha,

D = Net water Depth of irrigation requirement, m,

H = Head of pumping, m,

Ep = Efficiency of pumping system , and

Ei = Efficiency of irrigation .

Energy of human labor for system management:

Labor energy for system operation and management was estimated according to Batty *et al.* (I975):

EHL= (t .n .c)/A .NL Eq.13

Where:

EHL = Energy of human labor, MI ha^{-1} yr^{-1},

t = One irrigation Time, h,

n = Irrigation's number per year,

C = Energy input Coefficient means human labor energy, 1.26 MJ man^{-1} h^{-1},

NL = Required laborers number for one irrigation process, and

A = irrigated area, ha.

-Energy inputs of human labor with operation and control of the water were manual labor of water control structures installed means that eligible input energy of less than 0.42 MJ ha^{-1}y^{-1}. (Down *et al.,* 1986).

Total irrigation energy inputs (year) = Energy of installation + operating energy Eq.14

Relative consumed energy (RCE)

Relative consumed energy, RCE,(MJ/kg)= (Total Energy Input (MJ/ha))/(garlic grain yield (kg/ha)) Eq.15

Energy yield productivity, EYP: The annual yields of crops related to annual total irrigation energy inputs were calculated according to (Rao and Malik (1982), and (Canakci *et al.* (2005).

Energy Productivity, EYP,(kgm/MJ)= (garlic grain yields (kgm/Ha))/(Total energy input (MJ/ha)) Eq.16

Pumping energy requirement (Er)

The energy requirement of pumping analyzed based on the cultivated area was 50 hectares, and 4 basic main control valves, so in traditional scheduling of drip irrigation, the one irrigation process was done by starting by opening one valve not more and then the next valve according to irrigation scheduling reached to the fourth one and end irrigation. Where in Ultra low-flow irrigation all the 4 valves were opened together at one irrigation process, for this the irrigation hours of one irrigation process are the same number for both of tow drip irrigation.

Energy requirements (Er) and energy-applied efficiency (EAE) were determined for two drip irrigation systems (Batty *et. al.,* 1975), using the next formula:

Power consumption for pumping water (Bp) was computed as next:

$$Bp = \frac{\mathrm{Q * TDH * Yw}}{\mathrm{E\,i * Ep * 1000}}$$ Eq.17

Where:

Bp = Power consumption of Pumping, hp,

Q = Total system discharge, m^3,

TDH = Total dynamic head, m,

Ei = Efficiency of total system,

Ep = Pump efficiency, and

Yw = Water specific weight (9810 Nm^{-3}).

Pump efficiency (Pe) with diesel engine can be derived from the following relationship:

Pe=((272×TH×SFC))/((L/ML^(-1)×Dr×Df×Dt)) Eq.18

Where:

Pe = Efficiency of Pump, %,

272 = Conversion factor
TH = Total head, (m),
SFC = Specific fuel consumption (0.25 L/kWh),
L/ML = Fuel use (for ML of water pumped), and
Dr, Df, Dt, = De-Rating factors, (0.96, 0.99, 88.2).

A requirement of pumping energy (Er) (kW.h) was computes as next:

Er = Bp× H Eq.19

Where:
H = Irrigation time of season (h).

Efficiency of pumping energy applied (EAE) was computed as next:

EAE= (Total yields (fresh), Kg)/(Energy requirements, KW.h) Eq.20

Net Energy Gain (MJ.ha^{-1}) = Total of both of (Energy Output - Energy Input) (MJ.ha^{-1}) Eq.21

GHG Emissions (tons CO2e) for the season

GHG emission was calculated using the calculator for GHG emission avoidance from renewable electricity, renewable cooling, and renewable heating projects under the Innovation Fund, EU Grants (2021).

