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Özal Tarım ve Gıda Bilimleri Dergisi

Derleme Makale

Yüzeyaltı Damla Sulama Yöntemi Kullanım Olanaklarının Değerlendirilmesi

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ÖNE ÇIKANLAR

- Yüzeyaltı damla sulama (YDS), yüzey buharlaşmasını ortadan kaldırarak su kullanım etkinliğinde %20'ye varan artış sağlamaktadır.
- Endüstri bitkilerinde (mısır, pamuk, buğday) YDS uygulamaları, yüzey sulamaya kıyasla %10–15 daha yüksek verimle sonuçlanmaktadır.
- YDS ile yapılan fertigasyon, besin maddesi kullanım etkinliğini artırmakta ve derine besin yıkanmasını önemli ölçüde azaltmaktadır.
- Çok yıllık bitkilerde ve yem bitkilerinde (yonca) YDS, biçim sırasında ekipman hasarını ortadan kaldırarak sulama sürekliliği ve kuru madde veriminde artış sağlamaktadır.

MAKALE BİLGİSİ

Anahtar kelimeler:
Yüzeyaltı damla sulama
Su yönetimi
Su tasarrufu
Sulama verimliliği
Damla hattı performansı

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ÖZET

Küresel ölçekte artan nüfusun beraberinde getirdiği gıda ihtiyacının karşılanmasında, tarımsal üretimde verimliliği artıran temel faktörlerden biri sulama uygulamalarıdır. Değişen iklim koşullarının ve diğer su kullanıcı sektörlerin suyun üzerinde kurduğu negatif baskı tarım sektöründe suyun verimli kullanımını zorunlu hale getirmiştir. Bu durumda su, enerji ve iş gücünden tasarruf sağlayan, teknoloji ile uyumlu sulama yöntemlerinin kullanımı ve yaygınlaştırılması önem taşımaktadır. Damla sulamanın alternatif bir uygulaması olan yüzeyaltı damla sulama (YADS), damlatıcıların toprak yüzeyinin altına yerleştirilmesi yoluyla tarımsal üretimde farklı bir sulama yaklaşımı ortaya koymaktadır. Bu özelliği ile toprak altından su direkt olarak kök bölgesine uygulanmakta ve toprak yüzeyinden olan buharlaşmayı en aza indirdiğinden su tasarrufu sağlamak amacı ile tercih edilmektedir. İlk yatırım maliyeti yüksek olan YADS sistemlerinin uzun yıllar etkin ve sürdürülebilir şekilde kullanılabilmesi; doğru projeleme, uygun arazi uygulamaları ve etkin su yönetimi ile mümkün olmaktadır. Yüzeyaltı damla sulamada kullanılan tüm sistem elemanları toprağın altında yerleştirildiğinden sürdürülebilir toprak ve su yönetimi için sistemin işletme ve yönetiminde bilinçli davranmak önem taşımaktadır. Bu kapsamda hazırlanan çalışmada YADS yönteminin tarımsal üretimde kullanımını değerlendirmek amacı ile sistem avantaj ve dezavantajları değerlendirilerek kurulumu, işletme, bakım ve yönetiminde dikkat edilmesi gereken ele alınmıştır.

Compilation Article

Evaluation of the Potential of Subsurface Drip Irrigation

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HIGHLIGHTS

- Subsurface drip irrigation (SDI) improves water-use efficiency by up to 20% through the elimination of surface evaporation.
- SDI increases yields by 10–15% in major industrial crops (maize, cotton, wheat) compared with surface irrigation.
- SDI-based fertigation enhances nutrient-use efficiency while substantially reducing nutrient leaching below the root zone.
- In perennial and forage crops (e.g., alfalfa), SDI prevents equipment damage during harvest, ensuring continuous irrigation and increasing dry matter yield.

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ABSTRACT

Irrigation practices constitute a fundamental factor in enhancing agricultural productivity to meet the food demand driven by the globally increasing population. The negative pressure exerted on water resources by changing climate conditions and other water-consuming sectors has necessitated the efficient use of water within the agricultural sector. In this context, the adoption and dissemination of technology-compatible irrigation methods that provide savings in water, energy, and labor are of great importance. Subsurface Drip Irrigation (SDI), an alternative application of drip irrigation, introduces a distinct irrigation approach in agricultural production by positioning emitters beneath the soil surface. Through this mechanism, water is applied directly to the root zone, and the method is preferred for water conservation purposes as it minimizes evaporation from the soil surface. Although SDI systems involve high initial investment costs, their effective and sustainable long-term operation is achievable through proper design, appropriate field applications, and effective water management. Since all system components in SDI are located beneath the soil, conscious operation and management of the system are essential for sustainable soil and water conservation. In this context, this study aims to evaluate the use of the SDI method in agricultural production by assessing its advantages and disadvantages, while addressing critical considerations regarding its installation, operation, maintenance, and management.

