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Vjekoslav TANASKOVIK*[1], Veikko SHALIMBA[2]*, Ordan CUKALIEV[1], Simeon AMBUGA[2], Katrin BEYER[3], Sai Trinath SURYADEVARA[4], Svetoslav MALCHEV[5], Jan SIERING[6], Hossein AZADI[7], Stojance NECHKOVSKI[1], Margarita DAVITKOVSKA[1], Zvezda BOGEVSKA[1], Imaneh GOLI[7], Marija VUKELIKJ SHUTOSKA[1]

SUSTAINABLE IRRIGATION TECHNOLOGIES FOR ARID ENVIRONMENTS: A PILOT STUDY ON SLECI IN GEM SQUASH CULTIVATION

SUMMARY

Agriculture in arid and semi-arid regions such as Namibia is highly dependent on groundwater and finding solutions to optimize water use is crucial. Hence, this study aimed to compare the performance of a self-regulating, low-energy, clay-based subsurface irrigation system (SLECI) with surface drip irrigation in gem squash cultivation in terms of crop yield, water use, and irrigation water productivity (IWP). The study was conducted at the Ombe Gast Farm in Namibia from November 2022 to February 2023, using a field experimental design comprising five replicated rows of 40 m for each irrigation treatment. Irrigation water productivity was calculated by the ratio of fresh yield to volume of water used and the data were compared. The results showed a small difference of the gem squash yield when comparing the irrigation techniques. The surface drip irrigation produced 11,256 kg/ha fresh weight yield of gem squash or almost 19 % more than the 9,475 kg/ha recorded under sub-surface SLECI irrigation treatment. The water savings potential during the vegetation period was higher in sub-surface SLECI than the surface drip irrigation. Sub-surface SLECI

[1]Vjekoslav Tanaskovik (corresponding author: vtanaskovic@fznh.ukim.edu.mk), Ordan Cukaliev, Stojance Nechkovski, Margarita Davitkovska, Zvezda Bogevska, Marija Vukelikj Shutoska, University of St. Cyril and Methodius in Skopje, Faculty of Agricultural Sciences and Food, Skopje, NORTH MACEDONIA;
[2]Veikko Shalimba (corresponding author: vshalimba@nust.na), Simeon Ambuga, Namibia University of Science and Technology, Department of Biology, Chemistry and Physics, NAMIBIA;
[3]Katrin Beyer, Ombe Guestfarm and Safari, Okahandja, NAMIBIA;
[4]Sai Trinath Suryadevara, Institute of Polymer and Production Technologies, GERMANY;
[5]Svetoslav Malchev, Fruit Growing Institute – Plovdiv, Agricultural Academy, BULGARIA;
[6]Jan Siering, Robert-Schmidt-Institut, Hochschule Wismar University of Applied Sciences: Technology, Business and Design, GERMANY ;
[7]Hossein Azadi, Imaneh Goli, Department of Geography, Ghent University, BELGIUM.
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consumed only 3,011 m^3/ha water per season, while drip irrigation showed 125 % higher water use or 6,761 m^3/ha. In addition, the results for IWP showed that sub-surface SLECI produced 3.15 kilograms of fresh gem squash yield for every cubic meter of applied water or nearly one time more than treatment with surface drip irrigation treatment. Therefore, agricultural policymakers are advised to facilitate the transition to sustainable agriculture in drylands by promoting and supporting the deployment of low-energy and low-consumption technologies such as SLECI through subsidies, low-interest facilities, and training programs. This will ensure food security and the livelihoods of smallholder farmers in the long term, while preserving groundwater resources.

Keywords: clay-based self-regulating irrigation, surface drip irrigation, crop yield, irrigation water productivity

INTRODUCTION

The efficient use of water resources has become one of the most pressing global priorities, as the demand for freshwater continues to rise due to population growth, urbanization, and agricultural expansion (FAO, 2023). Agriculture, which accounts for nearly 70% of global freshwater withdrawals, is particularly vulnerable to water scarcity, especially in arid and semi-arid regions where irrigation is essential for crop production. The increasing reliance on groundwater has placed considerable pressure on this resource, threatening both agricultural sustainability and rural livelihoods. Therefore, rational irrigation, as well as innovative irrigation technologies are needed to optimize water use efficiency while reducing energy demand and environmental impacts (Abou-Shady *et al.*, 2023; Hu, 2020; Uttamkumar Vyas *et al.*, 2025; Xing and Wang, 2024).

