Review Article

Climate Resilient Water Management for Sustainable Agriculture

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ABSTRACT

The management of water resources in both irrigated and rain-fed agriculture is becoming an increasingly complex worldwide due to anticipated water scarcity, and compounded by the challenges of global warming and climate change. Climate-smart water technologies *viz.* Drip irrigation, Central pivot irrigation, Hydrogel and SWAT method need to be judiciously applied to overcome these challenges. Agriculture is a critical sector in India and other developing countries, providing substantial employment opportunities to rural populations and supporting efforts to achieve food and nutritional security. This paper addresses the challenge of increasing food production and improving rural livelihoods while safeguarding critical water resources for sustainable use, particularly in drought-prone regions, through adaptive measures for effective water management. An integrated approach is necessary for agricultural water management through the adoption of innovative technologies such as water harvesting, micro-irrigation, and resource conservation farming to increase water-use efficiency in agriculture and other critical services to humans and animals. The study aims to enhance understanding of the potential implications of climate change and adaptation options for agricultural water management, thereby enabling them to take up adaptation challenges and develop measures to reduce the farming sector's vulnerability to climate change.

Keywords:Drip irrigation, Central pivot irrigation, Sustainable, Hydrogel and SWAT Model

INTRODUCTION

The growth and productivity of crops are highly dependent on the availability of an adequate water supply (Morison *et al.*, 2008)[1]. Irrigation refers to the artificial application of a precisely controlled amount of water to the soil, with the intention of providing plants with the required moisture for growth (Obaideen *et al.*, 2022) [2]. Plants require additional water through irrigation when there is not enough rainfall (Levidow *et al.*, 2014) [3]. There are numerous irrigation methods available for providing water to plants, each with its own unique benefits and drawbacks. It is crucial to take into account these factors when deciding on the most appropriate irrigation method for local conditions (Zhang *et al.*, 2020) [4]. Water management involves the strategic planning, creation, allocation, and efficient administration of water resources to ensure their optimal utilization. Water is a basic need & No living being can survive without water. Due to a scarcity of water, it is crucial to save and manage it effectively in order to prevent shortages (Fedele *et al.*, 2021) [5]. Agriculture is clearly climate dependent. The impact of climate on crop growth and production poses a significant challenge for farmers (Rahman *et al.*, 2022) [6]. Climate impact is a challenge to crop growth and production. Because at present, crop production is affected by natural calamities like high rainfall, floods, drought conditions, storms etc. (Arora, 2019) [7].

EFFECTS OF CLIMATE CHANGE

Climate pertains to the extended trends of weather elements in a given region, encompassing temperature, precipitation, flooding, drought, and other variables. Regrettably, the current rate of climate change is taking place at a concerning speed, primarily because of human activities such as deforestation and the utilization of fossil fuels (i.e., oil, gas, and coal) for transportation, factories, and residential purposes (Shivanna, 2022) [8]. Crop growth and development depend on environmental factors such as climate and soil. The weather during harvest time plays a crucial role in the success or failure of crops. Although modifying the weather is challenging and not cost-effective, adjusting cropping patterns and adopting suitable agricultural practices can improve crop yields by reducing the negative effects of weather conditions. Climatic factors affect all stages of agricultural activity, from tillage to storage, emphasizing the need for farmers to have a sound understanding of these factors and their interaction with crops (Sadras *et al.*, 2016) [9]. The modification of the balance and concentration of greenhouse gases in the atmosphere, which include water vapor, methane, carbon dioxide, ozone, and PFCs, is accountable for climate change. The rise in greenhouse gas emissions contributes to the spread of communicable and non-communicable diseases, impacts negatively on nutrition, water security, and other social upheavals. Atmospheric pressure is gradually intensifying the greenhouse effect, causing a steady rise in the global average temperature. The concentration of CO2 has already surpassed 400 ppm (Mikhaylov *et al.*,2020) [10]. Starting from 1880, the temperature of the Earth has been increasing at a rate of 0.08°C per decade. This rate has more than doubled in the last 40 years, increasing to 0.18°C) per decade since 1981. As of 2020, surface temperatures were 0.98°C higher than the average temperature of the twentieth century, which was 13.9°C. Additionally, temperatures were 1.19°C higher than during the pre-industrial period of 1880-1900 (Lugo *et al.*, 2020) [11].

IRRIGATION

Irrigation is the process of artificially adding water to soil to provide the necessary moisture for plant growth. This technique helps ensure that crops have access to the required amount of water, which is essential for their growth and survival. Moreover, irrigation can provide a measure of insurance against short-duration droughts by maintaining adequate soil moisture levels (Seleiman *et al.*, 2021) [12]. Irrigation can provide several benefits to the soil and crops. Firstly, it cools the soil atmosphere, creating a more favorable environment for plant growth. Secondly, it can wash out excess salts in the soil, which can be harmful to plants. Lastly, irrigation can help soften tillage pans, making it easier for roots to penetrate the soil and access nutrients (S R Reddy, 2014) [13]. Irrigation can provide several benefits to the soil and crops. Firstly, it cools the soil atmosphere, creating a more favorable environment for plant growth. Secondly, it can wash out excess salts in the soil, which can be harmful to plants. Lastly, irrigation can help soften tillage pans, making it easier for roots to penetrate the soil and access nutrients (Burt *et al.*, 2000) [14]. Choosing the most suitable irrigation method is dependent on several factors, including: crop type, land characteristics, climate conditions, economic feasibility, water quality, availability of support infrastructure, and energy supply. There is no universally "best" irrigation method that can be applied in all situations. Hence, it is important to consider the local conditions and evaluate the various irrigation methods to determine the most suitable one for a particular area or crop (Burt *et al.*, 2000) [14].

