Chapter

Sustainable Irrigation Management for Higher Yield

Fahd Rasul, Hassan Munir, Aftab Wajid, Muhammad Safdar, M. Salman Ayub, Sobia Shahzad, Rehan Mehmood, M. Adnan Shahid, Abid Sarwar, M. Danish Majeed, Umair Gull, Wajid Nasim Jatoi, Muhammad Mubeen, Summera Jahan and Shakeel Ahmed

Abstract

Sustainable irrigation is sensible application of watering to plants in agriculture, landscapes that aids in meeting current survival and welfare needs. Sustainable irrigation management can help with climate change adaptation, labor, energy savings, and the production of higher-value and yield of crops to achieve zero hunger in water-scarce world. To ensure equal access to water and environmental sustainability, investments in expanded and enhanced irrigation must be matched by improvements in water governance. Sustainable irrigation must be able to cope with water scarcity, and be resilient to other resource scarcities throughout time in context of energy and finance. The themes and SDGs related to clean water, water resources sustainability, sustainable water usage, agricultural and rural development are all intertwined in the concept of "sustainable irrigation for higher yield." Sustainable irrigation management refers to the capability of using water in optimum quantity and quality on a local, regional, national, and global scale to meet the needs of humans and agro-ecosystems at present and in the future to sustain life, protect humans and biodiversity from natural and human-caused disasters which threaten life to exist. Resultantly higher yields will ensure food security.

Keywords: sustainable irrigation, higher yield, sustainable agriculture, modern irrigation, crop water requirements

1. Introduction

Agriculture has a crucial part in human water resource use [1]. Approximately 70% out of the total available freshwater consumption is applied for water to support the agricultural output of the world [2]. About 18% of worldwide farmland yet produces almost 40% of food [3, 4]. Water resources have an impact on the productivity of a variety of anthropogenic activities that sustain livelihood [5, 6]. Increased demand for agricultural supplies has put a strain on the world's freshwater resources in recent decades, leading to their unsustainable use in many cases. With over one-fourth of the world's land area experiencing acute water shortage, [7] approximately 35% of people globally live in and around water-deficient places [8], Overexploitation of water resources usually occurs at the price of economic progress, resulting in environmental damage [9]. Thus, water is a necessity of almost all processes of production and means of production which represent the life-sustaining liquid as fuel for production systems. Crop plants cannot survive without water and limited supply prove havoc on the production levels. Thus, a sustained water supply is imperative to guarantee a higher yield of crops along with other climatic, edaphic, and genetic factors.

The water requirement for different crops, rainfall frequency, intensity, and effectiveness along with moisture regimes of soil is showing the irrigation requirement of crops.

$$IR = WR - (ER + S)$$

Where IR stands for irrigation requirement, WR is water requirement, ER exhibits effective rainfall and S is soil moisture contribution. The factors affecting education requirement are given as single crop irrigation need, area of the crop, and farm level distribution of water losses, all the factors are expressed in cm/ha or cm, mm.

1.1 Net irrigation requirement

It is defined as the quantity of water required in the form of depth to bring the soil moisture to its field capacity level for the evapotranspiration demand of the crops. It is also defined as the differentiation between the field ability and moisture content of the soil before irrigation (**Table 1**).

Crops	Requirement	Production	Shortfall
Food-grains	50.0	31.5	18.5
Sugarcane	82.0	46.4	35.4
Cotton (lint)	3.5	2.7	0.8
Pulses	1.9	1.4	0.5
Oilseed	3.3	1.5	1.8
Vegetables	14.3	9.0	5.3
Fruits	16.1	9.0	7.1
Total	**171.0**	**102.8**	**69.4**

Source: Ref. [10].

Table 1.
Crops production, requirement and shortfall analysis for yield gap mitigation through sustainable water resource use in Pakistan.

DOI: http://dx.doi.org/10.5772/intechopen.107153

1.2 Gross irrigation requirement

Gross irrigation need is the term used to describe the overall amount of water used for irrigation. Net irrigation requirements, water application losses, and other losses are included. The approximate losses at different phases of crop development can be considered to find the gross irrigation need for farms.