Among these systems, several approaches have gained prominence due to their ability to precisely deliver water, optimize crop performance, and conserve resources under water-limited conditions (Abou-Shady *et al.*, 2023). Precision drip irrigation delivers water directly to the crop root zone, minimizing surface evaporation, runoff, and energy demand, while smart controllers and real-time soil-moisture sensors further improve scheduling efficiency and yield stability (Lakhiar *et al.*, 2024). Sub-surface irrigation systems, which distribute water below the soil surface IoT, have demonstrated significant reductions in water loss and higher irrigation water productivity in arid conditions compared to conventional surface irrigation (Mahler, 2024). Recent trials using IoT-enabled subsurface drip systems have also demonstrated improved canopy cooling, reduced plant stress, and enhanced yield in vegetables under limited-water regimes (Agbesi *et al*., 2025). Sensor-based irrigation scheduling, integrating soil moisture and climatic data, allows irrigation to occur only when required by the crop, thereby improving water-use efficiency and preventing over-irrigation (Xing and Wang, 2024). In parallel, renewable-energy-driven systems offer sustainable solutions for remote or resource-constrained regions by reducing dependence on fossil fuels and providing stable water supply in off-grid areas (Kumar *et al.,* 2015). Collectively, these advancements align with global efforts toward sustainable intensification and climate-smart agriculture, offering a technological pathway that enhances irrigation water productivity, conserves groundwater, and supports food security in arid and semi-arid environments.

The Self-regulating, Low-Energy, Clay-based Irrigation (SLECI) system is another approach that optimize water use efficiency while reducing energy demand and environmental impacts (Chaba *et al.,* 2026; Malchev *et al.,* 2025; Cukaliev *et al*., 2025; Mahler, 2024; Pereira *et al*., 2023). SLECI is a subsurface irrigation technique that relies on the suction force of the soil to regulate water release. It is designed to be simple and low-cost, and adaptable for rural farming contexts while conserving both water and energy. The development of SLECI integrates bio-based materials and products as alternatives, aligning with sustainable circular bio economy principles (Technical Report on SLECI Pilot Sites Installed within the DIVAGRI Project, 2025; Osei *et al*., 2025; Sechube *et al.,* 2023; Malchev *et al.,* 2022;). Unlike conventional drip irrigation, SLECI distributes water through clay drippers, which balance hydraulic pressure and soil suction, maintaining optimal root-zone moisture (Agbesi *et al*., 2025; Elmajetni *et al.*, 2025; Malchev *et al*., 2022).

Turning to vegetable and squash cultivation, sustainable irrigation technologies have gained increasing interest in recent years. In the cultivation of squash (e.g., Summer squash/Gem squash and other related cucurbits) field trials have compared drip versus subsurface systems, deficit irrigation regimes, and the coupling of water–fertiliser management. For example, a study on squash in Egypt compared two drip irrigation methods and found the soil-based depletion method yielded higher water-use efficiency (5.31 kg/m^3) than the reference evapotranspiration-based method (4.33 kg/m^3) (Fayed and Sheta, 2020). Another study by Bello *et al*., (2022) applied bio-organic amendments under arid-land conditions for squash and demonstrated that amendments improved yields and water-use efficiency, though the focus was more on fertilisation than irrigation mechanics. Additionally, research on pumpkin (a close relative) deployed deficit drip irrigation under mulch in arid climate and found that light water deficit improved water-use efficiency (12.47 kg/m^3) without significant yield loss (Li *et al.,* 2022).

Namibia is characterized by semi-dry climatic conditions, highly variable rainfall and prolonged dry periods, which significantly limit stable crop production (Mupambwa *et al.,* 2021). Namibia has very low rainfall compared to the rest of other countries in the southern area of Africa. Due to this climate condition, Namibia is recognized as one of the countries' most vulnerable to the impacts of climate change. There has been a predicted increase in temperature and evaporation, which has resulted in an increased variability of rainfall, aggravating the existing challenges that Namibia faces (Mupambwa *et al.,* 2021; Shiimi *et al.,* 2023). In such environments, irrigation becomes indispensable for food and nutritional security. According to Amwele *et al.,* (2021) the introduction of an irrigation system in Namibian conditions may be sufficient to offset the negative effects of climate change. The Ombe Guestfarm and Safari is nestled in the heart of Namibia, within the red Kalahari sandveld, a dry plateau where farmers rely on irrigation to grow high value vegetables. The average annual rainfall is around 350-400 mm (Mupambwa *et al.*, 2021) followed with often and long dry spells. Maize, onions, pumpkins and gem squash dominate the irrigated area because they fetch good prices and tolerate the sandy, slightly alkaline soils. Groundwater resources are under great pressure to keep crop production through the dry seasons in this region.