1. INTRODUCTION

In the Central Anatolia Region, where drought is prevalent and water resources are limited, the economic use of water has become a necessity. The expansion of new irrigated areas today requires substantial financial investment and, at the same time, leads to the accelerated depletion of groundwater resources. Enhancing the performance of irrigation water application and minimizing application losses through pressurized irrigation systems is considered the most viable solution to this challenge (Karaşahin & Sade 2011).

Drip irrigation systems have various application forms, one of which is Subsurface Drip Irrigation (SDI). The earliest studies on SDI began in 1959 as an advanced form of drip irrigation in the United States, initiated by Sterling Davis on lemon, orange, and potato crops (Hall, 1985). Although these early studies encouraged farmers, issues such as emitter clogging and root intrusion caused surface drip irrigation to advance more rapidly than SDI during the 1970s and early 1980s. Interest in SDI increased markedly in the late 1980s due to developments in plastics and related technologies. Today, SDI is widely used in areas facing water scarcity, environmental challenges related to irrigation, and in regions where wastewater is reused for irrigation. In the early years of its adoption in the United States, SDI was applied to crops such as sugarcane, vegetables, fruit trees, and pineapple. Over time, its use expanded to include many crops—such as cotton, maize, and vineyards—across diverse geographic regions (Camp & Lamm 2003; Irmak, 2016).

In Türkiye, SDI began to be used in the early 2000s, particularly in alfalfa, vineyard, and maize production in the Aegean Region. With the increasing adoption of modern irrigation techniques, SDI has been incorporated into national research activities under the 10th Development Plan through the Agricultural Research and Policies General Directorate (TAGEM). Extensive research has been conducted on regionally important crops—such as maize, soybean, cotton, sugar beet, alfalfa, tomato, pepper, strawberry, vineyards, apple, grapefruit, pistachio, almond, and olive—to develop appropriate techniques and guide support policies under diverse climate and soil conditions. Concurrently, diminishing water resources and the need for higher water-use efficiency have encouraged producers to adopt alternative irrigation systems compatible with automation and capable of saving water.

Irrigation increases the effectiveness of many agricultural inputs and is one of the key practices ensuring profitability in agricultural production (Kodal, 1995). Due to increasing water scarcity and the anticipated rise in domestic, industrial, and municipal water allocations at the expense of agricultural use, the pressure on irrigation water management continues to intensify, making water conservation increasingly critical.

2. SDI and advantages

Subsurface drip irrigation (SDI), in which drip lines are installed beneath the soil surface, has been designed to deliver water directly to the crop root zone, thereby facilitating more efficient water use in recent years (Figure 1).

Through SDI, water is conveyed directly to the root zone via buried polyethylene (PE) laterals. Because laterals are installed below the soil surface, evaporation and deep percolation losses are minimized. Nutrients required by the plant can be applied directly to the root zone through fertigated irrigation water. The major advantages of SDI in agricultural production are outlined below:

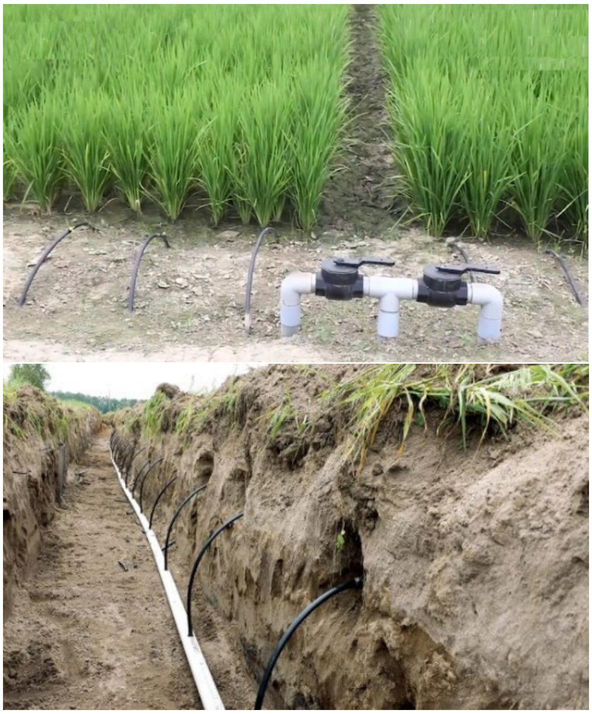

Figure 1. Subsurface drip irrigation system.

2.1. Efficient water application with SDI

The proposed system also supports regeneration management for the diesel particulate filter (DPF), a mandatory component in Stage-V engines. Automatic or manual regeneration assists in removing soot accumulated in the exhaust line, improving engine durability and ensuring compliance with emission regulations (Zhang et al., 2023; Johnson, 2014). This function is particularly critical for agricultural machinery operating under long-term, high-load conditions (Figure 2).

