ANALYSIS OF THE CURRENT STATE OF RESEARCH WORLDWIDE ON SYSTEMS DESIGNED FOR IRRIGATION OF AGRICULTURAL CROPS
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ANALIZA STADIULUI ACTUAL DE CERCETARE, PE PLAN MONDIAL, A SISTEMELOR DESTINATE IRIGĂRII CULTURILOR AGRICOLE

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ABSTRACT
This paper presents a comprehensive analysis of the global state of research and technological advancements in irrigation systems for agricultural crops, with a focus on the development of an energy-independent subsystem designed by the authors – SEMSI (Self-sustaining Energy Mobile Subsystem for Irrigation). SEMSI operates using renewable energy sources such as solar and wind power and is intended for use in areas lacking access to the electrical grid but with available water resources. To support the conceptualization and future optimization of this subsystem, the study outlines key principles of irrigation, reviews existing technologies and their performance, and analyses the functionality of both traditional and modern irrigation systems, including gravity, sprinkler, and drip methods. This documentation lays the groundwork for further development of the SEMSI system and serves as a reference base for theoretical modeling and experimental validation in future research stages.

REZUMAT
Lucrarea prezintă o analiză cuprinzătoare a stadiului actual al cercetării și al progreselor tehnologice la nivel global în domeniul sistemelor de irigații pentru culturile agricole, cu accent pe dezvoltarea unui subsistem energetic independent proiectat de autori – SEMSI (Subsistem Energetic Mobil Autonom pentru Irigații). SEMSI funcționează pe baza surselor de energie regenerabilă, precum energia solară și eoliană, și este destinat utilizării în zone fără acces la rețeaua electrică, dar cu resurse de apă disponibile. Pentru a sprijini conceptul și optimizarea viitoare a acestui subsistem, studiul prezintă principiile esențiale ale irigației, trece în revistă tehnologiile existente și performanțele acestora și analizează funcționarea atât a sistemelor tradiționale, cât și a celor moderne de irigație, inclusiv metodele gravitaționale, prin aspersiune și prin picurare. Această documentare oferă baza necesară pentru dezvoltările ulterioare ale sistemului SEMSI și servește ca punct de referință pentru modelarea teoretică și validarea experimentală în etapele viitoare ale cercetării.

INTRODUCTION
Globally, water management is becoming an increasingly sensitive issue. According to UN statistics, the world population is growing by 80 million people annually (*Alexandratos and Bruinsma, 2012*), implying an increase of 64 billion cubic meters of water needed for annual consumption. Currently, although the interest of the world's major powers is directed towards deposits, it is expected that in the long term the major global competition will be for water (*McVicker, 2024*).

Currently, about four billion people – almost half of the world's population – face a severe water shortage (*du Plessis, 2023*).

The demand for water for domestic and industrial use will increase rapidly and relatively slowly for agriculture. The developing world is expected to see a much greater increase in total water demand than the developed world, and approximately 93% of the additional demand will occur in developing countries (*Rosegrant and Cai, 2002*).

Water is the main limiting factor in agricultural production in regions where annual or seasonal rainfall is insufficient to meet crop water requirements (*Palma and Tomaz, 2024*). Globally, approximately 70% of all water withdrawn from water sources is used for irrigation (*Siebert et al., 2010*).

Irrigated agriculture plays a key role in feeding the world's population, accounting for 40% of global food production while occupying only 20% of global arable land (*Wang et al., 2022*).

Irrigation is the artificial application of water to crops to meet their requirements from the crown root initiation stage to maturity, in a controlled amount, according to the water requirements of the crop (*Askaraliev et al., 2024*).

Irrigation of agricultural crops refers to the process of controlled supply of water to cultivated plants, by various methods, to support their growth and development, especially in regions with insufficient rainfall, and aims to improve crop yield and quality (*Sabir et al., 2024*).

Proper water management in agriculture is essential for sustainable production, in the face of increasing water scarcity and climate change (*Ray and Majumder, 2024*). Climate change has a considerable impact on irrigated agriculture, which is vital for food and fibre production (*Gabr et al., 2024*).

Proper water management is achieved by drip irrigation systems, tubes and sprayers, as they can be used when natural water sources and rain are not sufficient to meet the water demand of plants and in areas where rainfall is irregular or drought periods are expected (*Shanu, 2024*).

Another type of sustainable water management is subsurface irrigation, which ensures the distribution of water within the soil layer, at a shallow depth, ensuring tailored results (*Rocha et al., 2024*). Subsurface irrigation eliminates surface evaporation, reduces the amount of salts, extends the life of the irrigation system by over 10 years, eliminates herbicide washout and its infiltration into the soil, reduces the need for personnel and reduces maintenance costs (*Codreanu and Malai, 2019*). Subsurface drip irrigation is recommended for cereal crops because it reduces evapotranspiration by about 25% compared to furrow irrigation and by about 15% compared to surface drip irrigation (*Umair et al., 2019*).

In these circumstances, sustainable irrigation - that is, irrigation for the production of healthy food through equitable use of water within planetary boundaries - is an important area of study, as it seeks to bring water systems and agricultural systems into balance, that is, harmonizing water use for food security, economic development and environmental sustainability (*Jain et al., 2021*).