Although there have been significant studies on irrigation efficiency and micro-irrigation in arid environments, there remains a theoretical and methodological gap when it comes to novel, low-energy, self-regulating subsurface clay-based irrigation systems (such as the SLECI system) applied to gem squash cultivation in sandveld settings. Methodologically, there is limited published evidence on yield vs water consumption vs irrigation water productivity (kg fresh yield per m^3 water) for gem squash under such systems, and little evidence from Namibia or comparable sandveld contexts. This research, therefore, presents results obtained from open field trial at Ombe Guestfarm and Safari near Okahandja, Namibia, where the sub-surface Self-regulating, Low-Energy, Clay Irrigation technique (SLECI) was introduced in gem squash crop and compared with surface drip irrigation.

The novelty of this study was in testing a self-regulating, low-energy, clay-based subsurface irrigation system (SLECI) under arid sandveld conditions, comparing it against conventional drip irrigation in terms of yield, water consumption and irrigation water productivity. It offers benefit globally by providing empirical data on a low-tech, bio-based irrigation alternative in an arid environment—potentially applicable to other sandveld and semi-arid vegetable production systems, thereby contributing to sustainable intensification and responsible water use in drylands. By generating locally adapted evidence on irrigation efficiency, the research contributes to broader debates on climate-resilient farming and sustainable intensification in Sub-Saharan Africa. Continued research on SLECI across diverse soil types, crops, and management systems will be critical for assessing its scalability and long-term contribution to agricultural water management. Hence, the main aim of the established research was to compare yield and water consumption by the respective technologies, as well as showing effectiveness of every cubic meter converted in the kilogram biomass gem squash. Key research questions include:

(1) How does the fresh weight yield of gem squash under SLECI compare to conventional drip irrigation?

(2) What is the total irrigation water consumption per season under each system?

(3) What is the irrigation water productivity (kg fresh yield per m^3 water) achieved under each system?

(4) Does the SLECI system provide water savings and/or productivity gains that make it a viable alternative in this arid sandveld context?

MATERIAL AND METHODS

The experimental field

The study was conducted with gem squash crop grown in open field during the growing seasons from November 2022 to February 2023, at the Ombe Guestfarm and Safari, Okahandja District, Namibia. The tested treatments were five rows with 40 m long sub-surface SLECI lines compared with five rows with 40 m long drip irrigation lines (simple row design; five replications per irrigation method). SLECI pipelines were installed a few centimeters underground, while drip irrigation lines on a small sand hill (Figure 1). Approximately 100 plants were used for plantation in each row.

Figure 1. Subsurface SLECI and surface drip irrigation installation

Furthermore, Axioma flow meters were installed to measure the water used by the irrigation treatments (Figure 2), while a solar pump was installed for pumping groundwater to the irrigation treatments.