1.3 Irrigation frequency

The time interval between the two successive irrigations' during crop periods is known as irrigation frequency. It is showing the total number of dry days between irrigations during dry throughout the crop period. It is based on the pace at which plants absorb water, the field capacity of the soil, and the soil moisture present in the root zone. As a result, it depends on the crop, soil, and environment. In general, irrigation should be applied when the effective root zone, where most of the roots are concentrated, is about 50% and not more than 60% depleted of the available moisture. The interval (days) between two irrigations at the time of maximum crop growth, or peak crop consumption, is the irrigation frequency to be employed when constructing irrigation systems.

1.4 Irrigation period

The number of days that can be allowed for applying one irrigation to a specific design area during the crop's peak consumption time is known as the irrigation period.

1.5 Growth duration

The time it takes for various crops to grow varies greatly. Seasonal crops are like sorghum, maize, groundnuts, pulses, etc. that can only grow for one growing season. Crops like cotton, red gram, chilies, etc., whose growth duration spans two seasons, are called two seasonal crops.

1.6 Critical phenological stages of cereals sensitive to moisture variation

Germination stage—is the emergence of radicals from seed.
Tillering—the division for differentiation and development of tillers.
Shoot elongation—the phonological stage standing for internodal expansion.
Booting—swelling and development of grain holding structure or peduncle.
Heading/inflorescence initiation—ear head emergence from the leaf sheath.
Flowering—the appearance of flowers.
Grain development—grain formation from fertilization to maturity which is further classified.
into Milky stage—milk-type fluid development.
Dough stage—dough raw material development.
Ripe stage—fully mature embryo just before shattering.

2. Irrigation type for crop type

All type of irrigation does not suit all crops, the diversity of crops responds differently to applied irrigation and all crops have varied requirements of water which also varies with the soil types and weather. Cereals generally have fewer requirements for water, but it does not fit with Rice and maize which require a higher amount of water. The delta of water of the same stature crop may also vary as in the case of millet, sorghum, and maize which are comparable in terms of the duration of crop, but their delta of water is quite different. Moreover, the varieties of the crop also have varying levels of gene expression for drought and flooding tolerance in the two extreme conditions.

The pulses group mainly including the beans require comparatively less water and are mainly short duration in semi-arid regions with plenty of sunshine justified adaptation to drought is clear and the water productivity of beans is higher compared to other crops of similar duration, especially if compared with vegetables which require much more water compared to beans. Rice and sugarcane are highly hydrophilic and are major consumers of water among all field crops. Thus, the need arises to link the irrigation type with crop type and then through the study of crop type can fine-tune the water requirements for phonological crop stages which could be critical to be influenced severely by moderate drought even.

Irrigation types vary and are mostly dependent on technological development and resource availability and influenced by topography as well. High-efficiency irrigation systems are more technical and water-saving solutions that have been finding their way into modern agriculture and transforming the irrigation system of the world. Only the places with higher rainfall do not require such technical intervention a in case of south China s province here rainfall throughout the year I sufficient to manage the whole year's crop of sugarcane and double cropping of rice as well. Desertification on the other hand is putting pressure on arable land for low and marginal productivity of crops. Modern water-saving technologies like drip irrigation, sprinkler, and center pivot systems are proving essential for drylands around the world and bringing barren land into cultivation thus bringing a contributive role in the planet's food security [11].