Various precision irrigation methods such as sprinkler irrigation techniques, drip irrigation systems in combination with technological innovations and data-driven strategies such as satellite imagery, GIS, including the Internet of Things (IoT), remote sensing are being promoted to optimize water use and facilitate real-time environmental monitoring (*Xing and Wang, 2024*).

Advanced irrigation systems, together with soil conservation techniques and scheduling, hold promise for maximizing water efficiency and sustaining soil fertility while addressing the challenges of climate change, hunger, and environmental sustainability (*Enahoro-Ofagbe et al., 2024*).

The irrigation sector has changed significantly in the last 50 years due to climate change, drought problems, urbanization and population growth, and the trend is to search for and develop modern methods to optimize irrigation to achieve higher crop yields (*Lakhiar et al., 2024*).

The performance of irrigation systems is conditioned by the knowledge of geographical conditions, the physiology of the treated plants, the soil, in essence by an entire theoretical apparatus that provides the calculation bases for the start and maintenance of the irrigation system. A series of theoretical studies have laid the foundations of the necessary knowledge.

The water requirement of a crop, which must be satisfied through efficient water planning and management in order to obtain maximum yield, is obtained in the work *Saccon, (2018)*. *Popa, (2021)*, claims that the need to apply irrigation for a certain area is established according to the moisture deficit calculated as the difference between water consumption and water supply sources of the soil and plants. In Romania, *Corduneanu, (2018),* states that after calculating evapotranspiration using the Thornthwaite method and performing the water balance, it was concluded that in most areas there is a deficit, especially noted in the summer months.

The soil moisture should not fall below a certain minimum ceiling, i.e. the soil moisture should not be expected to reach the wilting coefficient. The minimum soil moisture ceiling (MHCPM) is located on medium soils, generally at half the active moisture range, on light soils at 1/3 of the Active Moisture Range (IUA), and on heavy soils at 2/3 of the I.U.A. The minimum ceiling (PM) was established depending on the texture, the field capacity CC and the wilting coefficient CO (*Grumeza et al., 1989; Canarache, 1990*). The time interval between waterings (T), according to *Botzan, (1972)*, represents the time between two waterings, and depends on the size of the applied watering norm, respectively on the average total daily moisture consumption through evapotranspiration. According to *Gaudin and Rapanoelina, (2003)*, the watering rate can be determined very easily, if a nomogram is built, the analysis of which will be done in theoretical research.

The paper presents a comprehensive analysis of current global research and technological trends in agricultural irrigation systems, with a focus on the design principles, functional characteristics, and integration of an innovative energy-independent mobile subsystem (SEMSI) powered by renewable sources.

MATERIAL AND METHODS

The working process of equipment intended for crop irrigation

In general, there are two irrigation methods: gravity (traditional method) and pressure-driven (modern method). *Brumă, (2004),* considers that the water regime of plants refers to the set of processes of water absorption, from the substrate and the atmosphere, to its circulation along the path of the plant body and to the elimination of the water current in the external environment through the processes of transpiration and guttation.

Domuţa et al., (2002), considers that supply irrigation is applied with the aim of ensuring the soil moisture necessary for uniform plant emergence and to create a water reserve that the plants will use in the following phases of development.

The amount of water in the plant organism varies with age, physiological state, geographical region, metabolic intensity, etc. in general, young tissues contain a greater amount of water than old ones (*Dry et al.,1999*).

Knowing the water consumption of crops, by developing maps of the actual water consumption of crops (*Roerink et al., 1997*) is of particular importance in irrigated agriculture, as it serves both to establish the water requirement in irrigation systems and to establish the timing of watering and irrigation norms.

Gravity irrigation is the supply of water at the end of an inclined channel built on a plot, to ensure the necessary amount of water through continuous gravitational flow in three phases: the advance phase, when the water flow is ensured on the dry edge, the storage phase, upon the arrival of the water wave until the interruption of the water supply and the recession phase, which is composed of two subphases, the first vertical recession upon the interruption of the water supply until the disappearance of the water and the horizontal recession upon the disappearance of the total water depth (*Chavez and Fuentes, 2019*).

Gravity irrigation is one of the oldest and simplest irrigation methods used in agriculture, which is based on harnessing the force of gravity to transport water from a source such as a river or reservoir, through canals, ditches or pipes, to fields located at a lower level. Most irrigation practices in southern Europe have been based on gravity-fed surface irrigation systems. For example, Figure 1 shows a gravity-fed surface irrigation system located in northern Italy. Currently, efforts are being made to encourage farmers to adopt more efficient gravity-fed irrigation practices, thus achieving both economic and environmental benefits (*Masseroni et al., 2017*).

Fig. 1 - Example of a gravity-fed surface irrigation system located in northern Italy

For flood irrigation, machines are used to dig canals, ditches and furrows, which create drainage channels on agricultural lands at risk of flooding or water stagnation, mini-irrigation canals, or irrigation furrows.

