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Research Article

Modern Drip Irrigation Technology on Tomato and Head Cabbage Production and Its Economic Feasibility at Misrak Silti District, Siltie Zone, Ethiopia

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Abstract

In Ethiopia various techniques were applied to improve on-farm irrigation water management under surface irrigation, especially on furrow irrigation system for last many years, however, it was very difficult to achieve threshold limit of water use efficiency, wisely use of scarce water resources in irrigated field, crop water productivity, precisely controlled application of irrigation water to plant roots, uniform water delivery to all plants, crop yield and its quality, regulate flow, deliver optimum crop water requirement, field water losses, groundwater withdrawal and save labor. It is great practical significance and series of measures using drip irrigation system to solve mentioned problems in irrigated field, because the irrigated agriculture is largest water-consuming sector in this area. This study was aimed to demonstrate drip irrigation technology, prove its economic feasibility and create skills of farmers and extension experts on implementation of the drip system on tomato (Galila 555) and head cabbage (Copen Hagen) productions within groundwater source area on Balo koriso main station in Misrak Silti woreda, Siltie zone, southern Ethiopia. The activity was done for four consecutive years (2019 to 2022 G. C) on fixed plot of 2500 square meter area in collaboration with Agricultural Research Institute and Techno serve project. During demonstration all the costs were considered to economic feasibility including initial investment cost. The study found that the use of drip irrigation saved 3690 m^3/ha of water compared with use of furrow irrigation. This saved water may irrigate additional 2ha area of land by drip irrigation. This study also revealed that, a net income of 313066.04 ETB/ha in single irrigation season was obtained using modern drip irrigation technology. The farmers and local experts recognized noticeable saving water, fuel cost, irrigating time and labour, good crop performance from demonstrated drip irrigation system and shown interest to use the technology abundantly. Therefore, scaling up locally manageable drip irrigation system around the study area through comprehensive training of farmers and supportive staffs and allowing sufficient local market for drip kits and incentives or loan will be economically feasible and affordable to increase income and saves irrigation water.

Keywords

Drip Irrigation Technology, Irrigation Use Efficiency, Economical Feasibility

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1. Introduction

Agriculture under limited water resources cannot be profitable unless advance of water saving technologies which alleviate the risk of water shortage [25]. Furthermore, efficiently use of scarce water resources for irrigation purposes improves crop water use efficiency [9]. Surface irrigation, especially furrow irrigation system is the main irrigation method in Ethiopia. The country practiced various techniques like deficit irrigation, irrigation scheduling and alternative furrow irrigation methods without significant yield reduction to manage field irrigation water under mentioned irrigation system [21, 22]. Despite these efforts were made to manage irrigation water under surface irrigation for long time, still the improvements of irrigation water use efficiency through on-farm management is not satisfactory [20]. This might be happened due to lack of simple scheduling techniques, inaccessibility of soil water monitoring tools, local climate data, irrigation water measurement instruments; water was applied at a uniform level irrespective of the soil, growth stage, and climate and lack of willingness of farmers [23, 24].

The timing and regulating irrigation water and holding the required water level in the root zone is the act of irrigation water management, which increase land and water productivity by ensuring higher irrigation system efficiency [16, 17]. The absence of strictly controlled water management practices, insufficient technical skills, sedimentation of the weir and canal structure resulted poor irrigation system condition [13-15]. Selection of the best irrigation method used to improve on-farm irrigation efficiencies that increase water crop productivity within available area and water [12]. Thus, drip irrigation is one of advance water saving techniques which allows precisely controlled application of water with slow drip near to plant roots through a network of valves, pipes and emitters [11]. It familiarized primarily to minimizes field water losses, save water, increase the water use efficiency, allows uniform water delivery to all plants in agriculture, decrease in labor-intensive hand-irrigating of crops, increase crop productivity, enhance crop quality, save labor, and improve operation and management efficiency [8, 18].