3. Water scarcity, climate change, and crop yield uncertainties

Several uncertainties exist for sustainable crop yields in changing climate and in water-scarce regimes. In this study, the climate change impact on Pakistan's irrigation resources and food shortage are examined. According to the report, Pakistan's economy (21%) is built primarily on agriculture; nevertheless, the nation is struggling with crop food shortages, high inflation, and a lack of irrigation water. According to the study, even though Pakistan ranks 135th in the world in terms of per capita GHG emissions with 309 M tons of CO_2 equivalent emissions, which is only 0.8 percent of global emissions, the country is severely hit by changing climate compared to other nations because of trans-border emissions of greenhouse gases. As a result, there has been a continuous rise in temperature of 0.76°C in the nation as a whole and 1.5°C in Pakistan's mountainous regions, which are home to over 5000 glaciers in the KHH mountains. According to the study, Pakistan had a progressive decline in surface water availability per person from 5260 m^3 annually in 1951 to just 1000–1066 m^3 in 2008. Because the country, with its huge infrastructure and network of the largest integrated irrigation system globally, lacks adequate water reservoirs to hold extra water, the glaciers are melting and causing extreme events like floods as a result of rising temperatures, particularly in glacier-covered regions, and associated variations in precipitation pattern, Therefore, because glaciers tend to retreat quickly, a large amount of water is wasted into the ocean along with harm to crops, food reserves, billions of dollars worth of cattle, infrastructure, and land resources. In Pakistan, 84 out of 137 districts (primarily in Khyber Pakhtunkhwa, FATA, and Baluchistan) are said to be undersupplied with both crop- and animal-based food, or around 61 percent of the total. The main cause of the current food deficit is the low crop output brought on by the temperature increase and the lack of irrigation water. According to the study, farmers are switching from cultivating water-loving crops including rice, wheat, cotton, and sugarcane to low-water-requirement crops and vegetables. Moreover, the crops' production is lower because of heavy evaporation and the harsh summertime heat. According to the report, Pakistan's output of key basic foods like wheat, rice, and sugarcane has decreased over the first 10 years of the twenty-first century [12].

4. Soil water management

To actively take part in keeping soil water content at an ideal level for all specified goals, including environmental requirements, is to practice soil water management. An ideal state often involves striking a balance between conflicting demands and the need to take the soil water system's long-term viability into consideration.

To effectively manage irrigation systems, a full understanding of soil water is needed. Irregular water evaporation increased demand and crop water stress can occur from under-watering, which can reduce the amount of accessible water below essential levels. Two factors: 1) the Texture of the soil, which influences due to its water-holding capacity and vary soil moisture content, water potential, and infiltration; and 2) root depth, which finds the amount of water that is accessible for plants. Utilizing irrigation water resources more effectively may result in being able to control the soil water balance. For managing irrigation systems, the two most significant indicators of soil water are (1) Soil moisture content, which refers to the total quantity of water in the soil, and 2) Soil water potential, a measurement standing for ready availability of water to plants.

4.1 Soil structure constitution and composition

Soil includes the particles, air, and water the three major components (see **Figure 1**). Water and air are trapped in the soil particles in pore spaces a measure of which is the porosity of the soil.

4.2 Soil water potential

Irrigation management is not only about how much water is in the soil but also depends on the ability of plants to pump up or access water. The dynamic condition of soil water with moisture as a standard reference is known as its potential, which is often stated as energy per unit of volume (bars or centi bar unit). Gravitational potential, matric potential, and solute potential are the three main factors that make up total soil water potential. The gravitational potential results from gravity's force dragging the water in the soil downward. Matric potential also referred to as soil water tension, is the term used to describe the force that the soil matrix exerts on the water

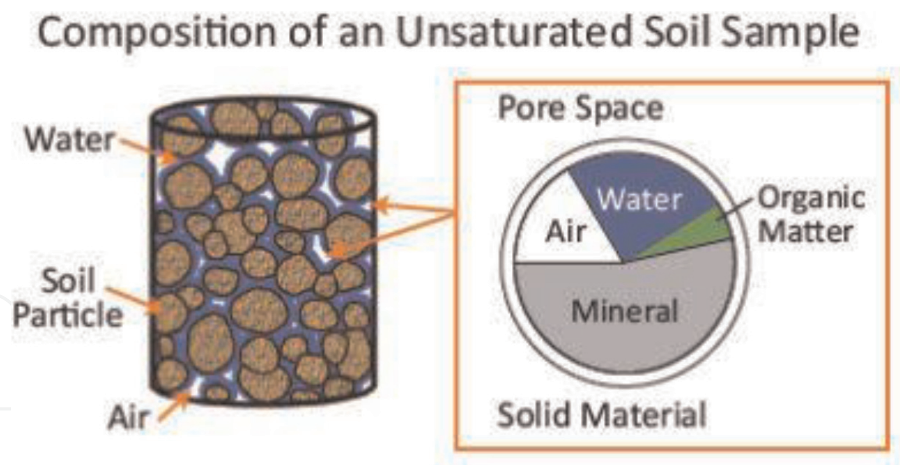


Figure 1.
Ref. [13].