Since drip laterals are buried at a certain depth, the soil surface remains dry. A dry soil surface prevents evaporation and surface runoff losses. Moreover, if irrigation is managed correctly, deep percolation losses can also be eliminated.

Similar to surface drip irrigation, SDI systems typically place laterals between crop rows; therefore, only part of the soil volume is wetted. By leaving the inter-row areas unirrigated, a greater portion of rainfall infiltrates the soil profile, reducing the net irrigation requirement (Lamm, 2002). This improves rainfall utilization efficiency. A dry soil surface also suppresses weed growth and reduces the occurrence of irrigation-induced fungal diseases and pests. Overall, the system meets all conditions for effective water use. Water losses occur only during flushing of the laterals and filtration system. Periodic flushing is essential for long system life and uniform water distribution.

As a result, SDI delivers water from the source to the root zone with minimal losses, achieving irrigation efficiencies above 95% and offering one of the highest application efficiencies among irrigation methods (Payero et al., 2005).

Applying fertilizers through irrigation water (fertigation) ensures that nutrients reach the root zone directly, promoting efficient nutrient uptake and yield improvement.

Figure 2. Installation of SDI laterals.

2.2. Subsurface placement of sdi components

Placing the irrigation system underground maintains a continuously moist subsurface zone, which reduces soil compaction and creates a well-aerated environment favorable for root development. In addition, the dry soil surface combined with moist and aerated subsoil prevents crust formation. With proper irrigation management, the dry surface allows agricultural machinery to enter the field during irrigation, facilitating field operations, maintenance, and harvesting.

Since all drip lines are underground, the system is not affected by meteorological constraints such as high wind speeds, freezing temperatures, or waterlogged soil surfaces.

SDI can also serve as an alternative method for using low-quality wastewater with unpleasant odor, as it prevents the transfer of pathogens to humans, plants, and animals by eliminating direct contact between irrigation water and aboveground plant parts.

Because irrigation water is not applied on the soil surface, a well-managed SDI system reduces the negative effects of saline water on topsoil. The system is typically buried below tillage depth, minimizing maintenance requirements. Drip lines do not need to be removed at the end of the season, nor reinstalled during the next season. Buried laterals are protected from damage caused by birds, animals, and theft (Lamm 2002, 2005; Camp & Lamm 2003; Payero et al., 2005).

2.3. Suitability of sdi infrastructure

The closed-loop, pressurized structure of SDI systems allows full integration with automation technologies. SDI systems operate at low pressures; thus, they require less energy, and they can be easily powered by renewable energy sources when combined with deficit irrigation strategies.

Since SDI system components are predominantly made of plastic-based materials, they are less susceptible to corrosion. Because the system remains permanently installed in the field, there is no need for annual removal and reinstallation, which significantly reduces labor costs and facilitates preparation for double-cropping systems.

SDI enables the application of fertilizers, acids, chlorine, and even pesticides through irrigation water. The system is designed to deliver small volumes of water at frequent intervals even within the same day. Such small and frequent applications prevent deep percolation and nutrient leaching while enabling precise irrigation management (Aguilar et al., 2015).

SDI can be designed for fields of any size and shape. The system can be dimensioned economically according to the available water source, offering design flexibility. When properly designed, operated, and maintained, SDI systems have long service lives, allowing investment costs to be amortized over many years. This makes SDI economically viable, despite its initially high installation cost (Payero et al., 2005).

In deficit irrigation applications, SDI minimizes yield reductions, allowing highly efficient irrigation scheduling and maximizing water savings (Karaca Bilgen, 2020).

3. Conditions limiting the use of SDI

Although subsurface drip irrigation systems offer significant advantages, they also present several disadvantages related to system cost, installation, operation, and maintenance. The major limiting factors associated with SDI are outlined below:

3.1. High initial investment costs of SDI

The initial installation cost of SDI is relatively high. The need for SDI-specific emitters, inlet and outlet manifold lines for each lateral, and essential control components such as valves, manometers, and air-release valves, increases overall system cost. Furthermore, installation requires specialized agricultural machinery and equipment, making SDI more expensive than other irrigation systems at the outset. System cost varies substantially depending on field size and shape, the distance and elevation of the water source, and the desired level of automation.

Despite high initial costs, pressurized irrigation systems become more economical in the long term when their annual operating expenses and long service life are considered, allowing them to amortize investment costs relatively quickly (Karaca & Selenay, 2000). This makes SDI systems more feasible over time.

Performance assessments conducted by the “Irrigation Training and Research Center” in California on SDI systems that had been in operation for 20 years demonstrated successful outcomes (Lamm, 2005). These results show that SDI effectiveness depends not on system age but on proper design, operation, maintenance, and management.

Within the national project initiated by the General Directorate of Agricultural Research and Policies (TAGEM) in 2015 titled “Development of Irrigation Scheduling Programs Based on Water-Saving Irrigation Methods Under Limited Water Conditions” SDI studies were undertaken. Field inspections conducted prior to the project revealed that existing SDI systems, when properly managed and maintained, had been functioning efficiently for up to 9 years.