Yang et al., 2023 revealed that, in the case of water shortage, drip irrigation can save water, increases crop yield by 28.92%, 14.55%, 8.03%, 2.32%, and 5.17% relative to flooding irrigation, border irrigation, furrow irrigation, sprinkler irrigation, and micro-sprinkler irrigation, respectively [10]. Also this study quoted that, it improves crop yields and water use efficiency, reduce freshwater resources scarcity, and decrease fertilizer leaching. The study conducted by Fan, 2022 concluded that, drip irrigation was the most effective water-saving technique for pepper production [5]. Lian et al., 2021 investigated that, drip irrigation had advantage to reduce the use of volume of irrigation water by 39.49% and 61.89% and improves irrigation water productivity by 25.37% and 77.16% over the sprinkler and border irrigation respectively [7]. The study carried out on effect of drip and furrow irrigation on water use efficiency and economics of maize crop by Fikadu and Teshome, 2021 revealed that, the use of drip irrigation has the significant grain yield, yield parameter and water use efficiency than furrow irrigation [18]. Berbel et al. 2018 also quoted that, it has become inevitable to use modern irrigation practices in agriculture, especially in horticultural crops to obtain higher yields of good quality products and to earn good revenue by the farmers. The study on effect of drip and furrow irrigation on onion yield and water use efficiency conducted by Teferi, 2015 found that, the use of drip irrigation practices even with deficit irrigation (100%, 80% and 60% ETc) had significant yield advantage, irrigation water saved to irrigate additional area and better water use efficiency over the use of furrow irrigation practices with full ETc (100%) [19]. Thus, use of drip irrigation helps farmers to earn better economic returns as compared to that of furrow irrigation. The use of drip irrigation on wheat production increases crop water productivity by 27.3–29.6% and irrigation water productivity by 37.1–42.0% [6].

In study area still the most popular method of irrigating the crop was conventional furrow irrigation system with inflow of water to the furrow using open field head ditch system. However, there was limitations to regulate flow and deliver optimum crop water requirement through open field ditch, efficient irrigation scheduling, even on-farm water distribution, sufficient irrigation duration, farmers' understanding on how much and when to irrigate which tend to over-irrigate where water is available and leads to conflicts where water shortage area. Furthermore, the groundwater is the most water sources in study area and high amount of groundwater is withdrawal during irrigation season. In this context, it is great practical significance using drip irrigation system in this area. Because, there is the scarcity of freshwater due to the population increasing and climate change. Hence, the largest water-consuming sector of irrigated agriculture has taken a series of measures termed as drip irrigation schemes to reduce evaporation and/or application losses, decrease excessive groundwater withdraw, manage water scarcity and optimize water productivity of the unit irrigated area [9]. Therefore, this study was aimed to demonstrate drip irrigation technology, prove its economic feasibility and create skills of farmers and extension experts on implementation of the drip irrigation system in Misrak Silti woreda, Siltie zone, southern Ethiopia.

2. Methodology

2.1. Description of Study Area

The study area is located at Misrak Silti district in Siltie zone, central Ethiopia. The experimental site was geographically located in 7.98°N latitude and 38.36°E longitude with an altitude of 1828 m above sea level. The area has usually bimodal rainfall conditions (Belg and meher season) with the first phase usually starting in March and the second phase of the rainfall begins in June. The main irrigation season is start in begging of October until the end of February.