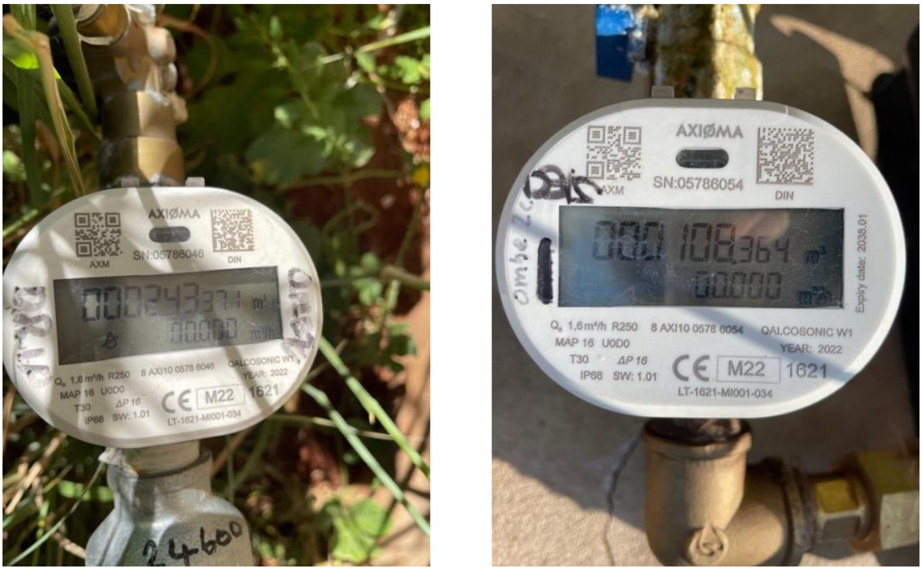

Figure 2. Axioma flow meters in SLECI and surface drip irrigation

The fresh weight yield and water use by gem squash were analyzed during the investigation. In addition, crop water productivity was estimated for each treatment. The effects of irrigation techniques on gem squash yield and IWP were statistically analyzed using ANOVA.

Weather and soil conditions

Weather conditions are very important factor for both crop growth and water demand. Table 1 summarizes the average monthly climate data in the Hochveld, Namibia.

Table 1. Climate data for Hochveld, Namibia

Climate data/Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Average Min. temperature (°C)	18.6	17.1	15.4	12.7	9.9	6.3	5.6	8.1	12.3	16.1	17.7	18.8	13.2
Average Max. temperature (°C)	28.8	27.5	26.3	24.5	22.7	20.3	19.7	23.6	27.5	29.5	29.4	29.3	25.7
Wind (km/h)	10.9	10.1	9.7	10.2	10.3	10.9	12.1	12.5	11.8	12.7	12.2	10.8	11.2
Sunshine (h)	9.6	9.3	9.6	9.6	9.8	9.8	9.7	10.0	9.8	9.5	10.8	10.2	9.8
Relative humidity (%)	42	51	53	49	38	35	35	24	19	20	36	35	36.4
Precipitation (mm)	44	93	42	20	1	0	0	0	2	11	23	58	294

The results showed that average maximum temperatures during the vegetation season varied from 27.5 in February to 29.4 °C in December. Gem squash seeds begin to germinate once soil temperatures rise above 16 °C, with more consistent germination achieved around 20 °C. Optimal growth and fruit production occur between 20 °C and 28 °C (Brodie, 2025). Furthermore, around 75% from total sum of precipitation arrives between the November and February, but still there is deficit of water to supply crop water deficit in the vegetation season in the region. Evapotranspiration between planting and final pick is about 450 mm, which is usually met by a mix of rainfall and irrigation, while the irrigation application needs (local practice) range form 250–300 mm of water per season. Gem squash tolerates mild water deficit once the fruit have set, but strong stress during flowering can cut yields sharply. According to Amer (2011) and El-Dewiny (2011), summer squash is affected significantly by water stress, too much or shortage of soil water content may damage roots and fruits; thus, good drainage of soils is appropriate for squash, reported same authors. Sheta and Fayed (2021) in their research with summer squash and drip irrigation for Egypt condition, reported from 317.67 to 405.24 mm seasonal irrigation water for squash plants. Additionally, the results in Table 1 showed gradually precipitation decreases from March to October, but still followed with warm days and low humidity, which has influence on referent evapotranspiration. According to the literature data (Mendelsohn *et al.*, 2002), average yearly evapotranspiration range up to 2000 mm, while water deficit is around 1300 mm per year.

Chemical and physical properties of the soil from the pilot site are presented in Table 2. According to texture classification (USDA-NRCS, 2025), the soil at pilot site was classified as loamy sand with 84.7 and 86.3 % composition of sand, 12.6 and 11.1 % of silt and 2.7 and 2.68 % of clay at 0-30 and 30-60 cm soil layer. That texture drains quickly after rainfalls or irrigation. Furthermore, the little content of clay explains the low cation-exchange capacity of 5.3 meq/100 g. According to the classification of soil based on the electrical conductivity (EC) classification supplied by Durand (1983), soil at the pilot site was extremely saline, while soil organic matter is less than 1 %, typical for semi-arid soils. The content of available P is low and K is moderate, and there is need for regular fertilization. According to the literature data and farmer practice, the commonly recommended fertilizer programs for pumpkin is 100-150 kg N and P_2O_5 and 100-200 kg K_2O per hectare (Đurovka, 2008). Under Namibian conditions, the recommended fertilization regime for gem squash consists of approximately 213 kg/ha nitrogen (N), 13 kg/ha phosphorus (P), and 166 kg/ha potassium (K) (Namibian Agronomic Board, 2024).