Importance and Necessity of irrigation

Water is a vital necessity for crops, just like sunlight and air. While rainfall is the primary source of water for crops, it is not always consistent or predictable. This is where irrigation systems come in as they ensure a controlled and steady water supply for crops. To obtain the maximum yield from crops, it is crucial to have a systematic and optimal irrigation system that provides water in the right quantity and at the proper intervals (Schoengold and Zilberman, 2007) [21].

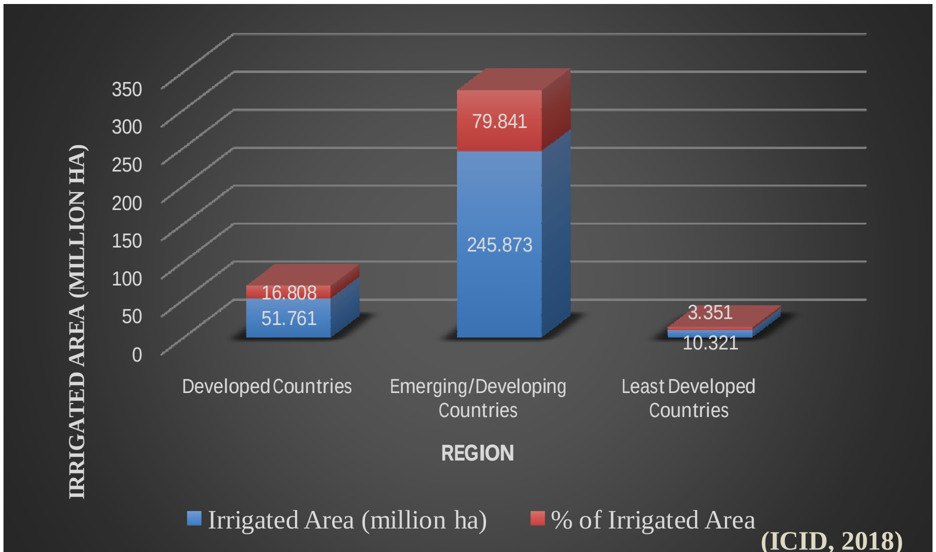


Fig. 1. World Irrigated Area

The importance of irrigation can be summarized as follows:

1. When there is insufficient or non-uniform rainfall
2. To increase crop yield
3. As a safeguard against drought
4. To enable the growth of multiple crops throughout the year

Water application methods grouped into different categories based on their characteristics

1. Direct application on the land surface
2. Applying water beneath the soil surface directly to the root zone
3. Spraying water under pressure.
4. Applying in drops under pressure.

<u>Type of irrigation system</u>

There are several irrigation methods available to provide crops with the necessary amount of water. The choice of irrigation method depends on the type of crops being cultivated. Below are some of the frequently used irrigation methods:

Surface irrigation*:* The irrigation method being described is surface irrigation, which involves the distribution of water over the soil surface using channels, furrows, or borders. It is a low-cost method commonly used for crops that can withstand waterlogging.

Subsurface irrigation*:* This approach entails supplying water to crops' roots using buried pipes, tubes, or porous containers. An efficient method minimizes water loss and soil erosion.

Sprinkler irrigation*:* This method involves spraying water over the crops using pipes and sprinkler heads. It is a versatile method suitable for a wide range of crops, but it requires higher upfront costs and regular maintenance.
Additional irrigation techniques comprise center pivot irrigation, lateral move irrigation, drip irrigation, and others. The choice of the most suitable method depends on a range of factors, including crop species, soil characteristics, water accessibility, and topography (Holzapfel *et al.*, 2009) [23].

Sprinkler irrigation system

Sprinkler irrigation is a technique that consists of discharging water into the air, letting it descend onto the soil surface, resembling natural precipitation. Water under pressure is channeled through tiny nozzles or orifices, often by means of a pump, creating the spray. Via are carefully choosing the appropriate nozzle sizes, operational pressure, and sprinkler spacing, it is feasible to achieve a nearly even distribution of irrigation water and replenish the crop root zone at a rate that aligns with the soil's infiltration rate. (Patel and Parjapati, 2020) [24].