through capillarity and adhesion. Salts that have dissolved cause the solute potential in the soil water.

4.3 Available soil water

The term "available soil water" or "available water capacity" (AWC), which refers to water that is available for plant use, refers to the water held between the field capacity and the permanent wilting point.

4.4 Infiltration

The rate at which water infiltrates the soil or, if water application is continued, the total volume of water that infiltrates the soil over time, can be used to define infiltration. The entire depth that has been penetrated following a certain amount of time for water application is known as cumulative infiltration.

4.5 Soil water balance

An understanding of the volume of water contained in the soil at any one time is necessary for planning irrigation. Growers who can control the soil water balance can prevent applying too much or too little irrigation water. The soil's texture and the plant's stage of development influence the root zone's ability to store water. Soil textureal classification is helpful to understand the ability of soil to hold water. For most crops, such as maize and soybeans, 50% of the water capacity can be used before plant stress sets in. To calculate the total amount of soil water that is accessible, multiply the rooting depth by the water storage ability:

$$\text{Total available water} = \text{rooting depth} \times \text{water storage ability}.$$

5. Water resources management

Water resources management is categorized into two types

- On-farm water management
- Off-farm water management

5.1 On-farm water management

On-farm irrigation water management includes adjusting factors like irrigation timing and volumes, flow rates, and water control systems. These and many other factors can be adjusted to meet desired agricultural production targets while staying within the limits given by soils, crops, climate, water availability, and economics, as well as social and other factors.

There are several advantages to proper on-farm water management. In general, an effective on-farm water management scheme aids in the maximization or optimization of output. It can assist minimize water and energy usage, allowing more water and energy to be used to irrigate more area while also lowering the cost of an irrigation system. It can prevent fertilizer loss due to excessive water application, lowering the quantity of fertilizer required to meet targeted production targets. A competent management program ensures that root zone salinity is kept below acceptable limits, and that soil water logging and excessive deep percolation losses are reduced or avoided. It can aid in the elimination of issues like erosion and the management of crop diseases caused by insufficient or excessive water application. Water management can help you save time on the machine and the job.

The engineer, technician, or farmer must first have a thorough understanding of the irrigation system before implementing an efficient irrigation water management scheme. They must be knowledgeable of the many design and management options available.

For example, more land may be irrigated in that location if water is used more efficiently in a project upstream. Users downstream, on the other hand, may have to rely on upstream users' return flows to keep irrigating. Implementing a good on-farm water management program is a highly specific and planned procedure that includes several components. Certain requirements needed as below:

1. Evaluate the farming system, considering the soils, crops, and irrigation systems. This contributes to the identification of the main issues with the current management system. The assessment also aids in estimating the advantages of adopting the needed adjustments.

2. Find the system's design, uplift, and management options and choose the best option (s).

3. Confirm that the system has been adjusted following the chosen design and/or revision.

4. Create a complete system management plan that includes watering timings, safeguarding, and other management factors.

5. Technicians and farmers will be trained so that they can carry out the program that has been set up.

6. Throughout the season(s), check the system for any necessary adjustments. The phase of system monitoring is critical to successful water management.

Following the implementation of the program, both technical experts and the farmer handle monitoring.