Table 2. Chemical and physical properties of the 0–30 and 30-60 soil layer at Ombe Guestfarm and Safari, Namibia

Chemical characteristics		
Depth	*0 – 30*	*30 – 60*
Reaction (pH in water)	8.5	8.6
Electrical conductivity (ECe dS/m)	15	17
$CaCO_3$%	0.3	0.2
Organic matter %	0.9	0.4
Available P ppm	37	14
Available K ppm	211	165
CEC meq/100g		5.25
Particle size of the soil layer		
Total sand in %	84.7	86.3
Silt in %	12.6	11.1
Clay in %	2.7	2.6

RESULTS AND DISCUSSION

Effect of irrigation on gem squash yield

Fruit weight determines the economic return for growers. Table 3 reported the fresh weight yield of gem squash harvested over three pickings periods in the vegetation season from November 2022 to February 2023. The results showed that fresh weight gem squash yield ranged from 9,475 kg in sub-surface SLECI up to 11,256 kg in surface drip irrigation treatment, or a difference of 1,781 kg. The results were statistically significant at 0.05 level of probability. The higher yield was probably due to better germination of gem squash seeds, which is the result of the higher amount of water provided by drip irrigation at the begging of growing season (Figure 3). Similar results were presented by many other reports (Chaba *et al.*, 2026; Cukaliev *et al.*, 2025; Malchev *et al.*, 2025; Technical Report on SLECI Pilot Sites Installed within the DIVAGRI Project, 2025), where rosemary, lavender and cowpea showed better yielding in drip than in SLECI irrigation treatments, while in tomato and maize SLECI matched or exceeded drip yields up to 78 % to only 7 %. In other research, the highest yield in SLECI system was recorded in bell pepper treatment under a burying depth of 5 cm (Osei *et al.*, 2025). In study with melon, where subsurface irrigation with ceramic emitter's (SICE) was compared with drip irrigation, results shown that SICE significantly improved fruit yield (Han *et al.*, 2025).

Table 3. Average gem squash yield

Treatment	Fresh weight (kg/ha)
SLECI sub-surface irrigation	9,475[b]
Drip surface irrigation	11,256[a]

**Values in rows followed by the same letter are not significantly different at p-value of 0.05 probability level*

Figure 3. Germinated/sprouted gem squash plants in sub-surface SLECI (left) and drip irrigation treatment (right)

First harvest (Figure 4) brought a total of 12,583 kg/ha yield or 4,583 in SLECI vs. 8,000 kg/ha in surface drip irrigation. The surface drip produced 3,417 kg/ha more gem squash yield than the sub-surface SLECI irrigation treatment. Second harvest yielded a total of 4,394 kg/ha gem squash, or 2,556 kg in SLECI vs. 1,839 kg/ha in drip irrigation treatment. In third harvest SLECI, produced 2,336 or 919.4 kg/ha more gem squash than the drip irrigation treatment (1,417 kg/ha). In short, SLECI maintained yield despite a slower start and fewer plants per row, hinting at better water delivery during the hot spells that coincide with fruit fill. These findings resonate with evidence that subsurface systems buffer crops against extreme evaporative demand (Malchev *et al.*, 2022). Subsurface systems often deliver comparable or higher yields while drastically reducing water use, as also reported in other semi-arid contexts (Ayars *et al.*, 1999). According to Elnemr and Elmetwalli, (2021) the highest yield was 21.9 t/ha under excellent uniformity with full irrigation, while the lowest was 14.5 t/ha under unacceptable uniformity with 80 % ETc deficit irrigation. In all cases, reduced irrigation led to lower yields. The optimal yield of gem squash under drip irrigation ranged between 20 and 25 t/ha (Namibian Agronomic Board, 2024). Ertek *et al.*, (2004) reported that for field-grown summer squash, the highest yields are achieved with 5-day irrigation intervals at a pan coefficient of Kcp3=0.85, while under water scarcity, more frequent irrigation with Kcp3=0.45 is more suitable. According to Li *et al.*, (2022), applying a light water deficit treatment during the seedling stage resulted in the highest water use efficiency (12.47 kg/ m^3), without significantly reducing yield, while also enhancing pumpkin fruit quality. Throughout the cultivation period, deficit irrigation had varying effects on zucchini yield; the application of 100% ETo (280 L/m^2) produced the highest yield (48.1 t/ha) with a water use efficiency of 18.15 kg/m^3 (Elsawy *et al.*, 2019).