3.2. Relationship between SDI and soil properties

Soil properties represent one of the most critical constraints in SDI installation. In field crop production, SDI must be installed below tillage depth; therefore, adequate effective soil depth is essential. Even if sufficient soil depth exists, the upper soil layer must have a low proportion of coarse fragments to avoid damage during installation.

During SDI design, water movement within the soil upward capillary rise, downward gravitational flow, and lateral redistribution must be evaluated according to soil texture and structure. Thus, soil characterization prior to installation is essential to determine appropriate lateral spacing and depth according to crop rooting characteristics and soil hydraulic behavior.

3.3. Priorities in SDI system design

Crop rotation patterns are among the most important factors influencing system cost. Since SDI is permanently installed below the soil surface, soil texture and structure must be considered during design. Components such as the mainline, manifolds, lateral diameter, length, depth, and emitter discharge rate depend entirely on soil and crop characteristics, and once installed, they cannot be modified easily.

Errors made during design are expensive to correct; therefore, SDI must be carefully designed and installed according to field conditions. The planned rotation system, crop type, soil characteristics, and cultural operations such as tillage must all be incorporated into the design.

3.4. SDI installation

During SDI installation, mainlines and manifolds must be buried underground, requiring excavation and backfilling. Laterals are installed at specific depths depending on soil and crop characteristics and require specialized equipment (Figure 2). Consequently, SDI installation is labor-intensive and requires substantial excavation, increasing initial system cost.

3.5. Rodent damage to SDI dystems

Rodents represent a significant threat to SDI functionality. Preventive measures and regular field monitoring are essential. Rodents typically damage laterals during dry periods when subsurface fauna experience moisture scarcity and attempt to access water within the pipes. In such cases, operating the system to moisten the soil surface can serve as an alternative to chemical control.

3.6. Need for supplemental irrigation during seed germination

The purpose of burying SDI laterals is to maintain a dry soil surface and reduce evaporative losses. While this is advantageous for water conservation, it presents limitations during seed germination. To raise moisture levels in the upper soil layer using SDI, larger irrigation amounts may be required, increasing deep percolation losses and reducing irrigation efficiency.

Under arid climatic conditions, an auxiliary irrigation method (e.g., sprinkler irrigation) may be necessary to provide the moisture required for germination. Insufficient moisture during early growth may lead to early-season water stress, poor emergence, and yield reduction. Therefore, supplemental irrigation should be provided through an alternative method during dry periods.

4. Key considerations for the efficient use of SDI systems

SDI has the potential to utilize increasingly limited water resources with high efficiency. However, irrigation performance is influenced not only by the system itself but also by appropriate design, installation, management, and maintenance practices. When SDI is correctly designed, installed, and managed, it can outperform many other irrigation methods.

4.1. Filtration

The long-term performance of SDI depends heavily on the proper operation and maintenance of all filtration units. The physical and chemical characteristics of the irrigation water determine which filtration components—such as hydrocyclones, sand–gravel filters, and screen/mesh filters—should be included in the control unit.

Initially, coarse and fine particles such as silt and clay must be removed before the water enters the laterals to prevent emitter clogging. For this purpose, inlet and outlet pressures of the filtration system must be regularly monitored, and backwashing should be performed (i.e., reversing the flow direction using system valves) when needed. Additionally, to prevent potential clogging in manifolds and laterals, flushing should be carried out periodically by opening the drainage lines every few irrigation events.

4.2. Emitter use

To minimize emitter clogging, laterals specifically manufactured for SDI applications must be used. SDI-specific emitters incorporate technologies that prevent the ingress of fine plant roots and include self-cleaning mechanisms. Therefore, the longevity of the system largely depends on the quality of materials used in lateral manufacturing.

4.3. System cleaning and monitoring indicators

Regular pressure monitoring using manometers installed at the inlet and outlet of manifold lines is essential. Excessive inlet pressure may cause pipe bursts underground, whereas high or low pressure differences between inlet and outlet manometers may indicate leakage or puncture in the buried lateral lines.

Subsurface leaks or ruptures can typically be detected through pressure drops and unusually high flow rates recorded by water meters. In such cases, the affected section should be identified often visible as a wet spot on the soil surface and repaired immediately. Therefore, consistent field inspections based on manometer and flowmeter readings are crucial for effective SDI operation.

4.4. Irrigation management and scheduling

Accurate irrigation scheduling is necessary to prevent both insufficient and excessive irrigation under SDI. In scheduling, soil, climate, and crop characteristics must be evaluated alongside SDI-specific parameters such as lateral depth and effective root zone distribution.

These factors determine the wetting pattern in the root zone, making compliance with the irrigation schedule essential. Proper scheduling also ensures efficient water use, prevents deep percolation losses, and maintains optimal plant growth under varying environmental conditions.