6. Advanced technologies adoption

6.1 Drip fertigation

Water is the most vital natural resource on the planet. Without water on the globe, no life form can survive. It is required for all major activities such as food production, as well as sectors such as energy, production, and manufacturing. Although we are aware that soil water content and quality are dwindling, this could be due to inefficient water usage, drastic climatic change, or the use of more chemicals to boost productivity. With the rapid expansion of the area under micro-irrigation, fertigation is gaining traction in several countries. The notion of fertigation is new to the Indian subcontinent, but it is gaining popularity and making 'Fertigation' easy to adopt. Drip fertigation, which is defined as the injection of fertilizers, additives, or water-soluble compounds into the irrigation system, is a significant technology in this case. Furthermore, fertigation is linked to chemigation, which is injecting chemicals into an irrigation system. In a drip fertigation system, water is dispensed at a slower pace through the drippers, and nutrients from the fertilizers are carried along with the water.

6.2 Solar powered tube well

Renewable resources of energy such as solar power can be utilized for a solar-powered tubewell that can be operated during the day. Because of their higher efficiency and delivery head, submersible pumps are commonly employed as solar-powered tube wells. For calculating horsepower to run the pump depending on groundwater levels can be used to estimate the number of solar panels. The multistage submersible pump is powered by a DC motor linked. For the installation of solar tube wells, a three-stage submersible pump is required. The discharge of the solar tube well fluctuates throughout the day depending on the position of the sun. The tube well's peak discharge is expected between 12:00 and 2:00 p.m.

6.3 High-efficiency irrigation system

Pressurized irrigation systems, such as drip system irrigation and sprinkler system of irrigation, are commonly referred to as high-efficiency irrigation systems. Sprinkler irrigation systems have an irrigation efficiency of 70–80%, while drip irrigation systems have an irrigation efficiency of 80–95%. Both systems have different levels of applicability depending on the terrain, soil, water source, and crop. Both technologies are considered water conservation methods because they provide superior control over irrigation water application.

6.4 Raised bed planting technology

Growing crops on raised beds is one of the enhanced irrigation systems used all over the world, and it has several advantages. Crop yields on the bed, for example, are boosted by better nitrogen management, root aeration, efficient use of irrigation, and reduced lodging risk [14]. In comparison to flat sowing, this approach reduces seed rates without sacrificing crop yields. Better crops stand and yields are also ensured by improved root development in bed planting [15]. Above important, compared to traditional sowing, bed planting promises significant water savings of 35 to 45 percent, as well as the elimination of crust formation on the soil surface [16]. When compared to flat sowing, the next crops on permanent beds have shown higher yields and water savings ranging from 20 to 40%.

The following are the main benefits of bed planting for wheat crops:

Percent saving of water	Yield increase percent
30–50%	25%

Other benefits which raised bed technology can give are improved water and fertilizer use efficiencies along with the least weeds and no lodging of the standing crop.

6.5 Laser land leveling

Traditional land leveling techniques, including utilizing an engineer's level and staff rod, are time-consuming, exhausting, ineffective, and costly. For farmers to accurately level their fields, the Department of Agriculture, Government of Punjab, adopted Laser Land Leveling technology. The technique of laser land leveling involves employing drag buckets that are equipped with lasers to smooth the ground surface with a maximum allowable variation from its average height of no more than 2 cm. With the help of laser land leveling, it is possible to level the fields at a slope of zero, distributing irrigation water evenly across the head, middle, and tail of the fields. The GPS and laser-guided equipment used for laser land leveling are installed on high-horsepower tractors and soil movers. Therefore, laser land leveling of irrigated areas can also result in the following advantages, either directly or indirectly. The land receives an even distribution of water, which increases irrigation effectiveness. In laser-leveled fields, about 30% of the water is conserved; as a result, more land can be watered. The leveled field will yield 20 percent more because of more consistent germination. Due to the equal distribution of fertilizer, its effectiveness and efficiency will both increase. Erosion risks would be reduced. It increases the effectiveness of machine usage (**Figure 2**).