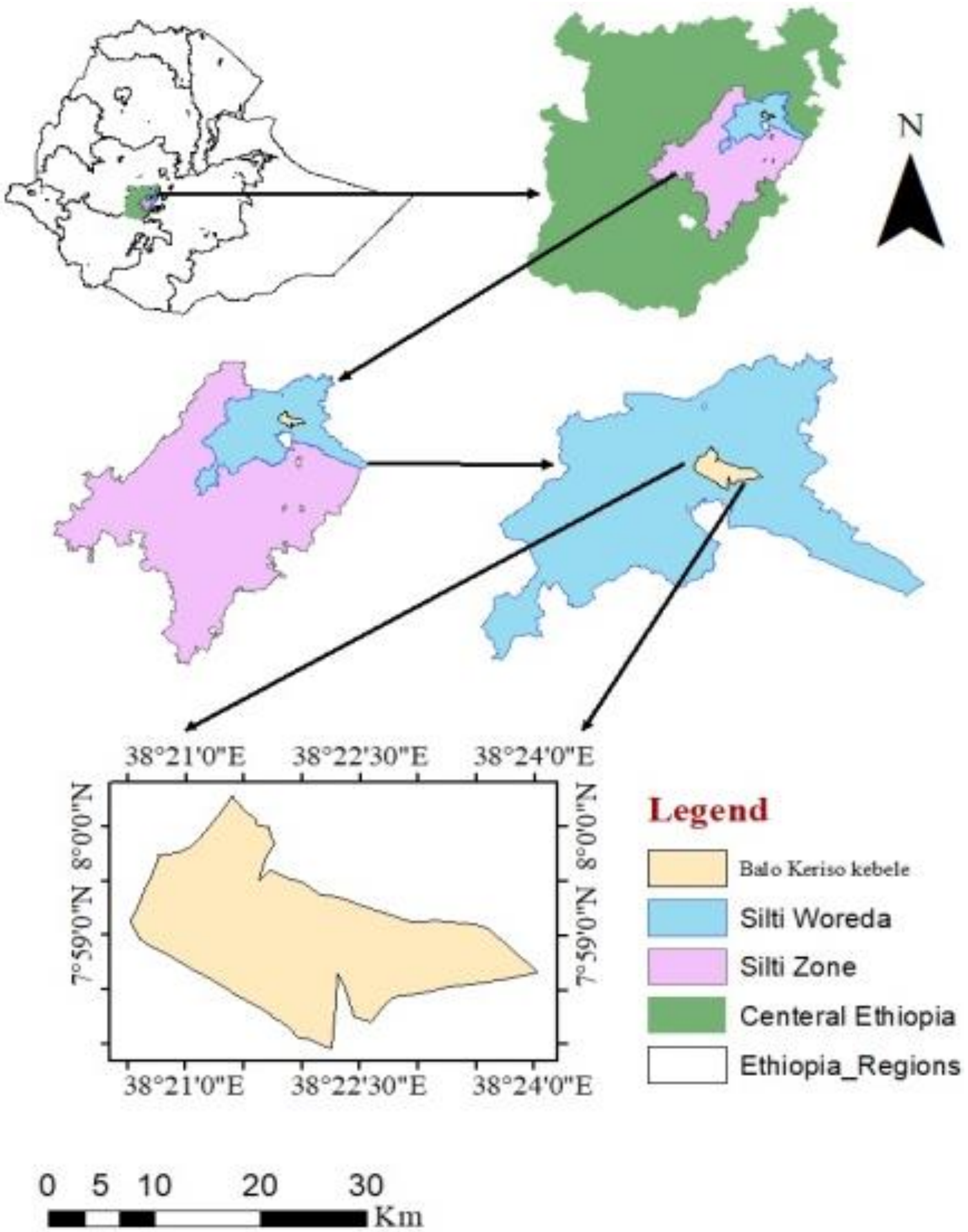

Figure 1. *Location map of the study areas.*

2.2. Framework of the Study

The study was undertaken based on research gap through technical procedures on the field level and interpreted considering the results collected from field level (Figures 2 and 3).