5. Installation of SDI and system components

The success of SDI in row crops depends equally on system design, installation, operation, management, and maintenance. While SDI shares many fundamental components with surface drip irrigation systems, its primary distinction lies in the installation of drip laterals at a specific depth below the soil surface. Consequently, SDI consists of both aboveground (pump unit, control unit, connection elements) and underground components (mainline, manifolds, lateral drip lines), as illustrated in Figure 3 (Rogers et al., 2003). A critical characteristic of SDI is the connection of both the head and tail ends of the buried laterals to manifold lines to prevent movement within the soil profile and to facilitate cleaning via flushing manifolds.

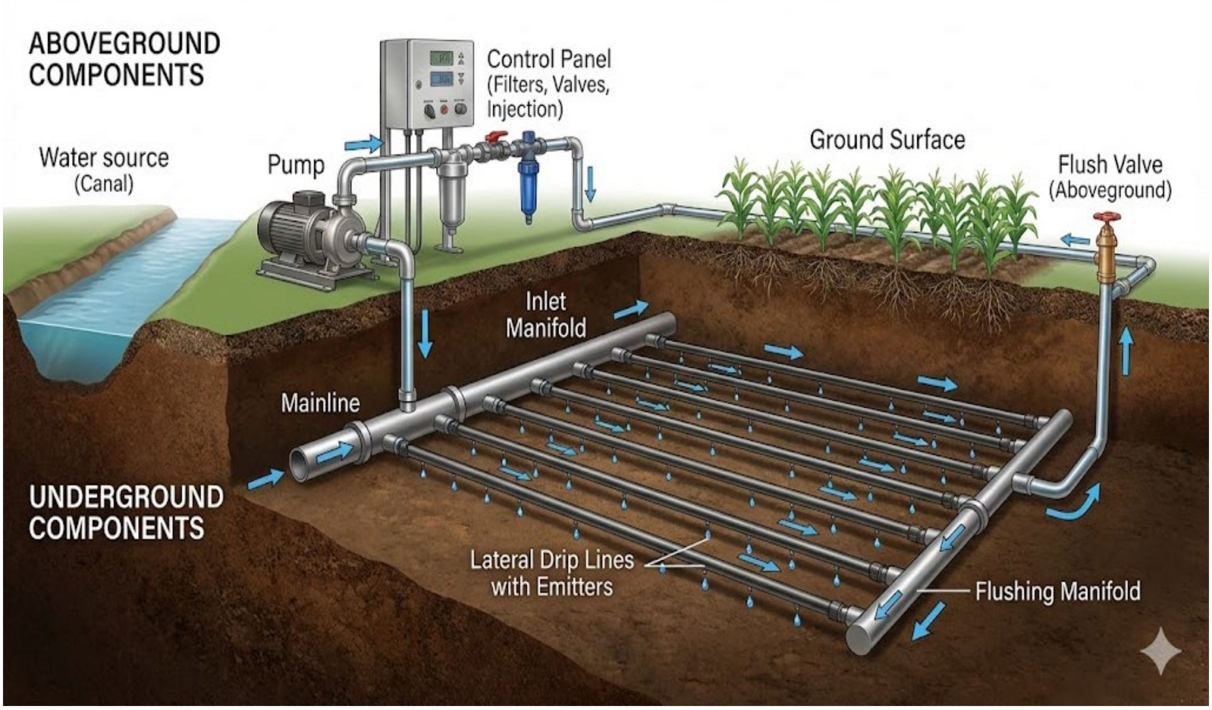

Figure 3. Components of a subsurface drip irrigation system.

5.1. Water supply and pumping unit

One of the most significant advantages of SDI is its ability to utilize a wide range of water sources, including low-quality waters such as effluents. This method is particularly recommended for crops that are directly consumed such as leafy vegetables as it significantly reduces pathogen transfer (Oron et al., 1995; Camp et al., 2000; Choi et al., 2004; Tripathi et al., 2014). Since SDI systems generally operate at low pressures (Rogers et al., 2003), the necessity of a pump depends on the natural head of the source. If the water source does not provide sufficient natural head, the required operating pressure must be supplied by a pump (Güngör & Yıldırım 1989). Depending on the water source (stream, canal, shallow well, or deep well), appropriate pump types such as horizontal centrifugal pumps for surface sources or deep-well/submersible pumps for groundwater must be employed (Kodal, 2019). The pump unit must also compensate for friction and head losses occurring across filters, valves, and distribution lines (Rogers et al., 2003).