Table 1. Sprinkler irrigation system

Type of Sprinkler	Precipitation Rate (mm per hour)
Low Volume	**<13**
Medium Volume	**13 – 25**
Large Volume (Raingun)	**>25**

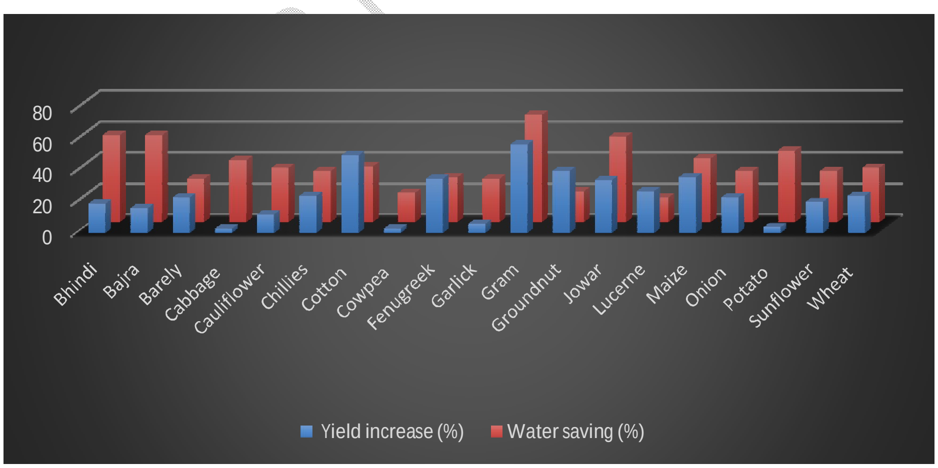


Fig.2. Response of different crops to sprinkler irrigation

WATER MANAGEMENT

Water management involves the strategic planning, developing, distribution and sustainable utilization of water resources according to established policies and regulations. The primary goal of water management is to regulate the distribution and movement of water resources, ensuring the protection of human life and property while promoting the efficient and effective use of available water (Loucks *et al.*, 2017) [15]. Water is a crucial component in agricultural production and is essential for ensuring global food security. Irrigated agriculture covers 20% of the world's cultivable land and is accountable for generating 40% of the world's overall food supply. (D'Odorico *et al.*, 2020) [17]. In contrast to rainfed agriculture, irrigated agriculture is usually more productive, generating at least twice the amount of yield per unit of land. This increased productivity enables greater production intensity and diversity of crops (Jaramillo *et al.*, 2020) [18]. The increase in population growth, urbanization, and climate change will intensify the competition for water resources, which will disproportionately impact agriculture. By 2050, the global population is projected to surpass

10 billion, driving demand for food and clothing. The rising consumption of calories and diverse foods, linked to income growth in developing countries, will require agricultural production to increase by approximately 70% by 2050 (SMF. Islam *et al.*, 2020) [19]. The International Water Management Institute (IWMI) predicts that by 2025, one-third of the world's population will experiencewater scarcity, highlighting the critical role that water management will play in the coming years (Ungureanu *et al.*, 2020) [20].

CROP RESPONSE

Experiments carried out in different areas of the country have demonstrated that utilizing a sprinkler system can lead to water conservation of between 16% and 70% relative to conventional methods. The crop yield improvement, which fluctuates depending on the crop and agro-climatic circumstances, has ranged from 3% to 57%.

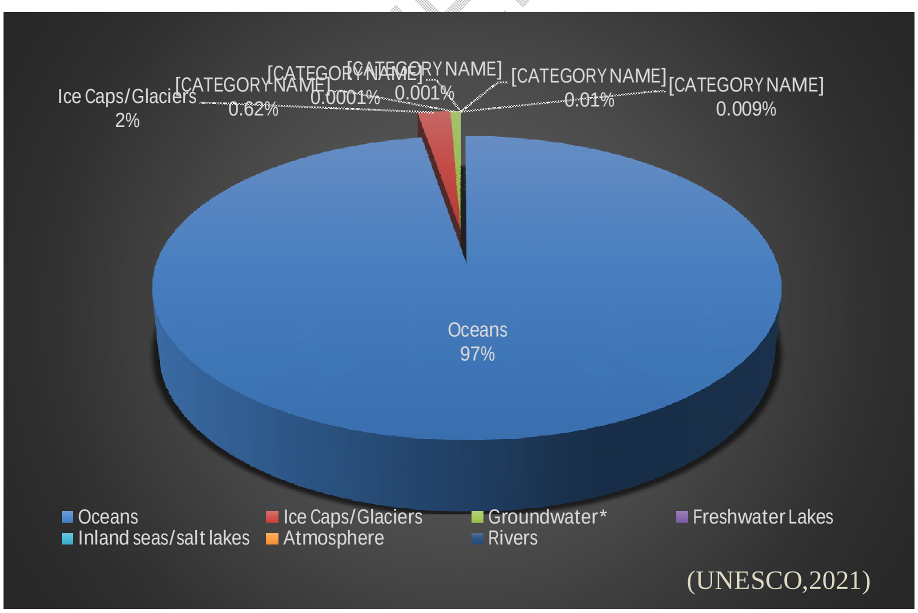


Fig. 3. Percentage of Water present scenario Worldwide

Source: - *https://agritech.tnau.ac.in/agricultural_engineering/spring_irrigation.pdf*

Suitable area for sprinkler irrigation

Slopes: - Sprinkler irrigation can be used on any type of agricultural land, regardless of slope. It is best to lay the lateral pipes along the natural gradient of the land to maintain uniform pressure and uninterrupted irrigation.