RESULTS AND DISCUSSION

First: Economic analysis

Cost analysis

Initial costs

Data clearly showed that the annual fixed costs of IFD system were lower than both SD and SSD by 27%. This difference was due to the initial costs of IFD being lower than traditional drippers by 27%. This reduction in initial costs was because of the reduction in nozzle costs, where the price of one ton of used raw material of IFD (clay + organic matter) was 100 USD, and for traditional drippers (plastic), it reached 1500 USD. In addition, clay was an ecosystem material that did not harm or pollute the environment. Moreover, IFD manufacturing relies on waste processing of agricultural waste by recycling it in the manufacturing process (Fig. 2) .

Operating cost (O)

The operating costs of IFD were lower than SD and SSD systems by 20.7%. This reduction was due to the decreased operating pressure, which reduced pumping energy, and a low-head system was used after the pumping system (Fig. 2).

Total annual cost (LE/year)

Data showed that the annual costs of IFD were lower than SD and SSD by 24.5% because of the reduction of initial and operational costs. And this led to the discovery that the IFD was an economic system more than SD and SSD (Fig.2).

Irrigation cost of water unit (LE/m^3)

Water unit irrigation costs were 0.5, 0.5 and 0.68 LE.kg^{-1} for SD, SSD AND IFD, respectively. As clear the highest value was IFD; for the first glance it seemed as a unwanted result, But it was a very good result because the increasing in value was due to the reduction of water saving to half. For that the value of water unit costs was higher for IFD than others, which used the double amount of applied water (Fig. 3).

Unit production irrigation cost (LE/kg)

Data showed that the highest value of unit production irrigation costs was SSD, SD and IFD respectively, where it was 0.199 for SSD, 0.147 for SD and finally 0.081 (LE.Kg^{-1}) for IFD, because the highest value of yield was 21600, 15820 and 11730 Ton ha^{-1} for IFD, SD and SSD respectively. The increasing yield under IFD was because of a long time of irrigated soil and still in available water phase more time compared with both SD and SSD, because IFD system presented availability of more time for the plant to take the desired water and element (Fig. 3).

The cost feasibility of IFD was due to the shape of the raw material used in IFD manufacturing. Moreover, the water hoses' diameters were reduced from 16 to 8 mm compared with GR hoses, where the commonly used diameter of irrigation tube was 16 mm. This size needs more raw material than the double-size IFD tube, whose diameter is 8 mm and not used in wild-scale drip irrigation but use as connectors between nozzles and common irrigation tube (16mm). Moreover, the Gr drippers, manufactured from polyethene material, in the IFD irrigation system were replaced by pottery media, considered a natural and environmental friend. In addition to, the common operating head of common discharge (4l/h) is 10 M, where the operating head of IFD drippers is 2m (lowhead) with discharge (1l/h) These results agreed with Batchelor (1996) and Loch (2005) who mentioned that whatever the amount of both of raw material of irrigation component and operating head of drippers, that leads to reduce fixed costs and operating costs, Then the total costs will reduce a result of that, and therefore the econmic feasability will be more high. As a result, a new innovative irrigation system IFD (Fig. 3).

Second: Energy analysis

Annual total irrigation energy inputs (ATEI)

The annual total irrigation energy inputs (ATEI) were the sum of yearly installation and operation energy. Moreover, it is related to the cultivated area and the total amounts of applied water, and as shown in the data, the applied water of IFD was lower than that of both SD and SSD systems (Fig. 4 and Table 2).

Installation energy (IE)