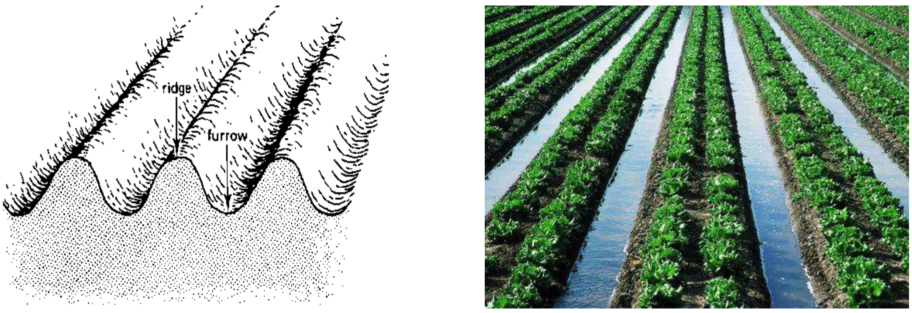
The furrows are made with special equipment, and figure 2 shows such agricultural equipment, which is composed of two guide wheels, five furrows and five compaction wheels for digging and compacting ditches for flood irrigation.

Flood irrigation requires a certain arrangement system (*Ivan et al., 2019*). The main technical elements of flood irrigation are the following: the thickness of the flood layer, the supply flow rate to achieve a certain thickness of the flood layer, the discharge flow rate (*Nicolaescu, 1981*). The design and evaluation of flood irrigation systems depend in part on the velocity at which water flows from the upper end of the furrow to the lower end, and knowledge of this velocity of advance for different flow rates allows the designer to choose the appropriate furrow length to achieve a certain uniformity of water distribution (*Davis, 1961*).

Fig. 2 - Aspects of an agricultural equipment for digging and tamping ditches for flood irrigation
(*https://www.centrulhidrauliccalarasi.ro/wp-content/uploads/2022/04/brazdar.jpg*)

In furrow irrigation (Fig. 3a), water reaches the plants by flowing along the natural slope, in the furrows that transport it due to the slope of the land between the crop rows, and it infiltrates into the soil as it moves along the slope (*Brouwer et al., 1988*).

Plants are usually grown on ridges between furrows. This method is intended for all row crops and for crops that cannot stand in water for long periods of time, such as corn, sugar beets, potatoes or vegetables. This method involves creating parallel furrows or grooves in the soil through which water is distributed to evenly moisten the soil around the roots of the plants.



a. b.

Fig. 3 - Furrow irrigation
a. top view and cross section of furrows and ridges; b. furrow-irrigated crop
(*https://www.fao.org/4/s8684e/s8684e04.htm*)

The management of gravity systems is not static, therefore farmers are supporting and experimenting with sophisticated systems, such as those based on computerization, automation and real-time optimization (*Singh, 2013*).

For example, a decision support system called SADREG has been developed to assist decision makers in the design and selection of furrow irrigation systems, which consists of a database, a simulation model, user-friendly interfaces and multi-criteria analysis models (*Gonçalves and Pereira, 2009*).

Pressure irrigation can be classified according to the way water is distributed to the plants and the type of equipment used.

Sprinkler irrigation. With this watering method, which is similar to natural rainfall, irrigation water is first sprayed into the air, from where the droplets fall as rain on plants and soil. Sprinkler irrigation is done with static, rotating or mobile sprinklers and is a modern irrigation system that uses water pressure to distribute water evenly and efficiently to agricultural crops or gardens. This method allows for more precise control of the amount of water applied, reducing waste and improving resource efficiency *(Nedelcu and Candea, 2009)*.

A significant example of sprinkler irrigation is represented by " **Irrigation system with ramp and watering cannon, IIRT"** (fig. 4), which is manufactured by Grup Romet SA Buzău for the irrigation of tall agricultural crops (corn, sunflower, hemp, etc.), medium (wheat, barley, rye, etc.) and low, sown in sparse rows (soybean, potato, alfalfa, clover, etc.) on medium and relatively large areas. The watering ramp mounted on the irrigation system ensures uniform water distribution, plant and soil protection, requires low pressures at the connection. In the case of using the watering cannon on the irrigation system, its working pressure is high to ensure optimal operation of the sprinkler.

Fig. 4 - Irrigation system with ramp and watering cannon, IIRT
(*https://www.romet.ro/resources/download/proiect_212_2008.htm*)

In aggregate with the 65 HP tractor on wheels, the installation is transported on the road arranged on the antenna line to one of the hydrants, where it will occupy two working positions. When it reaches the hydrant, the support legs and the jack are fixed in the working position and it is disconnected from the tractor.

The turret is pivoted, the drum is braked by manual operation and the hose is stretched with the help of the tractor. After the hose has been stretched, the operator releases the drum brake and tilts the ratchet on the gear ring; opens the ball valve on the main supply pipe and connects the installation to the hydrant; opens the hydrant and monitors the working pressure on the pressure gauge, adjusting it if necessary, using the connection.

The water intended for irrigation, under pressure, passes through the turbine and enters the drum shaft, then into the vertical pipe and further into the flexible polyethylene hose.

From here the water reaches the nozzles located on the ramp or in the watering cannon and is spread over the ground (watering circuit).

The turbine drives the reducer which in turn drives the drum with 4 speeds even with a low flow or pressure level, with minimal losses.

Rotating, the drum winds the hose and the trolley of the ramp or watering cannon moves towards the installation, the nozzles or cannon watering the ground on which it moves.

The rotational movement of the drum is transmitted via a chain to the device for setting the hose winding pitch. On the axis of the automatic stop device is the sensor for equalizing the speed of the trolley, which, depending on the number of layers of hose rolled on the drum, continuously adjusts the speed of the reducer through a system of levers.