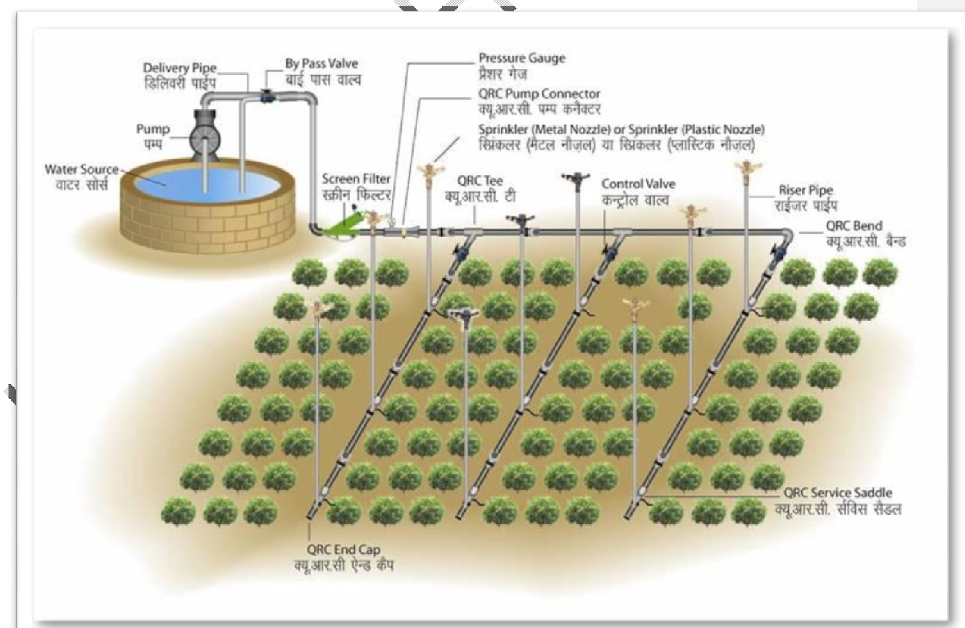
Crop: - Most crops can be irrigated with sprinklers, but larger sprinklers may damage delicate crops.

Soil: - Sprinkler irrigation is suitable for both sandy and clayey soils, but soil with a high infiltration rate is more adaptable. If soil has a tendency to form a crust, fine droplets of water should be used to avoid interruptions to uniform irrigation. The average rate of water application should be less than the natural infiltration rate to avoid ponding and runoff.

Irrigation water: - For efficient irrigation, the water quality must be checked. Clean water without suspended particles is suitable for sprinkler irrigation. Otherwise, particles can settle near the sprinkler nozzles, causing blockages and hindering water supply (Albaji *et al*., 2014) [25].

Components of a sprinkler irrigation system are:

1. A pumping unit
2. Debris removal equipment
3. Pressure gauge / water-meter
4. Pipelines (mains – sub-mains and laterals)
5. Couplers
6. Riser pipes
7. Sprinklers
8. Additional components commonly used in irrigation systems include valves, elbows, tees, couplings, plugs, and other fittings. (McLean *et al.*, 2000) [26].



Layout of Sprinkler Irrigation System (छिड़काव सिंचाई प्रणाली का रेखाचित्र)

Fig. 4. Layout of sprinkler irrigation system
Source: *https://vikaspedia.in/agriculture/agri-inputs/farm-machinary/sprinkler-irrigation-system*

Pumping unit: - It is an essential component of the sprinkler irrigation system, which is responsible for lifting water from a water source, such as a well or a reservoir, and delivering it to the sprinklers. The pump type typically used for this purpose is a high-speed centrifugal or turbine pump, which is driven by an electric motor or a diesel engine. The suction line of the pump is equipped with a foot valve to prevent backflow of water, and the discharge line is connected to the main pipeline of the sprinkler system.
Pipeline: -The two types of pipelines in a sprinkler irrigation system are mains and laterals. Primary pipelines convey water from the pumping unit to different sections of the field, and sub-main lines, in some instances, transport water from the mains to the laterals. Meanwhile, the laterals distribute water from the primary or sub-main pipeline to the sprinklers. The system's design and needs determine whether these pipelines are permanent, semi-permanent, or portable.

Couplers: -Couplers are used to connect two pieces of tubing or to connect tubing to fittings in a sprinkler system.

Sprinklers: -Sprinklers are available in both rotating and fixed types. Rotating sprinklers are versatile and can be customized to fit various application rates and spacing needs. They work efficiently within the 10 to 70 meters of head pressure range at the sprinkler, but for most farms, pressures between 16 and 40 meters of head are typically suitable. Conversely, fixed head sprinklers are usually utilized for watering smaller areas, like lawns and gardens.

Water meters: -These devices are utilized to measure the amount of water delivered by the sprinkler system.

Pressure gauges: - They play a crucial role in maintaining the desired pressure for uniform water delivery through the sprinkler system.

Debris removal equipment: - When utilizing surface water sources like streams, ponds, or canals, debris removal equipment is required. They prevent debris like sand, leaves, and sticks from plugging the sprinklers.

Fertilizer applicators: - These come in different sizes and are used to inject liquid fertilizers into the sprinkler system at the desired rate (Uddin, 2012) [27].