Installation energy was the sum of annual fixed energy to manufacture (AFE), machine energy used for land preparation or excavation (ME), energy associated with fuel consumption, energy associated with fuel consumption, and human labor energy(HLE). The data clearly showed that the higher values for installation energy were 1800 MJ.ha^{-1} for SD and SSD and 1558 MJ.ha^{-1} yr^{-1} for IFD. The installation energy saving was 13.4%. This difference is due to the replacement of polyethylene emitters by pottery and the reduction of the diameter of the polyether tube from 16 mm for SD and SSD to 8 mm for the IFD system. The manufacturing energy is the sum of the energy used to manufacture the irrigation net component from (pure) raw material (ERM) and the energy input to manufacture the irrigation net components from recycled materials (ERC), where the sum of both values is a multiple of the number of time the irrigation net component replaced and all values are related to the ecological lifetime. The effect of the expected service life and the number of irrigation hoses replaced is the same for all systems. The influence factors for both (ERM) and (ERC) were a result of the reduction in the diameter of the IFD system's irrigation tubing due to the reduction in the amount of raw and recycled material used to manufacture the irrigation system, with the diameter of the tube of IFD system's tubing being 8 mm compared to 16 mm for the conventional SD and SSD systems.6% of the conventional irrigation hoses, the energy of the buried hoses is not significant as it was generated by labor, so it consumed an insignificant value. The new results of this research were the saving of the applied installation energy, which saves both money and greenhouse gas emissions compared to the traditionally used irrigation hoses, as well as the replacement of the PE emitters of the traditional hoses in SD and SSD systems with clay drippers (Fig. 4).

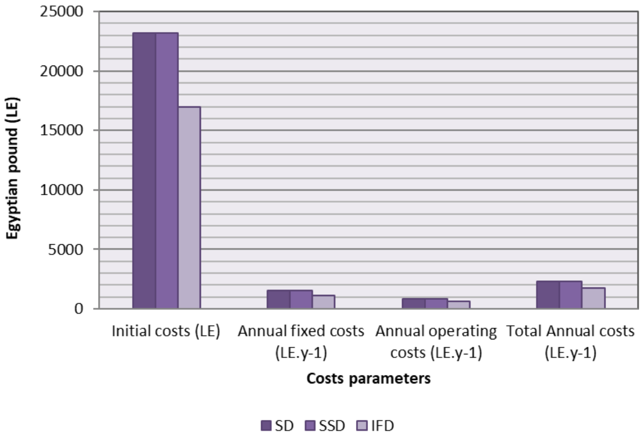

Fig. 2. *Annual costs parameters, initial, fixed, operational and total annual costs of surface drip, SD, subsurface drip, SSD and* Innovative Follicular Drippers*, IFD irrigation systems*

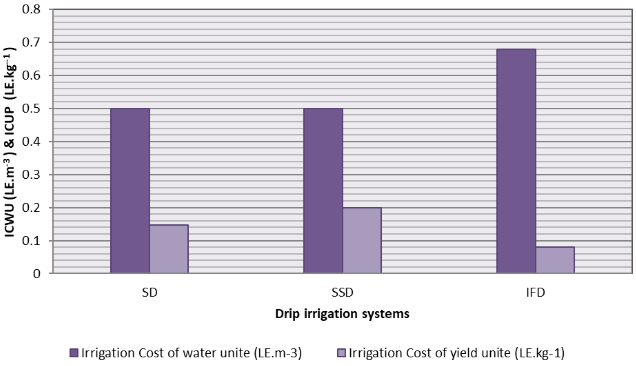

Fig. 3. *Irrigation costs of both the unit of water and yield under various system*

Operation energy (OE)

The operating energy includes the pumping energy, the annual maintenance energy for the irrigation system and the human labor for the operation and management of the irrigation systems. As can be clearly seen, the higher operating energy was 2274.4 MJ.ha^{-1} for both SD and SSD and then 1596.9 MJ.ha^{-1} for IFD systems, with a savings rate of 30%. The saving in operating energy is due to the saving in pump energy. It amounted to 2.5 kW for SD and SSD, 1.1 kW for IFD system as a result of water saving and also head saving which was 0.2 m for IFD and 10 m for SD and SSD. By saving 80% of the head for the IFD system compared to the conventional SD and SSD systems, The saving of operating energy is due to the saving of water volumes, pumping energy and operating pressure, with the IFD system saving 45% of the irrigation water used compared to the SD and SSD systems, for the same reason that 45% of the pumping energy and operating pressure is saved, it is important to note that regardless of the energy saved, the fuel consumption for the energy used is saved. Thus, greenhouse gas emissions are reduced economically and ecologically by saving fuel consumed and energy used compared to the conventional SD and SSD systems (Fig. 4).