When the trolley of the boom or watering gun has reached the drum, the electric motor is started by the programmable system of the work process, which drives the turbine bypass, stopping the water supply to the nozzles or watering gun. In this position, the installation is found by the operator, who raises the support legs and pivots the turret 180°.

The ramp or watering cannon will reach the other aisle, opposite the one where the previous watering was carried out and, using a mechanism with hydraulic cylinders operated by a manual hydraulic pump, the support legs are lowered. From this moment, the operations are resumed in the same order described and thus the second watering position is irrigated from the same hydrant (patent application RO126176A2, registration no. OSIM A00841/2009) (*http://pub.osim.ro/publication-server/pdf-document?PN=RO126176%20RO%20126176&iDocId=712&iepatch=.pdf*).

The drive mechanism of a pressure irrigation drum can be adjusted depending on the rotation speed of the drum and the movement of the sprinkler by:

- manual adjustment of the valve that changes the flow rate or pressure of the hydraulic motor;

- automatic adjustment, some installations being also equipped with a speed regulator to maintain a constant speed of movement of the sprinkler.

For example, the Bauer company uses the SmartRain application (fig. 5) to monitor the operation of the drum and hose sprinkler irrigation installations, which offers the possibility of controlling the drum and hose sprinkler irrigation installation from any location.

This obtains a remote overview with information about the real status, such as the remaining irrigation time, the remaining PE pipe, the time to change the irrigation tape and others, and the optimization of the installation can be done depending on the soil moisture and weather conditions through the irrigation management function.

It also receives error messages via SMS on the farmer's phone when the installation stops due to a malfunction or if it enters a dangerous area.

Fig. 5 - The SmartRain application developed by Bauer for monitoring the operation of sprinkler irrigation systems with a drum and hose
(*https://www.bauer-at.com/en/product/irrigation/smartrain/*)

Sprinkler irrigation is assessed using the following indices: irrigation uniformity, rain fineness and rain intensity (*Nagy and Luca, 1995*).

Irrigation uniformity is a particularly important index, because the way water is distributed on the land largely determines the quality of the irrigation, the efficiency of irrigation in the field, the uniformity and the increase in agricultural production.

Rain intensity, or pluviometry, represents the amount of water distributed by the ramp or irrigation cannon, per unit of time, per unit of surface area. It is expressed in mm/h, (*Luca and Nagy, 1999*).

The fineness of the rain from the ramp or the irrigation cannon of the irrigation system is determined by the size of the drops and is important in irrigation practice through the correlation that is made with the soil and the plant (*Nagy and Luca, 1995*).

In *Nedelcu, 2010*, it is stated that the duration of watering or the time of stationing, in a working position for applying the watering norm, depends on:

- the size of the watering norm;
- the pluviometry of the sprinkler;
- the chosen layout scheme.

The most common type of sprinkler system layout is shown in figure 5, consisting of a system of light aluminium or plastic pipes that are moved manually, and the rotating sprinklers are usually spaced 9-24 m along the side that is normally 5-12.5 cm in diameter, in order to be easily transported (*Brouwer et al., 1988*).

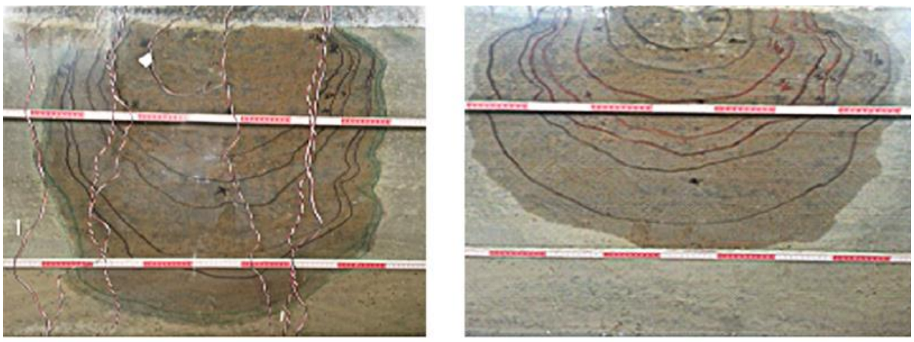
Fig. 5 - Sprinkler system with aluminium pipes

Watering ramps are mechanized systems used for pressure irrigation that are intended for drum and hose irrigation installations, in which water is transported through sections of metal pipes coupled together end to end and distributed to plants through nozzles or sprinklers. They consist of a movable arm (ramp) connected to a water source, which moves along a plot, evenly distributing water in the form of sprinkling or by other methods.

Figure 6 shows a TYPE-3 irrigation ramp, which consists of: a trolley for movement, a support structure for pre-assembled kits through which water is transported to the plants, kits that can be quickly mounted or dismantled on or off the support structure and that can be moved in the direction of increasing or decreasing the distance between them, depending on the distance between the rows of the irrigated crop, other pre-assembled kits for distributing water in the field depending on the chosen irrigation method, e.g. by continuous flow, by sprinkling, by dripping, the working height of the ramp can be adjusted using a manual winch system and some vertical slides with quick locking in position. To use the irrigation ramp (rain wing), the pressure at the entrance to the drum must be at least 2 bar. If the pressure is higher, the irrigation will be more intense, better in quality. The irrigation ramp is compatible with all irrigation drums on the market, with diameters of 90 mm, 110 mm, 125 mm, etc. The irrigation ramp (rain wing) can be equipped with nozzles, with different diameters: 4, 5, 6, 7, 8, 9, 10 mm (*Morimoto et al., 2021*).