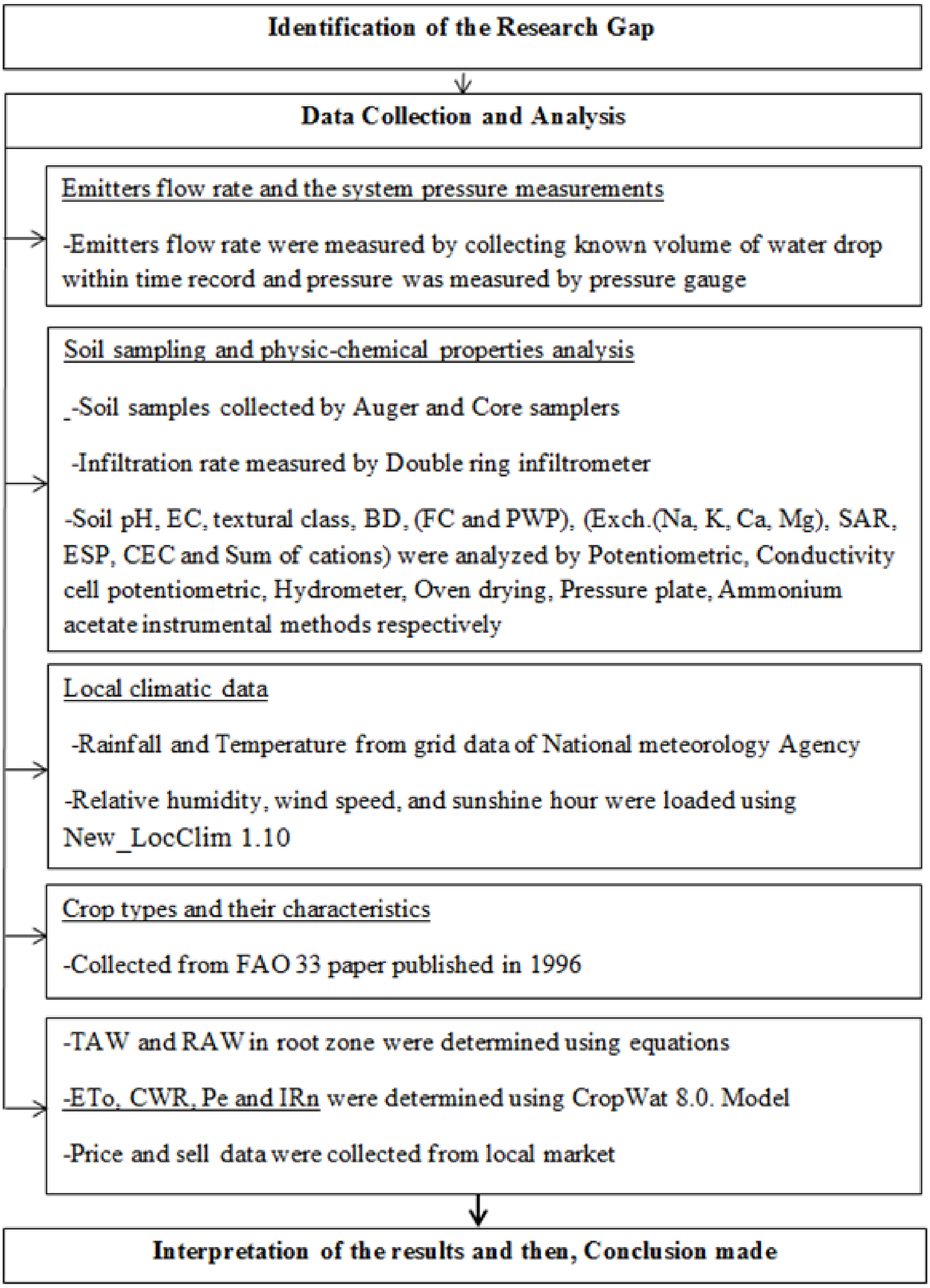

Figure 2. *Flow chart showing research methodology.*

2.3. Installation of the Drip System

The hand dug borehole was drilled and screed by cylinder as sources of irrigation water in the demonstration site. Then, water harvesting pond was constructed at the head of demonstration plot with its size of 10 meter long, 10 meter wide and 2 meter depth and lined by geo-membrane. The irrigation water was collected in to the constructed pond from borehole one day before each irrigation event. The land of demonstration plot was prepared neatly as easy to prepare beds for laterals and planting. At the head of demonstration plot the drip head system (main pipes, filtration tank, fertigation tank, valves, and connectors) and distribution and laterals pipes on the prepared beds installed. Diesel motor pump was used to pump water from pond to the system at irrigation events and the flow rate was managed by controlling (adjusting) the system power.

Figure 3. *Implemented drip systems on demonstration site.*

Figure 4. *Crop performance on demonstration plot.*

2.4. Demonstration Field Layout and Crop Performance Condition

The total size of the demonstration plot was 50 m*50 m and it was divided into two sub-plots each area of 25 m*50 m (1250 square meter). The head cabbage and tomato crops were demonstrated on sub-plots by rotating simultaneously in each irrigation season. The total of 42 beds was constructed demonstration plots for drip laterals placing and crop planting. Each bed was sized as 70 cm wide, 50 m length, and 40 cm height with 40 cm path way between consecutive beds. The sub-plot selected for head cabbage demonstration in each irrigation season had two laterals with two planting rows per bed because the head cabbage needs narrow spacing between each plant. Whereas the sub-plot selected for tomato had one lateral with one planting row per bed.