Advantages

1. Sprinkler irrigation eliminates the need for channels, reducing conveyance loss.
2. This method is suitable for irrigating high plant density crops, particularly oil seeds and cereals.
3. Sprinkler irrigation saves water by up to 35-40% compared to surface irrigation methods.
4. It is suitable for undulating topography or sloped lands.
5. Sprinkler irrigation reduces soil erosion.
6. It is effective for irrigating coarse-textured soils, such as sandy soils.
7. It can be used on most soil types except for heavy clay soils.
8. This type of irrigation creates a conducive micro-climate for crops.
9. Sprinkler irrigation can protect crops from frost and high temperatures.
10. It eliminates drainage problems.

11. Sprinkler irrigation saves land compared to surface irrigation.
12. It is possible to apply fertilizers and other chemicals via the irrigation water.
13. It allows for even distribution of fertilizers, preventing wastage.

Disadvantages

1. The initial investment cost for purchasing equipment for a sprinkler irrigation system can be high.
2. The use of sprinkler irrigation with saline water can lead to potential problems.
3. Sprinkler irrigation requires a continuous water supply to distribute water droplets evenly.
4. In windy and humid environments, water evaporation can occur during sprinkler irrigation.
5. Nozzles of the sprinkler system can potentially become clogged due to sediment and debris in the water supply.
6. Continuous power supply is necessary for operating the sprinkler irrigation system (Lamm, 2002) [28].

Drip Irrigation Method

Drip irrigation is a highly efficient method of irrigating crops, which offers several advantages over other irrigation techniques, including lower evaporation rates. This method is commonly known as "micro-irrigation" and is considered one of the most advanced techniques used in agriculture today. Compared to traditional spray irrigation, drip irrigation is much more efficient for certain crops as it minimizes water loss due to evaporation. Drip irrigation conveys water via pipes with tiny perforations, either buried or slightly above the soil, positioned next to the crops. Water trickles slowly onto the roots and stems of the plants. This approach minimizes water loss through evaporation compared to spray irrigation and allows water to be delivered specifically to plants that need it, leading to reduced water waste (Jamrey and Nigam, 2018) [29].

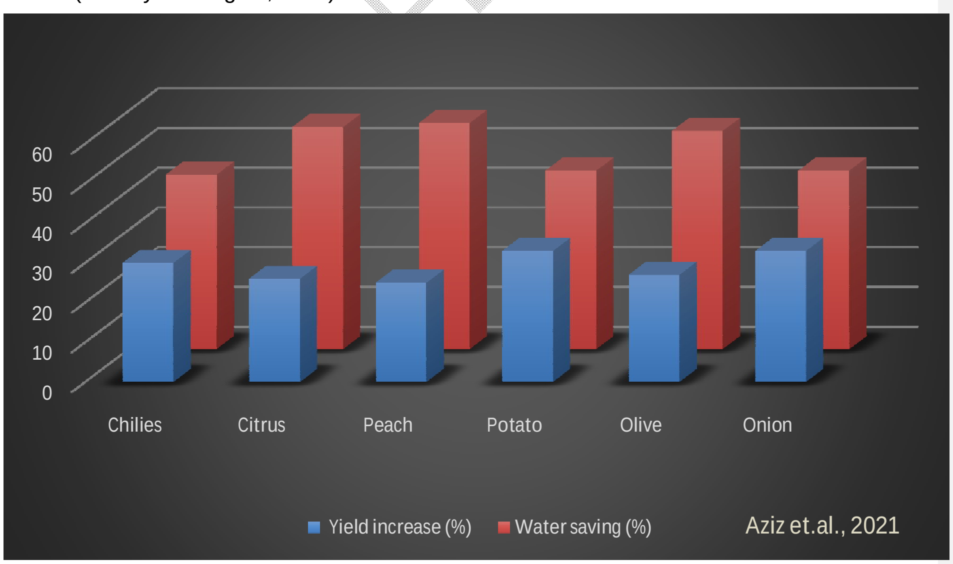


Fig. 5. Response of different crops to Drip irrigation

Component of drip irrigation system

1. The components of a drip irrigation system generally include a pump or elevated tank, a main pipeline, sub-main lines, lateral pipes, and emitters.
2. Water is transported from the mainline to the sub-mains and then to the laterals in a drip irrigation system.
3. The laterals are equipped with emitters that distribute water to the plants for irrigation.
4. Usually, black PVC (poly vinyl chloride) tubing is utilized in the production of mains, sub-mains, and laterals, as well as emitters.In addition to the above components, other essential elements of a drip irrigation system include regulators, filters, valves, water meters, and fertilizer application devices (Li *et al.*, 2015) [31].