Annual total irrigation energy outputs (ATEO)

The energy of raw garlic (digestible energy yield) was 623 kJ per 100 gm, it is also a calorie of garlic. The highest yield of garlic was 21600, 15820 and 11730 Ton.ha^{-1}for IFD, SD and SSD, respectively. The output energy of raw garlic (digestible energy yield), was 13457, 9856 and 7308 MJ.ha^{-1} for IFD, SD and SSD, respectively. The highest value of ATEO of IFD was because of the increased hectare productivity (Fig. 4).

Net Energy Gain (NEG)

The net energy gain equals the difference between output and input energy. So, the highest net energy gains were 10302.1, 5781.6, and 3233.6 MJ.ha^{-1} for IFD, SD, and SSD, respectively. The highest difference

Table 1. Average calculated consumptive use and irrigation requirements of garlic plants for both 2020 and 2021.

Growth stage	Months	ET_o mm day^{-1}	K_c	Et_c mm day^{-1}	I_r m^{3}ha^{-1}
Initial (71)	30 days of September	5	0.7	105	1050
	31 dayes of October	3.9		81.9	819
	10 days of November	2.7		18.9	189
Development (40)	20 days of November	2.7	0.95	51.3	513
	20 days of December	2.1	0.95	39.9	399
Mid (60)	10 days of December	2.1	1.0	21	210
	31 days of January	2.1	1.0	63	630
	20 days of February	2.7		54	540
Late (20)	10 days of February	2.7	0.7	18.9	189
	10 days of March	2.9		20.3	203
Total (I_r) + 10%	5216.25 m^3 ha^{-1}				

value of net energy gain was due to the energy saving of IFD system compared with other drip systems and the increasing garlic productivity of IFD, SD and SSD, respectively (Fig. 4).

Annual total irrigation energy inputs for applying water unite (AIEI)

The annual total energy was the summation of installing and operating energy divided by applied water. Data clear that the highest value of AIEI was 0.9 MJ.M^{-3}yr for both SD and SSD and then the lowest value was for IFD which equals 0.1 MJ.M^{-3}yr (Fig. 4).

Relative consumed energy (RCE)

The relative consumed energy was the ratio of Annual total energy inputs and garlic grain yield, data clear the highest value of RCE was SD, and SSD had equal value and the lowest value was for IFD system as a result of increasing garlic yield per hectare. The highest values of REC were 0.35, 0.26 and 0.15 Mj.kgm^{-1} of SSD, SD and IFD systems, respectively (Fig. 4).

Energy yield productivity (EYP)

The energy yield productivity was the conversion of Relative consumed energy, so the highest value of EYP was 6.8, 3.9 and 2.9 kg .MJ^{-1} of IFD, SD and SSD respectively. The increasing EYP value was because of the increasing garlic yield and the reduction of annual total irrigation energy inputs (Fig. 4).

Pumping requirements (Er)

The pumping requirement was the multiple of both pumping power and the number of irrigation hours, as it is clear in data that both of SD and SSD values were the doubles of IFD according to the reduction of irrigation time operating as a result of the saving of half of the applied water amounts. And it was also because of the reduction of operating pressure of IFD systems.

Energy Applied Efficiency (EAE)

Energy applied efficiency was the ratio of yield and irrigation requirements and reflected the efficiency of energy applied to various irrigation systems. Data show the highest value of EAE was 80.7 35.9 and 26.6 kg kW^{-1}.h^{-1} for IFD, SD and SSD systems, respectively (Fig. 4).

All of the last parameters were the effect of reducing and saving both water and energy. Considering the reduction of energy was caused by many factors, the most important one was water saving, and then the reduction of net hose diameters and the reduction of operating pressure of IFD systems. All of the last results lead the IFD system to emit a low GHG in terms of saving energy.