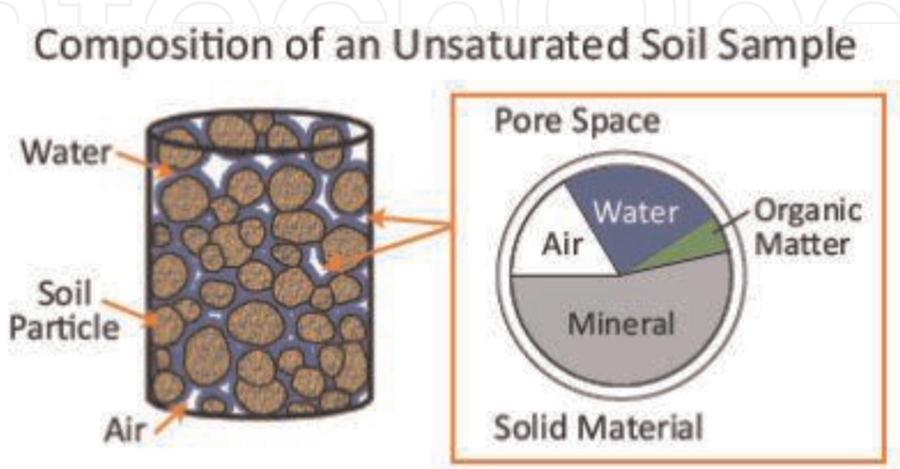


Figure 2.
Laser land leveling at WMRC, UAF, experimental area. Source: Water Management Research Center, University of Agriculture, Faisalabad Pakistan.

6.6 Zero tillage

No-tillage, also known as zero tillage, is a farming technique in which crop leftovers are left on the field after harvesting but the ground is not plowed. The following crop is directly sown using no-till planters (Zero Tillage Machines). For instance, in a rice-wheat rotation, wheat is planted using a Zero Tillage Drill right into a field that has previously produced rice without the use of any tillage equipment. Such methods, especially on sloppy terrains, are very effective in reducing soil erosion caused by wind or water. Due to the roots of the previous crop remaining in the soil and crop residue covering the ground surface to lessen the effects of heavy rainfall, zero-tillage reduces soil erosion.

7. Problems of irrigation system

The irrigation and drainage infrastructure of Pakistan, which is now experiencing serious issues, will determine the country's agricultural destiny. Some of these issues include rising salinity and water logging, overuse of fresh GW, low water use efficiency, and unequal and erratic supply. Rigid system design and inadequate drainage, low delivery efficiency and inequitable distribution of water, waterlogging and salinity, and over-exploitation of groundwater in fresh areas represent major problems in Pakistan's irrigation system.

7.1 Rigid system design

Despite the greater distribution control provided by the development of barrages, reservoirs, and link canals, the irrigation system is nevertheless managed following outdated canal diverting patterns that frequently do not match water demands. Due to inadequate reservoir capacity as well as the seasonal pattern in river flows, which can provide about 85% of the water throughout the summer, limited water supply occurs at the beginning and end of the summer and throughout the winter. The inconsistency between water supply and demand reduces agricultural productivity.

7.2 Inadequate drainage

Because of its flat terrain and lacking well-defined drainage channels, the Indus Plain has an urban drainage problem, which is being made worse by the construction of roads, railroads, flood bunds, and water systems that obstruct natural drainage flows. In irrigated areas, drainage has been a priority since the 1960s, and numerous sizable drainage programs are still in operation today. About 6.5-million-hectare acres of the 16.7-million-hectare acres of gross canal-controlled land need to be drained, of which 1.86 million-hectare acres are being worked on right now. It is a significant task to provide drainage to such a huge area. The predicted water table depth for a region of 2.38 million hectares is less than five feet.

7.3 Low delivery efficiency and inequitable distribution

Canal delivery is incredibly inefficient as a result of aging, excessive use, and poor maintenance. From the canal head to the root zone, delivery efficiency is between 35 and 40 percent on average, with the majority of losses happening in watercourses. There is less water available for agriculture because of the significant surface water loss, which enhances water logging and salinity. Excess water and water losses during irrigation are frequently returned to rivers and utilized once more downstream in irrigation systems with drainage. As a result, there is less efficiency damage to the river basin as compared to efficiency loss to individual systems. Unfair distribution is a key concern as well.