However, unexpected challenges were happened in the demonstration plot which means at the tail part of the demonstration plot the soil was partially affected by sodicity. The agronomic and yield data were collected from only health part of the demonstration plot and converted to hectare base to tack the challenges. Therefore, the salinity and sodicity status of the soil from healthy and problematic part of the demonstration plot were analyzed separately.

2.5. Data Collection and Analysis

2.5.1. Agronomic Data

The spacing between plants for tomato and head cabbage were 40 cm and 30 cm, respectively. The seedlings were prepared and transplanted to the main field in each year. NPSB fertilizer and urea were applied 150 kg/ha and 150 kg/ha rate, respectively for two crops equally. For tomato Urea applied at 3 rounds, 40% after 40 days of planting, 40% at flowering and 20 % fruit setting. For head cabbage urea applied in two rounds, 50% urea was applied after 30 days of transplanting and 50% after 60 days of transplanting.

2.5.2. Soil Data

The soil's physico-chemical properties (bulk density, textural class, infiltration rate, FC, PWP, soil pH-H_2O, EC (ms/cm), Exch. Na, K, Ca, Mg (meq/100 gm of soil), SAR, ESP, CEC (meq/100 gm of soil) and Sum of cations) were analyzed in the Arba minch soil laboratory. The pH-H_2O, electrical conductivity, textural class, (Exch.(Na, K, Ca, Mg), SAR, ESP, CEC and Sum of cations) were analyzed by Potentiometric, Conductivity cell potentiometric, Hydrometer, Ammonium acetate instrumental methods respectively. But the infiltration rate was measured at the field level using a double ring infiltrometer having 30 and 60 cm diameters of the inner and outer ring respectively before field operation.

$$BD = \frac{\text{Weight of dry soil (g)}}{\text{The volume of the same soil (cm}^3)} \quad (1)$$

where BD is the soil bulk density (g/cm^3)

$$FC = \frac{\text{Weight of water retained in a known volume of soil}}{\text{Weight of the same volume of dry soil}} \times 100 \quad (2)$$

$$PWP = \frac{\text{Weight of water retained in a known volume of soil}}{\text{Weight of the same volume of dry soil}} \times 100 \quad (3)$$

where FC is field capacity at 1/3 bars pressure and PWP is permanent wilting point at 15 bars.

2.5.3. Climatic Data

The local climatic data like rainfall, maximum and minimum temperature were collected from National Meteorological Service Agency. However, average monthly data for relative humidity, wind speed, and sunshine hour were loaded using New_LocClim 1.10 software.

2.5.4. Crop Data

The crop data for head cabbage and tomato (development stages, crop coefficient, rooting depth, critical depletion level, and yield response factor) were adopted from published papers [2-4].

2.5.5. Determination of Reference Evapotranspiration, Crop and Irrigation Water Requirement

The reference evapotranspiration for each month of irrigation season was computed using Cropwat 8.0 models based on the collected climate data. Crop water requirement over the growing season was determined using Cropwat 8.0 models based on determined reference evapotranspiration, collected soil and crop data [4] by Eq. (4). The model considers modified FAO Penman-Monteith method. Irrigation requirement was calculated using Cropwat 8.0 models by Eq. (5) below. Gross irrigation requirement was computed by adopting a field application efficiency of 90% for drip by Eq. (6). As usually the drip irrigation moist about half of the total area, the half of irrigated area was considered for determination of the volume of irrigation water applied for drip case. However, application efficiency of 60% was used to determine gross irrigation in case of furrow irrigation in order to know the amount of water saved using drip irrigation [2]. The irrigation interval was determined based on the net seasonal and daily irrigation requirement of the crops by Eq. (7). The readily available water at the effective root zone was computed from the total available water and depletion levels of each irrigated crop by Eq. (8). But the total available water at the effective root zone was computed by Eq. (9). The irrigation requirement was computed for tomato and head cabbage separately. However, two crops were irrigated in the same plot. The maximum irrigation requirement was used for field application.