The energy analysis cleared the saving of applied energy because of the reduction of the operating head of IFD irrigation systems compared with Gr and the reduction of raw materials used in manufacturing irrigation net components. The water applied per season was 4672 m3 for SD and SSD, compared to 2569 m3 for IFD, which means that IFD saves 45% water. The yield is 15820 and 11730 kg/ha for SD and SSD, respectively, while the maximum yield for IFD was 21600 kg/ha. For IFD, the yield increased by 84%, which is due to the water saving and the longer duration of irrigation, which reduces water losses through deep percolation or evaporation due to excessive irrigation and gives the plants more time and opportunity to meet their water needs during the longer duration of irrigation and ultra-low flow of IFD systems.

These results agreed with Kefa *et al.* (2013), where the maize crop grain yields under the clay pot system were higher than that under the furrow system by 32.24%, while the fresh fruit tomato yields were higher in the clay pot system than the furrow system by 43.68%.

GHG emissions (Tons CO2e) for the season

A new report from the UN Climate Change Secretariat provides the next important clarification: countries worked to reduce global greenhouse gas emissions, but this step was not enough to limit the global temperature rise to 1.5°C by the end of the century. The collective climate pledges of the 193 parties to the Par

Table 2. Analytical parameters under surface drip, SD, subsurface drip SSD and Innovative Follicular Drippers (IFD) irrigation systems

Parameters	**SD**	**SSD**	**IFD**
AW (M^{3})	4672.08 ^{a}	4672.08 ^{a}	2569.64 ^{b}
Y(kg)	15820 ^{b}	11730 ^{c}	21600 ^{a}
Bp (kW)	2.5 ^{a}	2.5 ^{a}	1.1 ^{b}
IC (LE) (LE)	23176 ^{a}	23176 ^{a}	16990 ^{b}
AFC (LE y^{-1})	1506 ^{a}	1506 ^{a}	1104 ^{b}
AOC (LE y^{-1})	827 ^{a}	827 a	655 ^{b}
TAC (LE y^{-1})	2334 ^{a}	2334 ^{a}	1760 ^{b}
ICWU (LE.m^{-3})	0.5 ^{b}	0.5 ^{a}	0.68 ^{a}
ICUP (LE.kg^{-1})	0.147 ^{a}	0.199 ^{a}	0.081 ^{b}
CF L/m^{3}	25 ^{a}	25 ^{a}	15.11 ^{b}
TCF L/season	116.8 ^{a}	116.8 ^{a}	38.83 ^{b}
IE (MJ. Ha^{-1})	1800 ^{a}	1800 a	1558 ^{b}
OE (MJ. Ha^{-1})	2274.4 ^{a}	2274.4 ^{a}	1596.9 ^{b}
ATEI (MJ. Ha^{-1})	4074.4 ^{a}	4074.4 ^{a}	3154.9 ^{b}
ATEO (MJ.ha^{-1})	9856 ^{b}	7308 ^{a}	13457 ^{a}
NEG (MJ.ha^{-1})	5781.6 ^{b}	3233.6 ^{c}	10302.1 ^{a}
AIEI (MJ.M^{-3}yr)	0.9 ^{a}	0.9 ^{a}	0.1 ^{b}
Er (kW.h)	441 ^{a}	441 ^{a}	267.6^{b}
EAE (kg kW^{-1}·h^{-1})	35.9 ^{b}	26.6 ^{c}	80.7 ^{a}
Wp (Kg.M^{-3})	3.4 ^{b}	2.5 ^{c}	8.4 ^{a}
RCE (MJ. kgm^{-1})	0.26 ^{b}	0.35 ^{a}	0.15 ^{c}
EYP (kgm .MJ^{-1})	3.9 ^{b}	2.9 ^{c}	6.8 ^{a}
GHG (tons CO$_{2}$e/season	0.313 ^{a}	0.313 ^{a}	0.104 ^{b}

Data on the same row with different superscript (a, b, c,) are significantly different at $p < 0.05$

Abbreviations :