Fig. 6 - Watering ramp TYPE-3
(https://www.apftrade.ro/spatii-verzi/rampa-de-udare-type-3.html)

Drip irrigation involves dripping water onto the soil in very small amounts (2-20 litres/hour) from a system of small-diameter plastic pipes fitted with holes called emitters or drippers. The water is applied close to the plants so that only a portion of the soil where the roots grow is wet (fig. 7), (*Marimoto and al., 2021*), unlike surface and sprinkler irrigation, which wet the entire soil profile. Drip irrigation water is applied more frequently (about 1...3 days) than other methods to ensure a high level of soil moisture favourable to agricultural crops.



A B

Fig. 7 - Comparison of soil moisture distribution in sandy soil with emitter flow rate of 2 L/h
A) Pulse drip irrigation; B) Continuous drip irrigation

Drip irrigation can be used on any agricultural crop. Normally, the crop should be planted along the contour of the water supply lines and pipes (laterals). However, drip irrigation is most suitable for row crops (vegetables), tree crops and vines. Figure 8 shows an automated drip irrigation and/or microsprinkler installation for greenhouses and solariums, which consists of a branch (1) for connection to a water storage tank (2), a self-priming electric pump (3), a water meter (4), a pressure gauge (5), some routing elements (6) for water transit through a control head (7) with a fertilizer tank and a filter (8) to a pipe (9) provided with some strips (10) with drippers incorporated in a bay (11) for drip irrigation/fertigation and/or to another pipe (12) provided with some microsprinklers (13) for foliar irrigation/fertigation, a humidity transducer (14), conductivity and temperature in connection with a Data Logger (15) provided with software for controlling solenoid valves (17) in the drip and/or micro-sprinkler irrigation/fertigation circuit, with another software for controlling a frequency converter (16) that controls the rotation speed of an electric pump (3) and with another software for controlling the application of drip and/or micro-sprinkler irrigation/fertigation based on preset programs, depending on the time factor, in the situation when the transducer (14) is inactive (defective) *(Marin et al., 2014)*, (*https://oaji.net/articles/2015/1672-1448748396.pdf*).

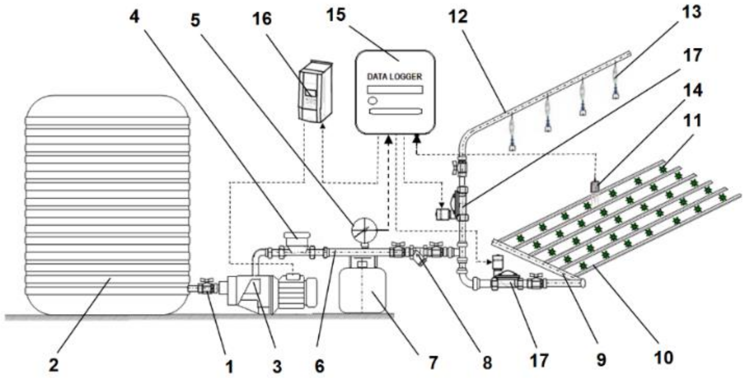


Fig. 8 - Automated drip and/or micro-sprinkler irrigation system

Subsurface drip irrigation (SDI) is the buried version of the traditional drip irrigation system, in which the drip line is buried below the soil surface, instead of being installed directly on the ground, supplying the plant with water directly at the root, and the precise monitoring of soil moisture levels in the plant root zone with the Internet of Things (IoT) ensures long-term productivity (*El-Sheshny et al., 2024*).

For example, an underground irrigation installation was implemented in an experimental plot with an area of 500 m2 (50 m long and 10 m wide) under a grant from the Romanian Ministry of Research and Innovation CCDI - UEFISCDI, Project "Innovative technologies for irrigation of agricultural crops in arid, semi-arid and subhumid-dry climates" (*Șovaiala et al., 2018*).

Figure 9 shows aspects of the irrigation lines being buried with special equipment (*Manea et al., 2021*), of a drip line that was placed in the soil at a depth of 20 cm and of the plot on which the underground irrigation system was installed for a sorghum crop located on the land of SCDCPN Dăbuleni. The distance between two adjacent drip lines was 1 m. The drip tubes that were used are with pressure-compensated and anti-siphon drippers, the distance between the drippers being 33 cm, and the outer diameter of the tube 16 mm. The underground irrigation system was supplied with water from an above-ground irrigation canal, using a Lorentz pump powered by electricity from a hybrid, solar and wind source.

a b c

Fig. 9 - Underground irrigation system implemented in a plot on the land of SCDCPN Dăbuleni

a) Equipment for burying underground irrigation lines; b) Underground irrigation line buried in the ground; c). Plot with underground irrigation system

Subsurface drip irrigation has significant economic effects by reducing water evaporation by about 25%, due to the fact that pH, P, K and Mg influence the structure of the microbial community, according to table 2 presented by Quach and extending the life cycle of the materials used in the entire system, (*Quach et al., 2022*). The advantages of subsurface drip irrigation are related to longevity - it can last up to 20-25 years without major repairs, minimal operational costs, reduced costs for crop maintenance and less use of water resources, which leads to the optimization of crop growth (*Cahn and Hutmacher, 2024*). The disadvantages are related to some external impacts that affect the irrigation system, the most important of which is the fact that, if in the case of an aboveground system, we can quickly notice any possible water loss due to a leaky joint, in the case of underground systems, this is more difficult to detect. Therefore, prior to actual burial of the components, it is necessary to conduct tests to confirm their proper functioning (*Wang et al., 2022*).