5.2. Control head and filtration system

The control unit is the operational heart of the system, housing all necessary equipment for pressure management, fertigation, and filtration (Figure 4). Regardless of the water source, high-quality filtration is essential to prevent emitter clogging, which is critical given the cost and difficulty of replacing buried laterals. A typical filtration assembly is installed on a reinforced concrete platform and includes various combinations of filters based on water quality:

- Hydrocyclones: Essential for deep-well

water, these units use centrifugal force to remove sand and particles larger than 2 mm.
- Sand–Gravel Media Filters: Used primarily for open water sources (ponds, canals), these tanks utilize layers of basalt, quartz, and gravel to remove organic matter and coarse sediments. Differential pressure indicates when backwashing is required (Yıldırım, 2008).
- Screen and Disk Filters: Installed downstream of the fertilizer tank, these provide fine micro-level filtration. To prevent clogging, the mesh diameter must be smaller than one-quarter of the smallest passage diameter of the emitter flow path.

Integrated into this unit is the fertilizer tank, which enables the injection of chemical inputs and fully dissolved fertilizers into the system using diaphragm pumps or venturi injectors (Roger & Lamm 2012). Pressure differences monitored via manometers at filter inlets and outlets serve as indicators for cleaning requirements.

Figure 4. Components of the control unit.

5.3. Distribution network: mainlines and manifolds

The distribution network transfers filtered water to the crop root zone. The mainline consists of underground PE pipes transporting water from the control unit to the field. A defining feature of SDI is the manifold system; the inlet manifold distributes water to laterals, while the flushing manifold collects water from the tail ends for system cleaning. To ensure proper operation, air-release valves must be installed on both manifolds to eliminate trapped air during startup and shutdown. Additionally, manometers on these lines allow for the monitoring of pressure fluctuations, aiding in the detection of leaks or clogging within the buried network.

6. Determination of lateral depth and spacing

The most appropriate lateral depth for SDI is determined by crop type, soil characteristics, climatic conditions, cultural practices, and grower experience (Lamm & Rogers, 2012). Although crop species largely influence lateral depth, tillage depth is the primary criterion for SDI installation (Karaca Bilgen, 2020). In Türkiye, primary tillage using a moldboard plow is typically performed at 25–30 cm depth (Aykas et al., 2005). In addition to tillage depth, soil texture and structure, as well as the effective rooting depth of crops in the planned rotation system, must be considered when selecting lateral depth.

Capillary water movement which varies depending on soil texture must also be accounted for. In light-textured soils, upward capillary movement is limited; therefore, laterals should be positioned more shallowly. In contrast, in medium- and heavy-textured soils, capillary rise is more effective, allowing laterals to be placed deeper.

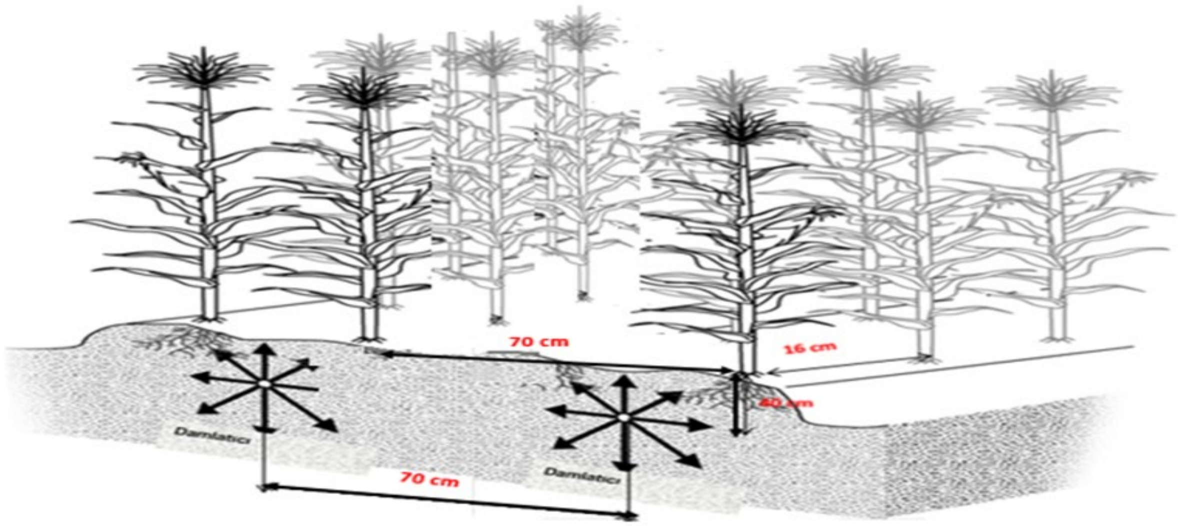

Figure 5. Lateral spacing and depth for SDI systems.

Lateral spacing must be determined by considering soil texture and all crop characteristics within the rotation system. Some crops are grown in narrow row spacing; in such cases, installing laterals at narrow intervals increases SDI cost (Aguilar et al., 2015). Thus, both agronomic requirements and economic factors should guide decisions regarding lateral spacing.

Research generally recommends placing laterals either in every crop row or every other row. For small-seeded crops and sandy soils, closer spacing is necessary to prevent yield loss (Lamm & Rogers 2012).