AW M^{3} = Applied water per season,
Y (kg) = Yield of garlic bulb,
Bp (kW) = Break power of pumping,
IC (LE) = Initial costs,
AFC (LE y^{-1}) = Annual fixed costs,
AOC (LE y^{-1}) = Annual operating costs,
TAC (LE y^{-1}) = Total Annual costs ,
ICWU (LE.m^{-3}) = Irrigation Cost of water unite ,
ICUP (LE.kg^{-1}) = Irrigation Cost of yield unite production ,
CF L/m^{3} = Consumed fuel / pumped water ,
TCF L/season = Total Consumed fuel for season,
IE (MJ. Ha^{-1}) = Installation energy,
OE (MJ. Ha^{-1}) = Operation energy,
ATEI (MJ. Ha^{-1}) = annual total irrigation energy inputs,
ATEO (MJ.ha^{-1}) = annual total irrigation energy outputs,
NEG (MJ.ha^{-1}) = Net Energy Gain,
AIEI (MJ.M^{-3}yr) = Annual total irrigation energy inputs for applying water unite,
Er (kW.h) = Energy requirements,
EAE (kg kW^{-1}·h^{-1}) = Energy applied efficiency,
Wp (Kg.M^{-3}) = Water productivity,
RCE (MJ. kgm^{-1}) = Relative consumed energy,
EYP (kgm .MJ^{-1}) = Energy productivity, and
GHG (tons CO$_{2}$e/season = Green House Gas Emissions,

Agreement could bring the world to 2.5°C by the end of the century (UN Climate Change News, 2022).

For the Alsharqia Govrenrate site, the data shows that the IFD system has the lowest value of GHG emissions, tons CO2e for the season, with the lowest value of GHG being 0.104 tons CO2e/season from IFD and 0.313 tons CO2e/season from SD and SSD. In other words, the GHG emissions of the IFD system were 67 lower than those of SD and SSD. The main reasons for the reduction in greenhouse gas emissions are the water savings and the increase in applied energy efficiency. This led to a reduction in the amounts of cumulative diesel fuel-producing CO2 and CO gasses. It is important to mention that CO2 and CO gasses are

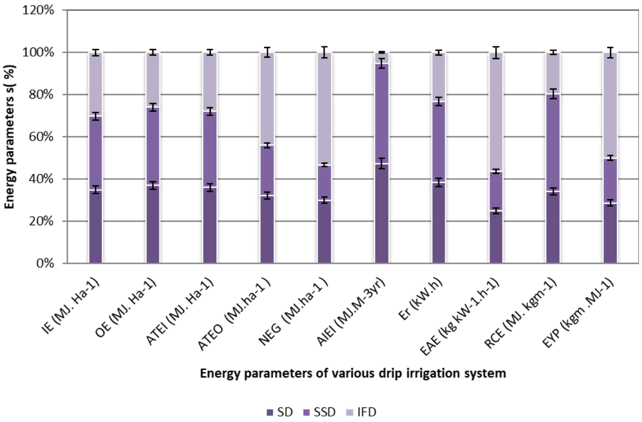

Fig. 4. *Percentage of energy parameters under SD, SSD and IFD irrigation systems*

among the most important factors of man-made greenhouse gasses that increase the earth's temperature. The value was good and must be increased in all GHG areas while promoting innovations such as IFD Fig. (4). The reduction of GHG was due to the decrease in applied energy of IFD compared with SD and SSD irrigation systems and saved applied water. For that, IFD was an ecosystem. These results agree with Landolsi and Miled (2024), who mentioned that the energy intensity and the emission coefficient negatively affect the increase in carbon emissions. They were the main important factors for policy design.

Conclusion

The present study on environmental and economic returns for developing and managing innovations in modern irrigation systems concluded that i) The irrigation water saving by using IFD was 45% and the yield of garlic (*Allium sativum L.*) was 21.6 tons/ha was the maximum as compared to SD and SSD). The water productivity for garlic was IFD, SD and SSD, respectively; ii) The operating energy of IFD was lower than GR dripper by 80% and by the same token, the lowest value of greenhouse gas emission was for IFD than SD and SSD by 67%. Thus, IFD is needed to increase in all GHG fields during support innovation. The innovative follicular drippers system was a very economical ecosystem that saved energy and irrigation water.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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