$$ET_c = K_c \times ET_o \quad (4)$$

$$IRn = ETc - pe \quad (5)$$

$$IRg = \frac{IRn}{Ea} \quad (6)$$

$$\text{Irrigation interval (days)} = \frac{IRn}{ETc} \quad (7)$$

$$RAW = TAW \times p \quad (8)$$

$$TAW = 1000(FC - PWP) \times BD \times Dz \quad (9)$$

where: ET_c is crop water requirement (mm/day), K_c is crop coefficient (constant), ET_o is reference evapotranspiration (mm/day), IRn is net irrigation requirement (mm), Pe is effective rainfall (mm), IRg is gross irrigation, Ea is application efficiency of drip irrigation (90%), TAW is total available water (mm), FC is the gravimetric soil moisture content at field capacity (fraction), PWP is the gravimetric soil moisture content at permanent wilting point (fraction), Dz is the effective root zone of a crop (m), BD is bulk density (g/cm^3), RAW is readily available water (mm), and p is critical depletion level for each crop (fraction).

Soil SAR and ESP were measured as a ratio of exchangeable sodium (Na) relative to exchangeable calcium (Ca), exchangeable magnesium (Mg) and exchangeable potassium (K) in the water extract (solution phase) from a saturated soil paste by Eq. (10) and Eq. (11) respectively. When using these formulas for SAR and ESP the cconcentrations of all constituents are expressed in meq/100 g soil.

$$SAR = \text{Exchangeable } \{Na/(Ca + Mg)^{-0.5}\} \quad (10)$$

$$ESP = \text{Exchangeable } \{Na/(Ca + Mg + K + Na)\} \times 100 \quad (11)$$

[http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_exchangeable_sodium_percentage.html]

2.5.6. Yield, Yield Related, It's Price and Sell Data

The yield data such as marketable and non- marketable yield weight were collected for each crop during harvest. Total irrigation water applied, every cost invested (unit price, net income, total income and total cost of each year) including initial investment cost were assessed and recorded. Farmers' perceptions also were collected in each irrigation season. Finally, the data were analyzed using descriptive statistics and total average income of four years result was determined.

3. Results and Discussions

3.1. Soil Physic-Chemical Properties Analysis

The analyzed soil laboratory result indicated that the soil texture is clay type in demonstration plot as indicated in Tables 1. In this study the soil salinity, sodicity or saline-sodicity was classified based on Anthony, 2015 by considering the laboratory soil results [1]. Based on his classification the healthy part of the soil is typical agricultural soil as indicated in the Table 1. However, result also indicated that, the soil is sodic in problematic part of the demonstration plot as indicated in Tables 1. This contains a high level of sodium relative to the other exchangeable cations (i.e. calcium, magnesium and potassium) and it reduced water infiltration to near zero. Thus, addition of gypsum leads to the removal of sodium and allows natural aggregation of particles that eventually, restores good soil structure.

Table 1. *Results of Soil physic-chemical properties Analysis.*

Analyzed Parameters	**Results**	
Profile Code	**Health soil**	**Problematic soil**
pH-H_2O (1: 2.5)	7.47	9.82
EC (ms/cm) (1: 2.5)	0.16	1.01
Sand (%)	26.91	26.9
Clay (%)	42.25	27.69
Silt (%)	30.83	45.41
Textural class	clay	Clay
Exch.Na (meq/100 gm of soil)	1.71	22.51
Exch.K (meq/100 gm of soil)	1.33	1.35
Exch.Ca (meq/100 gm of soil)	27.21	12.55
Exch.Mg (meq/100 gm of soil)	13.36	5.79

Analyzed Parameters	Results	
Profile Code	Health soil	Problematic soil
CEC (meq/100 gm of soil)	50.84	47.7
Sum of cations (meq/100 gm of soil)	43.60	42.21
SAR of the soil water extract	10.9	96.4
ESP (%)	3.9	53.3

3.2. Determination of the Volume of Water Saved by Drip Irrigation System

As indicated Table 2 below, due to its advantage of minimum field irrigation water losses and reduced area moistness the drip irrigation saved 922.5 m^3 per 2500 m^2 area (3690 m^3 per ha) of water over surface irrigation. This saved water irrigates additional 2ha area of land by drip irrigation methods. The study conducted by Thompson, 2016 found that use of the drip irrigation improve the efficiency of water applications and reduce water losses from runoff and deep drainage when compared to furrow irrigation [26]. So, this in line with the finding by Fikadu and Teshome, 2021, concluded that using drip irrigation system on maize production increased water use efficiency by four times than conventional furrow irrigation with 100%ETc application [18]. Drip irrigation has lower weed control, cultivation, laser levelling and irrigation labour expenses.