Depending on soil type, crop, and climatic conditions, laterals are typically buried at depths ranging from 33 to 50 cm (Irmak, 2005; Karaca Bilgen, 2020). Table 1 presents examples of lateral depths and spacings used for maize under various soil textures and climatic conditions.

Regardless of crop type, variations in lateral depth and spacing are influenced by soil characteristics, cultural practices associated with crop rotations, and economic conditions. Since SDI does not excessively wet the soil surface, cultural operations can be performed easily, and greater irrigated area can be achieved with the available water. By applying water and nutrients more efficiently, SDI enhances yield and crop quality. Minimal evaporation from the soil surface reduces total irrigation water requirements (Ayars et al., 1999).

7. Emitter characteristics

Emitters are one of the most critical components of an SDI system. Because negative pressure may occur after irrigation, emitters must be designed to prevent the entry of soil particles and fine plant roots into the flow path. With technological advancements, emitters with anti-siphon mechanisms and root intrusion protection have been developed specifically for SDI applications. Without these features, emitters are highly susceptible to clogging, which would prevent the system from functioning effectively over long periods. Therefore, laterals equipped with emitters suitable for subsurface installation must be selected for SDI.

8. Connection components

Since most SDI components are buried underground, correcting any design errors after installation becomes more difficult. For this reason, SDI requires a greater number of components than other micro-irrigation systems, and the proper functioning of these components is essential for system sustainability (Payero, 2004). Figure 6 illustrates the essential components used in SDI systems, including valves, air-release valves, water meters, and manometers.

Air-Release Valve: Air-release valves are used to expel air from the system during startup and shutdown. They are placed at the highest points on both the inlet and flushing manifold lines. By releasing trapped air, these valves prevent excessive air pressure buildup, protecting the manifold lines and laterals.

Table 1. Lateral depths and spacings used in maize under different soil texture classes

References	Soil texture	Lateral	
		Depth (m)	Spacing (m)
Ademsen, 1992	Loamy Sand	0.35-0.41	0.91
Caldwell et al., 1994	Silty Loam	0.40	1.50
Camp et al., 1989	Sandy Loam	0.30	0.76-1.52
Darusman et al.,1997a	Silty Loam	0.40-0.45	1.5-3.1
Darusman et al.,1997b	Silty Loam	0.40-0.45	1.50
Evett et al., 1995	Clay Loam	0.450	1.52
Howell et al., 1997	Clay Loam	0.300	1.50
Kruse & Israeli, 1987	Loam	0.12-0.37	1.50
Lamm et al., 1995a	Silty Loam	0.40-0.45	1.50
Lamm et al., 1995b	Silty Loam	0.45	0.76-3.05
Lamm et al., 1997a	Silty Loam	0.40-0.45	1.5-3.0
Lamm et al., 1997b	Silty Loam	040-0.45	1.50
Manges et al., 1995	Clay Loam	0.45	0.76-3.05
Mitchell & Sparks, 1982	Silty Loam	0.34-0.37	0.76
Mitchell, 1998	Silty Loam	0.36	0.90
Oron et al.,1991	Silty Loam	0.30	0.95-1.90
Powell & Wright, 1993	Clay Loam	0.38	0.91-1.82-2.74
Payero et al., 2008	Silty Loam	0.40	1.50
Arbat et al., 2010	Silty Loam	0.33	1.50
Grabow et al., 2011	Clay Loam	0.30	1.5-2.3
Irmak et al., 2011	Silty Loam	0.40	1.52
van Donk et al., 2012	Silty Loam	0.40	1.50
Sorensen et al., 2012	Sandy Loam	0.30	0.9-1.8
Jordan et al., 2014	Sandy Loam	0.25	0.91
Chatterjee et al., 2019	Silty Loam	0.40	1.50
Sorensen et al., 2010 b	Fine Sandy Loam	0.05	1.80
Sorensen et al., 2013	Sandy Loam	0.31-0.36	0.9-1.8
Spurgeon & Yonts, 2013	Very Fine Sandy Loam	0.28	1.10
Sorensen & Lamb, 2015	Fine Sandy Loam	0.038	1.80
Sorensen et al., 2016	Fine Sandy Clay Loam	0.03	1.80
Irmak and Djamam., 2016	Silty Loam	0.40	1.52
Irmak et al., 2016	Silty Loam	0.40	1.52
Lamm & Rogers, 2017	Silty Loam	0.40-0.45	1.50
Murley et al., 2018	Clay Loam	0.30	1.50
Şen et al., 2015	Clay Loam	0.30	1.40
Demirok, 2017	Clay	0.30	0.70
Güney et al., 2018	Clay Loam	0.40	1.40
Sandhu & Irmak, 2019	Silty Loam	0.40	1.50
Evett et al., 2019, 2020	Clay Loam	0.30-0.36	1.50
Gonzalez et al., 2023	Sandy Loam	0.25	1.12
Solano et al., 2023	Clay Loam	0.10-0.20-0.30	0.50
Gong et al., 2023	Sandy Loam	0.30	1.20

Figure 6. Valves, air-release valves, water meters, and manometers used in SDI.