Other disadvantages of subsurface drip irrigation in commercial agriculture compared to alternative irrigation systems include higher capital cost per unit of land area (except for small plots of land), unfamiliar management and maintenance protocols that can exacerbate the potential for emitter clogging, visibility of system attributes (components and design) and performance characteristics, and susceptibility to damage (i.e., rodents and tillage) of subsurface drip lines. Despite these disadvantages, subsurface drip irrigation continues to be adopted in commercial agriculture in the US, and research efforts to evaluate and develop systems continue as well.

In the case of daily watering, the watering rate correlates with the daily water consumption, thus maintaining a constant soil water reserve, close to the field water capacity of the soil (*Grumeza and Klepș, 2005*, *Țenu, 2004*). Since the water pressure dissipated on the path to the dripper outlet is a determining factor for determining its flow rate, sophisticated passage models for high pressure dissipation have been developed (*Schwankl, 1992*).

- ***Specifications for mobile irrigation equipment***

Mobile irrigation equipment is a flexible and easy-to-move system, mainly used to irrigate large areas, but also for spot applications or on various terrains.

Table 1 presents some mobile irrigation equipment manufactured by IRRIMEC (*https://www.irrimec.com/?lang=en*).

Table 1

Mobile irrigation equipment manufactured by IRRIMEC -

	Model	Diameter [mm]	Hose length [m]
 Mini Rain AAg irrigation reel	50 TG	50	200
	63 TG	63	160 – 200 – 240
	70 TG	70	180 – 200 – 230
	75 TG	75	110 – 145
 Rain Sky A5 irrigation reel	50 F	150 50	150 – 180 – 200
	58 F	110 58	110
 Rain Sky AAA irrigation reel	40 F	110 40	110 – 130

 Eco Rain ST 2 irrigation reel	63 TG	63	250 – 280 – 300
	70 TG	70	220 – 240 – 270 – 300
	75 TG	75	200 – 220 – 230 – 245 – 250 – 300
	82 TG	82	180 – 200
 Eco Rain ST 3 irrigation reel	63 TG	63	280 – 350
	70 TG	70	265 – 280 – 300 – 310
	75 TG	75	245 – 300 – 320 – 350
	82 TG	82	220 – 270 – 300 –
	90 TG	90	200 – 230
 Opti Rain ST 4 irrigation reel	75 TG	75	350 – 400 – 430
	82 TG	82	350 – 380 – 400
	90 TG	90	300 – 320 – 340
	100 TG	100	240 – 270 – 300
	110 TG	110	200 – 230

Irrigation with drones is a cutting-edge technology that uses modern technology to improve irrigation efficiency and reduce water consumption, making it an ideal method for precision agriculture (*Khadse, 2021*).

This represents an important step towards sustainable and resource-efficient agriculture, and the choice of an irrigation drone should be based on the specific irrigation needs, land size, crop type, and available budget (*Rakhade et al., 2021*).

Types of drones:

- **DJI Agras**: DJI is a leader in drone technology, and its range **DJI Agras** offers specific drones for irrigation, with large water tanks and efficient spraying systems (*https://www.dji.com/global*).
- **Parrot Bluegrass**: Parrot is another brand well-known for its agricultural drones. The Parrot Bluegrass is equipped with multispectral cameras and can be used for crop monitoring as well as irrigation. (*https://www.parrot.com/en*).
- **XAG P150 (table 2 row 3)**: An irrigation drone from China, which is used to spray water, pesticides and fertilizers on large agricultural fields (*https://hse-uav.com/products/xag-p150*).

DJI Agras T30 (table 2 row 1) is a great example of a spraying drone with a 30-liter tank and 16 nozzles that can be used for irrigation. Waterproof and equipped with a high-precision RTK system, this drone offers extensive coverage and optimized spraying, making it ideal for a variety of terrains, including farmland and orchards (*https://www.dji.com/global/t30*).