Figure 4. Gem squash plants before first harvesting in sub-surface SLECI (left) and drip irrigation treatment (right)

Irrigation water use

Table 4 presents the water use during the vegetation season for each treatment from the pilot site metered by Axioma flowmeters. The results for irrigation water use presented high differences between the treatments during the season. Drip irrigation consumed 6,761 m^3/ha water, whereas SLECI used 3,011 m^3/ha, or a 125 % water saving in comparison with surface drip. Because both systems shared the same pump and scheduling, the observed differences are likely the result due to the self-regulating release of water from the clay emitters, which shuts off once the surrounding soil is wet, and minimal surface evaporation and percolation of water in soil. Many authors (Agbesi *et al.*, 2025; Elmajetni *et al.*, 2025; Malchev *et al.*, 2022; Hansen and Siering, 2018) reported that SLECI is a highly water-efficient system, supplying only small but steady rates of water. Furthermore, SLECI demonstrate lower irrigation water use compared with drip irrigation across moringa, cowpea, tomato, sweet cherry, lavender, rosemary, and maize (Chaba *et al.*, 2026; Cukaliev *et al.*, 2025; Malchev *et al*., 2025; Technical Report on SLECI Pilot Sites Installed within the DIVAGRI Project, 2025). Cultivating summer squash with full cover and irrigating at 60 % of crop ETc using sub-surface drip irrigation can save approximately 42–44 % of applied water while increasing marketable yield by about 15–16 % across both seasons compared with the control treatment (Sadik and El-Aziz, 2018). In the study of Li *et al.*, (2022), the fully irrigated treatment had the highest water consumption (4,084 m^3/ha), while water deficit regulation at different growth stages significantly reduced pumpkin water use to 3,116–3,742 m^3/ha.

Table 4. Applied irrigation water per season

Treatment	Applied water (m^3/ha)
SLECI sub-surface irrigation	3,011
Drip surface irrigation	6,761

Irrigation water productivity

In agriculture, IWP is defined as the ratio of the actual crop yield achieved and the water use, expressed in kg/m^3 (Cetin and Kara, 2019; Fernandez *et al.*, 2020). It is a commonly used indicator to compare irrigation technologies in water scarce regions like Namibia. Table 5 presents the figures for the experimental site where IWP in sub-surface SLECI and surface drip irrigation were compared.

Table 5. IWP in gem squash by different irrigation treatments (kg/m^3)

Treatment	Gemsquash fresh weight yield (kg/ha)	Irrigation water use (m^3/ha)	IWP kg/m^3	% from Drip surface irrigation
SLECI sub-surface irrigation	9,475^b	3011	3.15^a	188.6
Drip surface irrigation	11,256^a	6761	1.67^b	100