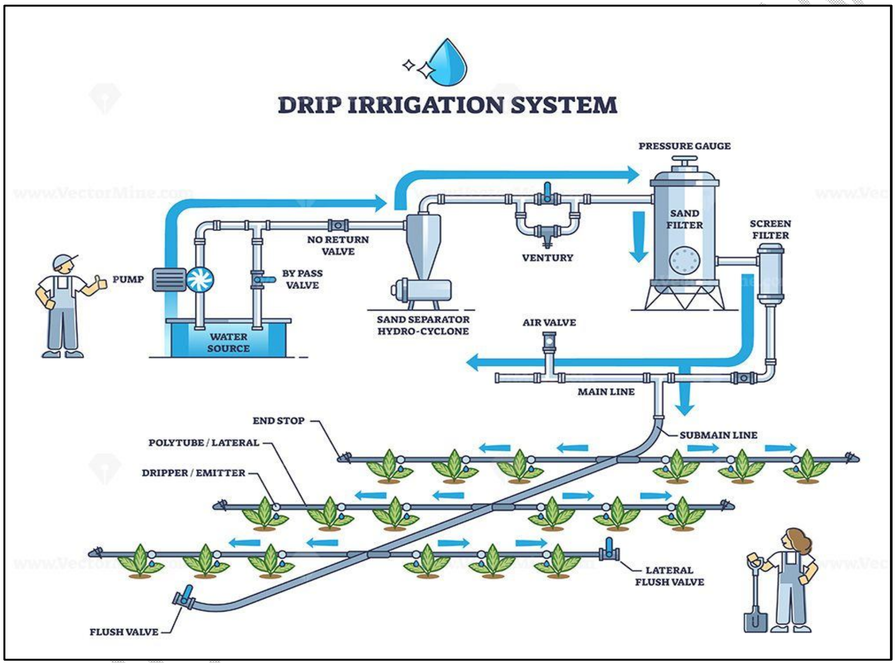


Fig. 6. Drip irrigation system
***Source: -** https://images.app.goo.gl/4ZGAQN6FBBEpuKSR6*

Pump: - A pump generates pressure required to move water through a drip irrigation system, including the mainline, laterals, drippers and emitters. Commonly, centrifugal pumps powered by either engines or electric motors are utilized. Laterals can function under low pressures ranging from 0.15 to 0.2 kg/cm2, but they can also handle higher pressures of 1 to 1.75 kg/cm2. It is worth noting that the water discharged from the emitters is typically at or near atmospheric pressure.

Tank: - Certain drip irrigation setups feature a reservoir at the start of the system to introduce herbicides, fertilizers and other chemicals into the field concurrently with the irrigation water. This tank is known as a chemical tank.

Filter: -The filter system is a crucial component of a drip irrigation system as it helps to prevent blockages in the pipes and emitters/drippers. This system typically includes valves and a pressure gauge that enable regulation and control of the water flow.

Emitters: - Drip nozzles, commonly known as emitters or drippers are spaced evenly along the laterals in a drip irrigation system. Emitters enable water to seep out slowly, often as tiny droplets. The volume of water released by each emitter over time primarily hinges on the opening's size and pressure. Typically, emitter discharge rates vary from 2 to 10 liters per hour. Micro-tubes may also be incorporated in the lateral pipes of a drip irrigation system. They serve various purposes, such as acting as emitters, connectors, and pressure regulators (Arshad, 2020) [32].

Advantages

1. **Reduced water usage: -** Drip irrigation specifically targets the root zone, thereby curtailing water loss on regions that do not benefit the plant, resulting in lower water consumption.
2. **Healthier foliage: -** Unlike above watering that leaves the plant's foliage wet long after irrigation, drip irrigation keeps the leaves dry, promoting healthier foliage.
3. **Prevents fungus: -** Drip irrigation prevents the spread of fungus like powdery mildew that is caused by wet leaves, by keeping the foliage dry.
4. **Prevents soil erosion: -** Drip irrigation's slow and gentle flow curbs runoff and limits soil erosion.
5. **Reduce weeds: -** Drip irrigation reduces weed growth as areas between plants don't receive water.
6. **Nutrient runoff minimized: -** With drip irrigation, nutrient runoff is minimized since less water is being used, reducing nutrient loss.
7. **Drainage and leveling don't require: -** Unlike typical irrigation setups that require proper location leveling and drainage to avoid standing water, drip irrigation requires less leveling and drainage since water is directed directly to the root system, and less water is left on the soil surface.
8. **Work under low pressure: -** Drip irrigation works well with low pressure, unlike most overhead irrigation systems that require pressure tanks when there are many sprinkler heads.

Disadvantages

1. The initial installation cost of drip irrigation can be high.
2. Drip irrigation requires more technical knowledge and skills for optimal operation and efficiency.
3. A reliable and decent quality water source is necessary for drip irrigation as a poor water source can lead to issues such as increased salinity or clogging of drippers.
4. Maintenance costs can be high if the system is not managed properly, and clogging of drippers/emitters can be a major issue.
5. Lack of third-party support and customer service can be a problem for drip irrigation users.
6. Availability of spare parts can be an issue in some regions.
7. Drip irrigation only waters a specific portion of the land, which may prevent complete development of soil microbiota and mineralization of soil organic matter and amendments across the entire field (Lamm,2002 [28] and Dasberg *et al.*, 1999) [33].

Central Pivot Irrigation system

Center pivot irrigation is a type of mechanized irrigation system that uses rotating sprinklers mounted on a long lateral arm. The arm is attached to a central pivot point, which is usually a well or water source. As the pivot rotates, the sprinklers apply water in a circular pattern, irrigating the crops below. The system is capable of covering large areas of farmland with minimal labor requirements, and is often used in regions with low rainfall and high evaporation rates. While center pivot irrigation can be highly effective, it also has some potential drawbacks, such as high installation and maintenance costs, the need for reliable water sources, and the risk of soil erosion (Shilpa *et al.*, 2019) [34].