Water Meter: Water meters measure the volume of water passing through the system. SDI management depends heavily on precise irrigation scheduling. To prevent the upward movement of water to the soil surface or excessive deep percolation below the root zone, the amount of water delivered must be carefully controlled. Water meters ensure accurate monitoring of system discharge.

Manometer: Manometers are installed at both the inlet and outlet ends of SDI lines for pressure monitoring. They are crucial for identifying problems such as emitter clogging, lateral line blockage, or pipe rupture. A pressure difference greater than 0.5 atm between the inlet and outlet manometers indicates a potential leak or rupture in the buried lateral lines. The greater the pressure difference, the more severe the rupture. Wet spots forming at the soil surface often reveal the location of leaks, allowing prompt repair. Therefore, systematic monitoring of manometer readings and regular field inspections are essential for reliable SDI operation.

9. Application areas of SDI

Subsurface drip irrigation (SDI) systems are a modern irrigation method that enhances water-use efficiency, reduces evaporation losses, and improves product quality in field crops, horticultural crops, and forage crops. Research conducted on industrial crops such as maize, cotton, and wheat has shown that SDI systems can provide up to 20% water savings and increase yield by 10–15% compared with surface irrigation (Lamm & Trooien, 2003; Ayars et al., 1999; Camp, 1998). Improvements in fiber quality have been reported in cotton, while reduced surface evaporation and compatibility with dense planting systems have been noted for wheat. In crops such as sugar beet and peanut, SDI has been reported to facilitate salinity control, reduce early-season water stress, and enhance yield (Enciso et al., 2005).

In vegetable and fruit crops, SDI prevents moisture accumulation on the soil surface, thereby reducing foliar diseases and weed growth; when combined with fertigation, it also increases nutrient-use efficiency (El-Shikha et al., 2007; Kafkafi & Tarchitzky, 2011). In vegetable production, lateral depth generally ranges between 20–30 cm, while in fruit trees it ranges between 30–45 cm; suitable lateral spacings are typically recommended between 0.9–2.5 m (Nakayama & Bucks, 1986; Ayars et al., 1999). Positive effects on fruit size, shelf life, and yield have been observed in crops such as tomato, pepper, and melon (Hanson & May, 2003). In perennial crops such as citrus, vineyards, and apples, SDI systems offer long-term installation advantages, providing both water savings and improvements in fruit quality (Phene et al., 1994).

In perennial forage crops, SDI prevents damage to surface irrigation equipment during harvest operations, ensuring continuity of irrigation. In crops such as alfalfa, placing lateral lines at depths of 25–35 cm has been shown to increase dry matter yield and improve water-use efficiency (Lamm et al., 2000; Enciso et al., 2005). In this regard, SDI represents a strategic technology for sustainable agricultural practices in arid and semi-arid regions.

In conclusion, the successful implementation of subsurface drip irrigation systems depends on determining appropriate lateral depths and spacings according to crop type, soil characteristics, and climatic conditions, as well as ensuring proper system design and regular operation and maintenance. In this context, SDI stands out as a high-efficiency, environmentally friendly, and sustainable irrigation alternative for industrial crops, horticultural production, and forage crops.

10. CONCLUSIONS

The planning and design of subsurface drip irrigation (SDI) systems must ensure that all plants receive approximately equal amounts of water. A successful SDI system is closely associated with proper design, installation, management, and maintenance. As demonstrated in previous studies and practical applications, it is not sufficient for SDI systems to be merely well-designed; when correctly installed and properly managed and maintained, they can increase crop yield and ensure significant water savings in agricultural production. The main disadvantages of SDI include high initial investment costs, emitter clogging, and rodent damage. However, studies have indicated that the system becomes highly functional when appropriate preventive measures are taken (Ademsen, 1992; Lamm, 2005; Karaca Bilgen, 2020).

In conclusion, with the rapidly expanding global use of SDI systems and their increasing adoption in Türkiye, particularly in the Aegean Region significant savings in irrigation water and labor can be achieved. This technology reduces production costs for farmers, and at a national scale, its widespread use is expected to reduce water consumption and ensure that water is applied at the right time and in the required amount. By eliminating soil-surface evaporation, SDI reduces total irrigation water demand and increases the proportion of water utilized directly by the crop, thereby enhancing overall water-use efficiency. Moreover, because fertilizers applied through irrigation reach the root zone directly and are not lost through deep percolation, environmental risks are minimized. The absence of surface water also facilitates field operations and reduces weed pressure, leading to savings in both labor and time. Transferring the knowledge and experience gained from SDI applications to farmers at regional and national levels will contribute to increased income and improved welfare among agricultural producers.

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