Table 2

Several types of agricultural drones used for crop irrigation

Crt. No.	Type of drones	Characteristics
1	 DJI Agras T30 (*https://www.dji.com/global/t30*)	- Operational efficiency (per hour) 16 hectares; - Spray tank volume 30 L (fixed tank); - High-precision radar; - AI intelligent engine for 3D operation planning; - High-precision flow meter; - Intelligent altitude control: Automatic altitude adjustment to maintain a constant height - Total weight (without battery): 26.4 kg

2	 ADT FALCON 50L (*https://appiadronetech.com/agricultural-and-farming-drones/adt-falcon-50l/*)	- Spraying efficiency up to 5280 m²/min - Liquid tank volume is 50 litres - Flight time 10-15 minutes - Flight range 0-1500 m - Flight height 0-20 m - Flight speed 0-10 m/s - Downward air flow 4-15 m/s - Wind resistance 10 m/s - Net weight 24.5 kg
3	 XAG P150 (*https://www.xa.com/en/p150/p150specs*)	- Maximum take-off weight: 96 Kg - Number of rotors: 4 - Liquid tank capacity: 50l - Maximum spraying flow rate: 22 l/min - Spraying width: 5...10 m - Solids tank capacity: 80 l - Spreading width: 3...7 m - Maximum distribution quantity: 150 kg/min

Pumping units can be motor pumps or electric pumps depending on the availability of the water resource, supplied directly from the source (irrigation canals, water courses) or reservoirs (metal basins, concrete or waterproofed basins), when the water resource is limited or taken from boreholes (*Alijanov et al., 2020*).

At irrigation pumping stations (unlike water supply pumping stations), the uniform operation of the pumping equipment is characterized by relatively constant flow and pressure over a certain period of time, and the pump must operate under optimal conditions with the highest efficiency (*Kan et al., 2020*).

The efficiency criterion of the pumping station is the degree of completeness of the coverage of the water consumption program by the water supply program, provided that minimum operating costs, health and safety requirements are met (*Platonov et al., 2019*).

In the works *Eckstein, 1990*, and *Al-Ibrahim, 1997,* a detailed theoretical analysis was developed to determine the characteristics of the motor and pump.

- ***Specifications regarding the commissioning and operation systems of irrigation installations***

The commissioning and operation of irrigation systems involves the use of pumps, which play an essential role in the operation of agricultural crop irrigation, with the main purpose of ensuring the circulation of water in the system, at the required pressure and flow rate (*Guler, 2001*).

There are many recognized brands that produce irrigation pumps, each with specifications adapted to various agricultural, horticultural or residential applications. Here is a list of the most popular brands of irrigation pumps and their characteristics:

Submersible pump Grundfos SP 9-11 is suitable for pumping clean water. Grundfos SP are stainless steel pumps, designed for pumping groundwater. It can be installed vertically or horizontally. This pump is approved for drinking water. The characteristics of the Grundfos SP 9-11 Rp2 4"3X380-415/50 2.2kW submersible pump are on: *https://www.pompe-grundfos.ro/pompe-apa-grundfos/sp9-11-rp2-43x380-41550-22kw-98699055*.

Submersible pump Grundfos SQE 2 – 100: is a 3" multistage submersible pump designed for domestic water supply, liquid transfer in tanks, irrigation and environmental applications. The pump has flooded impellers, each with its own tungsten carbide/ceramic bearing. The characteristics of the submersible pump - Grundfos SQE 2 – 100 are on: *https://www.pompe-grundfos.ro/pompe-apa-grundfos/pompe-grundfos-sq-sqe*.

Centrifugal pump Grundfos CR 5-3: the characteristics of the submersible pump - Grundfos CR 5-3 are presented on: *https://product-selection.grundfos.com/products/cr-cre-cri-crie-crn-crne-crt-crte/cr?tab=models*.

Pedrollo CB2 - F 50/250A pressure groups: the pressure groups are composed of two pumps assembled in a ready-to-install unit. The groups are designed in such a way that at any request for pressure increase from the user, one or both pumps will automatically start in succession. The operation of the pumps is necessary to satisfy the water demand, significantly reducing energy consumption and the electronic circuits present in the electrical panel alternate the operation of the pumps. The characteristics of the pressure group Pedrollo CB2 - F 50/250A are: *https://pompesubmersibile.ro/grupuri-pompare-pedrollo/grup-pompare-pedrollo-CB2-F-50-200A*.

Submersible pump Wilo Sub-TWI 5 505: a multistage submersible pump for pumping clean water from tanks, cisterns, wells and shallow wells, up to an immersion depth of 17 m. Suitable for applications such as water supply, sprinkling, spraying, rainwater recovery. All components that come into contact with the pumped fluid are protected against corrosion. The pump characteristics Wilo Sub-TWI 5 505 (1~230 V, 50 Hz) are: *https://pompesubmersibile.ro/grupuri-pompare-pedrollo/grup-pompare-pedrollo-CB2-F-50-200A*.

Limiting noise and vibration of irrigation pumps is dictated by many circumstances, including direct technical requirements and operating conditions. Factors leading to damage to pumping units are: long-term static effects, stresses; static effects and repetitive stresses; noise and vibration effects; wear of the device design; corrosion and fatigue effects (*Bekchanov et al*., *2021*; *Chițoiu et al, 2020*) give an example of calculating the time-averaged sound pressure level for the noise source of a WTH 60 centrifugal pump equipped with an internal combustion engine.

With the increasing demand for energy worldwide, the generation of electricity based on solar energy produced by photovoltaic panels, which is based on the direct production of electricity through silicon cells, has become promising and suitable for pumping water for irrigation in agriculture (*Aliyu et al*., *2018; Mateescu et al., 2023*).