Table 2. The volume of irrigation water saved by drip irrigation.

Irrigation methods	IRn (mm)	Ea (%)	IRg (mm)	Area (m^2)	Volume of IRg (m^3)	Irrigation water saved (m^3)
Surface irrigation	332.12	60	553.5	2500	1383.75	922.5
Drip irrigation	332.12	90	369	1250	461.25	

IRn is net irrigation requirement, IRg gross irrigation requirement, Ea is field application requirement, Area is area considered to moist by irrigation out of total plot area and Volume of IRg volume of gross irrigation applied in irrigation season.

3.3. Yield and Economic Feasibility Analysis

As indicated in Table 3, the yield obtained for both tomato and head cabbage was decreasing by 20% to 30 % from year to year. This might be due increasing of sodicity effects in the demonstration plot as indicated in soil laboratory result. A net income 313066.04 ETB/ha per one irrigation season was obtained using modern drip irrigation technology as indicated in Table 3. The study conducted by Teferi, 2015 found that, use of drip irrigation saved water to irrigate 0.42 to 1.36 hectare of additional area in which this earns better economic returns as compared to that of furrow irrigation method [19]. However, it needs strong commitment to treat sodicity of the area in order to obtain more net income using this technology instead of furrow irrigation system. The study conducted by Demeke, 2022 argues that, use of drip irrigation for vegetable crop production and areas where water is scarce makes irrigated farm more productive [27]. Thus, policy makers, irrigation administrators, and development practitioners should support the development of drip irrigation in financially and technically.

Farmers' Perception

Farmers' perceptions, attitudes and preferences of low-cost drip irrigation systems were collected through prepared field days including experts from zone, woreda and kebele's development agents. Information was focused on efficiency of water usage, water savings, crop performance, easiness to install and manage the system, reduction in labour-intensive, generate additional income and reduce time-spent irrigating. About 47 stakeholders were participated in field day and training on drip demonstration (30-male farmers, 10-female farmers, 5 zone and woreda experts and 2 Development Agents) were participated in each year. They were visited and learned on feasibility and technical functionalities of whole drip system. The farmers and local experts recognized a noticeable saving water, fuel cost, irrigating time and labour, good crop performance and interest to use the drip irrigation system.

Table 3. *Net income of each year and total net income.*

Demonstrated years	Crops	Yield	Unit Price (birr)	TI (birr/ha)	Cost (birr/ha)	Net Income (ETB/ha)
(1st year)	Tomato (tons/ha)	78.85	11	867350		
	Head cabbage (no.)	50550	8	404400		
	Total			1271750	436300	835450
(2nd year)	Tomato (tons/ha)	21.9	13	284700		
	Head cabbage (no.)	36114	10	361143		
	Total			645843	214100	431743
(3rd year)	Tomato (tons/ha)	25.79	15	386850	192000	194850
(4th year)	Tomato (tons/ha)	25.5	20	509.6		
	Head cabbage (no.)	16138.9	20	322777.6		
	Total			323287.2	220000	103287.2
Average				656932.55	265600	313066.04

4. Conclusion and Recommendation

The use of drip irrigation was saved 922.5 m^3 per 2500 m^2 area (3690 m^3 per ha) of water over surface irrigation and it might irrigate additional 2ha area of land. A net income 313066.04 ETB/ha per one irrigation season was obtained using modern drip irrigation technology. It was concluded that investing on drip irrigation was economically feasible and affordable to increase income and save water. Therefore, scaling up locally manageable drip irrigation system around the study area through comprehensive training of farmers and supportive staffs and allowing sufficient local market for drip kits and incentives or loan will alleviate hunger and generate additional income to farmers and sustain suitability of the irrigable land.

Abbreviations

CEC	Cation Exchangeable Capacity
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
ETc	Crop Evapotranspiration
FAO	Food and Agricultural Organization
SAR	Sodium Association Ratio

Conflicts of Interest

The authors declare no conflicts of interest.

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