Components

Center pivot irrigation systems consist of a series of components that work together to deliver water to crops. The main components include a pivot point, a water supply, a control panel, a drivetrain, wheels, sprinkler heads, and end guns. The pivot point serves as the anchor point for the system and allows it to rotate around a center point. The water supply is typically a well or reservoir that pumps water to the system's control panel, which monitors and adjusts the water flow.The drivetrain and wheels allow the system to move in a circular pattern, while the sprinkler heads distribute water to the crops. The end guns are located at the end of the pivot arm and are used to deliver water to areas beyond the system's radius (Matilla *et al.*, 2020) [35].

Fig. 7. Center pivot irrigation systems
***Source: -**https://www.agrivi.com/blog/center-pivot-system-an-efficient-and-economical-solution-for-irrigation/.*

Advantages

1. **Efficient use of water: -** The center pivot irrigation system is an efficient water usage method, delivering water directly to the crops with high accuracy. Directly delivering water to the root zone curtails water loss caused by wind and evaporation.
2. **Uniform distribution: -** The system provides uniform water distribution across the field, mitigating the risk of over-irrigation in some areas and under-irrigation in others.

3. **Reduced labor costs: -** The center pivot system requires less labor compared to traditional irrigation methods, as it can be fully automated and controlled from a central location, thus reducing labor costs.
4. **Improve crop quality: -** The system's efficient and uniform water distribution results in improved crop quality and yield, contributing to improved agricultural productivity.
5. **Suitable for large field: -** Center pivot irrigation systems are well-suited for large fields, as they can cover a significant area and operate on varying terrain.
6. **Reduced soil erosion: -** By applying water gently and slowly, the center pivot irrigation system reduces soil erosion and the loss of topsoil, thus promoting soil conservation.
7. **Ability to apply chemical: -** Center pivot irrigation systems can also be used for chemigation, enabling the application of chemicals such as fertilizers, herbicides, and pesticides directly to the crops through the irrigation system.

Disadvantages

1. **High Initial Cost -** The installation cost of a center pivot irrigation system can be high, and may not be affordable for small-scale farmers.
2. **Energy Consumption -** The system requires a considerable amount of energy to function, often in the form of electricity or fuel, leading to higher operational expenses.
3. **Maintenance and Repair Costs -** Like any complex machinery, center pivot irrigation systems require regular maintenance to function properly. If not maintained properly, repairs can be costly.
4. **Water Quality Requirements -** The water source must be of adequate quality for use with the system. Poor water quality can cause clogging and damage to the equipment.
5. **Limited Flexibility -** Center pivot irrigation systems are best suited for large, circular fields, and may not be appropriate for fields with irregular shapes or obstructions like trees or buildings.
6. **Environmental Impact -** Overuse or improper use of the system can lead to negative environmental impacts such as waterlogging, soil salinization, and depletion of aquifers.
7. **Potential for Crop Damage -** If the system malfunctions or is not properly calibrated, it can result in over- or under-irrigation, potentially damaging crops (O'Shaughnessy *et al.*, 2019) [36].

HYDROGEL

Hydrogels are composed of hydrophilic polymer chains that are cross-linked at a macromolecular level, giving them the capability to absorb aqueous fluids or water. The most commercially effective types of hydrogels are referred to as superabsorbent polymers or superabsorbent hydrogels, as they have a high absorption capacity (Zhouriaan-Mehr *et al.,* 2010) [37]. Hydrogels typically have a high-water absorption capacity, with the ability to absorb up to 10 times their weight in water (Kabiri *et al.,* 2011) [38]. hydrogel is a popular agro-chemical used in agriculture to improve water retention capacity (Sharma, 2004) [39]. Hydrogels are a unique state of matter that exhibit both liquid and solid-like properties, resulting in fascinating relaxation behaviors that are non-observed in pure solids or pure liquids. They can undergo significant volume changes when exposed to certain external provocations such as pH, temperature, solvent quality, or electric fields. This characteristic makes them useful in various fields, including drug delivery, tissue engineering, and biosensors (Tanaka, 1978) [40].

Table 2. Application rate of Hydrogel

Type of soil	Dosage of Hydrogel
Arid and Semi-arid Region	4-6 (g/kg) soil
For all water stress treatment and improved irrigation period	2.25 (g/kg) soil
To delay permanent wilting point (PWP) in sandy soils	0.2-0.4 (g/kg)
To reduce irrigation water by 50% in loamy soil	2-4 (g/plant) pit
To improve RWC and leaf water use efficiency (LWUE)	0.5-2.0 (g/pot)
To reduce drought stress	0.2-0.4 (%) of soil
To prohibit drought stress totally	225-300 (kg/ha) cultivated area
To decrease water stress	3% by (weight)

Features of hydrogels

Hydrogels have several properties that make them ideal for agricultural applications. These properties include their colorless, odorless, and non-toxic nature, as well as their high-water absorption capacity. They can also perform well in high-temperature environments, making them suitable for arid and semi-arid conditions. Additionally, hydrogels can improve the physical properties of soil, such as porosity, bulk density, water holding capacity, and permeability. Additionally, they can absorb water at a desired rate as per the application requirement and have low levels of soluble content and residual monomer, making them cost-effective. Hydrogels are also highly durable and stable in swelling environments and during storage, while being biodegradable without the formation of toxic byproducts. They are pH-neutral after swelling in water, photo-stable, and possess re-wetting capability (Bairwa *et al.,* 2020) [41].