**Values in rows followed by the same letter are not significantly different at p-value of 0.05 probability level*

SLECI sub-surface irrigation converted each cubic meter of irrigation water into 3.15 kilograms of fresh gem squash, while with same quantity of water, drip irrigation achieved 1.67 kilograms fresh yield. SLECI sub surface was more productive than drip surface for about 90 %, or in other words, SLECI system produced the same amount of fresh yield with almost one time less quantity of water. Additionally, IWP was significantly higher under SLECI sub surface irrigation. The obtained results also speaks to drought resilience in water scarcity regions and proper water use in agricultural sector. Technologies like SLECI can result in less water use comparable tonnage of fresh gem squash yield in semi-arid regions with low water retention capacity soils like in Ombe Guestfarm and Safari pilot site in Namibia. The results for IWP in our investigation correspond with those reported in SLECI technology applied in cowpea, moringa, tomato, sweet cherry, rosemary, lavender and maize (*Chaba et al.,* 2026; Cukaliev *et al.,* 2025; Malchev *et al*., 2025; Technical Report on SLECI Pilot Sites Installed within the DIVAGRI Project, 2025). Additionally, the results for subsurface irrigation with ceramic emitter's (SICE) in melon crop showed increased water productivity by 13 % in comparison with subsurface drip irrigation (Han *et al*., 2025). Osei *et al.,* (2025) in their investigation with bell pepper crop presented better water use efficiency of SLECI irrigation lines in burying depth of 15 cm compared lower depth (5 and 10 cm). Furthermore, results showed that probably drip irrigation could be more operational and effective than same results presented for the drip treatment in this research, of-course if there is simulating irrigation regimes with ultra-low water application rate. Moreover, in other research with summer squash, the highest value of water use efficiency was obtained in drip irrigation treatment scheduled by soil properties in comparison with estimation of referent evapotranspiration (Sheta and Fayed, 2021). Furthermore, better values of water productivity were obtained at full drip irrigation squash in comparison with deficit irrigation (Elenmr and Elmetwalli, 2021). Different water deficit irrigation strategies affected pumpkin water use efficiency at each growth stage: a mild deficit at the seedling stage gave the highest efficiency (12.47 kg/m^3), while moderate deficits at the vine extension and fruit expansion stages reduced efficiency by 4.52 % and 12.03 % compared with the control (Li *et al.,* 2022). Okasha *et al.,* (2020) found that in both seasons, drip irrigation every 7 days gave the highest total and marketable yields and water productivity of squash, while flood irrigation every 11 days resulted in the lowest values. Management practices that include subsurface drip irrigation and the subsurface applications of natural deposits have high potential for improving squash fruit yield and WUE (Al-Omran *et al.,* 2005).

Finally, the results of this study highlighted an opportunity for farms connected to diesel or solar pumps to reduce operating hours and conserve water for other crops supplied from the same wells.

CONCLUSIONS

The obtained results at the Ombe Guestfarm and Safari research sites showed that water-saving potential during the vegetation period was higher in the sub-surface SLECI than in the surface drip irrigation treatment. Namely, SLECI reduced pumped irrigation water by more than half without reducing gem squash fresh yield. In addition, the results for IWP showed that sub-surface SLECI produced 3.15 kilograms of fresh gem squash yield per cubic meter of applied water, which was nearly twice as much as the yield obtained under the surface drip irrigation treatment. In semi-arid countries, where crop production is highly dependent on additional irrigation inputs, this difference represents a decisive factor. The research also showed initially lower germination rates and plant emergence under the SLECI system compared with drip irrigation, suggesting that soil wetting in SLECI systems should be carried out a few days before sowing or planting. From a farmer's perspective, the findings indicate that the SLECI system was more suitable for small farms, where installation labor was manageable.

The results of this study were focused on bio-based alternative in a real-world setting by introducing and testing the SLECI system. Irrigation technologies were further extended, and it was shown that sustainable solutions did not have to be complex or expensive. Furthermore, since the study was conducted in the Namibian Sandveld environment (sandy soils with fast drainage and low organic matter), the results of this study can be representative of many arid and semi-arid regions of the world. In fact, the results of this study demonstrated in practice that subsurface irrigation systems achieved significant water savings and significant increases in water productivity without significant yield reduction by reducing surface evaporation and deep infiltration losses, even in sandy soils with low water holding capacity. This finding confirms the principles of soil hydraulic theory and subsurface irrigation in real field conditions.

Therefore, the inclusion of SLECI systems as an option in national climate change adaptation and water security plans in Namibia is recommended. In this regard, supporting domestic production or import of raw materials required for the construction of SLECI systems (such as clay pipes) is recommended to reduce the cost. Moreover, the formation of local cooperatives for the maintenance, repair and development of these systems can be useful. In addition, holding field training workshops by agricultural extension centers to demonstrate the performance and benefits of the SLECI system and financial support for the modernization of irrigation systems to help farmers meet part of the initial costs of installing SLECI systems are recommended. To ensure the robustness and sustainability of the SLECI system, future studies are recommended to investigate the performance of these systems over a long term under different water and soil conditions (saline, clay, silt, etc.). A socio-economic analysis is also recommended for future studies in order to accurately analyze the cost-benefit of installing and maintaining the SLECI system from the perspective of the smallholder farmer.

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