The energy converted from the photovoltaic cell depends on the day-night cycle, the latitude of the place where it is captured, the seasons and the cloud cover. The photovoltaic array has an optimal operating state known as the maximum operating point (MPP), which is dependent on the level of irradiation, and when it shines and when the climatic conditions are favourable, the sun provides a power of 1 kW/m^2. Photovoltaic panels allow the direct conversion of 10 - 15% of this power into electricity (*Singh, 2013*). *Enescu et al., 2020,* conducted an analysis of the values recorded in the peak months (May-September) of a photovoltaic park for the supply of electricity to pumps at an irrigation system station and the values of the off-season months.

- **Factors influencing the process and qualitative indices of equipment intended for crop irrigation**

The irrigation process and the quality of irrigation equipment are influenced by a number of technical, economic and environmental factors. When choosing irrigation equipment for crops, it is essential to consider these factors to ensure the efficiency, durability and sustainability of the system.

The optimal design of a gravity irrigation network involves water availability, crop, soil characteristics, land topography and associated cost (*Holzapfel et al., 2009; Fouial et al., 2017; Duan et al., 2022*).

The main factors influencing the process and qualitative indices of crop irrigation equipment are:

- the type of crop because each crop has different requirements in terms of the amount of water needed, the type and characteristics of the soil, for example clay soils have a higher water retention capacity compared to sandy soils,
- climatic conditions and rainfall regime,
- the type and efficiency of the irrigation equipment, thus sprinkler irrigation is suitable for large fields, and drip irrigation offers precise water distribution,
- installation and maintenance costs, such as those by drip or automated sprinklers, may involve higher initial costs,
- access to the water source and its distribution and the durability and materials of the equipment, in order to have a long lifespan, they must be built from durable materials and resistant to UV, frost, extreme heat and humidity.

In *Pelea, (2021)*, the results of a study on the uniformity of irrigation application and water quality for irrigation within the local irrigation arrangement Emiliana West Rom Srl Plot Aranca are given. The main objective of the study was to analyse the uniformity of watering application for the linear and centre pivot type sprinkler irrigation installation.

Balaj, (2018), conducted studies and research on establishing the possibilities of using solar energy in land improvement arrangements, especially for local arrangements, on small areas especially in areas where there is adequate solar radiation and there is no electrical network to supply electric current to the pumps. For this purpose, Balaj used the Solar platform of the West University of Timișoara which includes a Solar Radiation Monitoring Station (SRMS) and three experimental stands dedicated to testing PV modules. The Solar Radiation Monitoring Station is equipped with first-class DeltaOHM pyranometers, in accordance with the ISO 9060 standard. The platform monitors global, diffuse, reflected and total solar irradiance. The measurement of all parameters (electrical, meteorological, radiometric) was made according to (*http://solar.physics.uvt.ro/srms/*).

Choudhury et al., (2011), considers that the passing wind drives the blades of a wind turbine, generating lift and exerting a turning force so that the blades rotate a shaft in a speed multiplier, which drives a generator to convert the rotational energy into electrical energy. In *Johari et al., (2018),* are described the results of some research on the performance of the HAWT wind turbine compared to the VAWT. The HAWT wind turbine has already been used since 5000 BC where people extracted energy from the wind to move boats along the Nile River.

Farrokhi & Parvaresh, (2022), consider that energy plays a vital role in ensuring security, development and economic stability within societies and especially given the fact that in the agricultural sector, the transition from surface irrigation to pressurized irrigation systems was adopted to increase the efficiency of water consumption. This change led to an increase in energy consumption and the largest part, about 70% of energy consumption in the agricultural sector is pumps in pumping stations.

Qin et al., (2024), estimate that irrigation contributes 216 million metric tons of CO_2 emissions and consumes 1896 petajoules of energy annually, representing 15% of greenhouse gas emissions and energy used in agricultural operations, especially since only 40% of irrigated agriculture relies on groundwater sources, groundwater pumping represents 89% of total energy consumption in irrigation.

CONCLUSIONS

The research presented in this paper constitutes a foundational step in the development of SEMSI – an innovative, mobile, energy-independent subsystem designed for irrigation systems that operate without conventional energy sources. Through an extensive review of global irrigation practices, equipment types, and energy integration methods, the paper consolidates key knowledge required for the design and optimization of sustainable irrigation technologies.

This study contributes a structured synthesis of the operating principles, design specifications, and influencing factors of various irrigation systems, with a particular focus on mobile equipment and renewable energy integration. The collected data and theoretical background support the formulation of a mathematical model and provide essential inputs for the experimental research and validation phase of SEMSI.

Irrigation is an important technological measure, with the following effects:

- obtaining high yields, regardless of the amount of precipitation, because irrigation completes the water deficit, which is distributed in relation to the requirements of the plants;
- using fertilizers by plants with greater efficiency by increasing the degree of solubilization of substances;
- extending the vegetation period of plants and better staggered production.

A synthesis of studies conducted on the working process of equipment intended for crop irrigation and the factors that influence it was presented through a general analysis of the irrigation process, a study of the working process of equipment intended for irrigation, a study of some specifications regarding mobile irrigation equipment and systems for commissioning and actuating irrigation installations and finally, the factors that influence the process and qualitative indices of equipment intended for crop irrigation.

The findings highlight the importance of efficient water management in agriculture and the growing need for adaptable, energy-efficient irrigation solutions. Future work will build on this foundation to simulate, improve, and implement SEMSI in real-world scenarios, contributing to climate-resilient agricultural practices and sustainable rural development.

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