SWAT MODEL DESCRIPTION

The Soil and Water Assessment Tool (SWAT) is a hydrological model developed by the United States Department of Agriculture's Agricultural Research Service. The tool is used to predict the impact of land use and management practices on water quantity and quality in a watershed. This model considers the effects of climate, soil, topography, and land management practices on the hydrology and water quality of a watershed. By simulating various land management practices and their impacts on water resources, SWAT can help in identifying the best management practices to minimize water pollution and maximize water availability for different uses. (Arnold *et al.*, 2012) [42]. It is a comprehensive model that integrates several disciplines including hydrology, soil science, vegetation, and weather data to estimate the impacts of land use changes on water resources. The model follows a watershed-based approach by dividing the watershed into sub-basins and taking into account various factors such as precipitation, runoff, erosion, sedimentation, and nutrient cycling (Williams *et al.*, 2008) [43].

SWAT is a versatile model that can be applied to different land use scenarios such as agricultural, urban, and forested areas. It provides valuable information for sustainable water resource management, and can be used to simulate the effects of land management practices on water resources. The model's outputs can be used in decision-making to improve water quality and decrease non-point source pollution (Di Luzio *et al.*, 2004) [44].

SWAT has been widely adopted and validated in many watersheds across the world. It has been utilized in research, planning, and management of water resources, as well as to study the impacts of climate change on watersheds. With its open-source code and comprehensive documentation, the model is accessible to researchers, practitioners, and decision-makers interested in sustainable water resource management (Daniel *et al.*, 2011) [45].

Advantage of SWAT

1. The SWAT model takes a comprehensive approach by combining different disciplines such as hydrology, soil science, vegetation, and weather data to provide a thorough analysis of how land use changes impact water resources.
2. Its versatility allows the model to be applied to various land use scenarios, making it a valuable tool for different types of watersheds.
3. The outputs generated by the model provide decision-making support for sustainable water resource management.
4. The model's open-source code makes it accessible to researchers, practitioners, and decision-makers interested in watershed management.
5. The model has been verified in many watersheds across the globe, making it a trustworthy instrument for research and management of water resources.
6. The SWAT model provides the ability to predict the effects of land use modifications and management techniques on the amount and quality of water in a watershed.
7. The SWAT model can save time and resources by simulating scenarios and predicting outcomes without requiring physical experiments, which can be expensive and time-consuming (Akoko *et al.*, 2021 [47] and Deng *et al.*, 2021 [48]).

Disadvantages of SWAT

1. **Data requirements:** The model requires extensive data input, which can be challenging to obtain for some watersheds. Lack of data can limit the model's accuracy and effectiveness.
2. **Complex model:** The model's complexity may make it difficult for non-experts to use and understand. This can limit its usefulness for decision-making processes that involve stakeholders without specialized knowledge in hydrology or environmental modeling.
3. **Calibration and validation:** The model require extensive calibration and validation processes to ensure accuracy and reliability. These processes can be time-consuming and require significant expertise.
4. **Limited applicability:** The model's applicability is limited to watersheds with similar characteristics to those it has been validated in. Using the model in watersheds with different characteristics may produce inaccurate results.
5. **Lack of consideration for social factors:** The model primarily focuses on hydrological and ecological factors and does not consider social factors such as land tenure, cultural practices, and governance structures, which can impact land use decisions.
6. **Uncertainty:** Like all models, the SWAT model has inherent uncertainties. This can affect the accuracy of its predictions and the usefulness of its outputs for decision-making processes.
7. **Maintenance and updates:** The model require regular maintenance and updates to ensure its continued accuracy and relevance. Failure to update the model can make

it outdated and less effective for current land use management practices (Deng *et al*., 2021 [48]).

CONCLUSION

In summary, it is vital to prioritize climate-resilient water management practices to promote sustainable agriculture in the face of climate change. Farmers need to adopt water management techniques that guarantee reliable access to water, minimize water waste, and improve water use efficiency due to severe weather events are occurring with greater frequency and severity such as droughts and floods. Some effective strategies for achieving this include drip irrigation, sprinkler irrigation, central pivot irrigation systems, hydrogel, and soil and water assessment tools. By investing in these climate-resilient water management practices, we can support the livelihoods of smallholder farmers, alleviate poverty, ensure food security, and promote sustainable agriculture for the long term. Effective management of irrigation water is crucial, given the excessive consumption of water that varies with seasons. Since a considerable amount of water is used in agriculture, its management is essential. Climate change has caused droughts, increased the water demand of crops while reducing water availability. Hence, traditional irrigation methods need to be replaced with drip and sprinkler irrigation systems, among others. Additionally, effective irrigation management involves replacing high-water demanding crops with those that require less water, according to changing climate conditions.

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Check all references are traceable to put on the DOI at the end of each reference.

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FIG. 8. SWAT MODEL

SOURCE: FIGURE ILLUSTRATED THE SWAT MODEL BY TOUCH ET AL., 2020 [46]