7.4 Waterlogging and salinity

According to the World Bank (1992), Pakistan may be unable to produce about 25% of the important crops that may be produced there because of soil salinity. In an area such as the Indus Basin, which has a flat topography, insufficient natural drainage, permeable soils, and just a semi-arid climate with significant evaporation, it is unavoidable that water tables will rise and salinity will grow. As a consequence of the greater diversion of stream flow for irrigated and seepage through canals, and watercourses, especially irrigated regions, the groundwater level has gradually risen. By the 1960s, many SCARPs had already been established. Nevertheless, despite these precautions, the gross protected area is wet in around 30% of instances, with about 13% of those instances being classified as extremely waterlogged.

7.5 Inadequate operation and maintenance (O&M)

Because of neglected maintenance and overuse, Pakistan's irrigation and drainage system has been deteriorating. Provinces agreed to keep spending on surface irrigation and subsurface saline drainage facilities at 1988 levels as part of Bank Projects.

7.6 Poor investment planning

In Pakistan, there are three stages to the investment planning process for drainage and irrigation. A sectorial plan provides a framework for intermediate- to long-term Sectorial development, five-year plans are used for short-term planning, and the Annual Development Programme allows monies annually (ADP). Sectorial planning has previously attracted a lot of attention. Plans like the Revised Action Programme (RAP) and the Water Sector Investment Planning Study (WSIPS), which were developed with assistance from abroad, thoroughly evaluate the needs and objectives of each sector.

8. Sustainable irrigation for best crop yields

Sustainable irrigation is the sensible use of all activities associated with the watering of plants, whether in agriculture, landscape, or ornaments, in such a way that it aids in meeting current survival and welfare needs without jeopardizing future generations. The term "sustainability" is frequently used to refer to the management, use, and protection of natural resources in such a way that future generations will have access to them [17–19]. In anthropocentric words, "sustainability" refers to a state in which current generation demands are met "without jeopardizing future generations' ability to fulfill their wants." [20]. As a result, sustainable irrigation encompasses the need to examine a variety of factors, particularly those relating to the deterioration, loss, or depletion of resources such as soil, water, and energy, as well as biodiversity and environmental preservation. Because water is a renewable resource, it is possible to aspire for great sustainability when it comes to irrigation. Of course, water resources may be non-renewable on a local level, like in arid regions with low rainfall inputs and large non-renewable groundwater reserves. The exploitation of groundwater (commonly referred to as "groundwater mining") is a classic example of unsustainable water usage in such areas [21]. The aspect of sustainable irrigation encompasses not only the geographical location where irrigation is used but also the production and transportation of necessary equipment and supplies, as well as discharges and waste consequences. The consequences of the construction, operation, and maintenance of the works, which are either directly or indirectly required for irrigation and are frequently located over great distances, should not be overlooked.

Irrigation must be able to adapt to changing climates to remain sustainable. As a result, it must combat droughts as well as the impacts of global climate change on a broader scale. As a response, relying on other disciplines like crop selection and development, automation and telecommunications, institutional governance, and others might be critical.

Irrigation can help with climate change adaptation, labor and energy savings, and the production of higher-value crops. On the other hand, irrigation agriculture must be made more egalitarian, efficient, and sustainable to achieve zero hunger in an increasingly water-scarce world. Irrigated agriculture is contributing to, and being affected by, increased strains on freshwater resources, with more than 60% of global irrigated cropland under significant water stress. To ensure equal access to water and environmental sustainability, investments in expanded and enhanced irrigation must be matched by improvements in water governance. Improved data and knowledge on water resources and their use and well-defined water rights are cornerstones of better water governance [4].

Finally, just as sustainable irrigation must be able to cope with water scarcity, it must also be resilient to other resource scarcities throughout time, such as energy and finance. The themes of "water resources sustainability, "sustainable water usage," and "agricultural and rural development" are all intertwined in the concept of "sustainable irrigation."

Water resource sustainability refers to the ability to use water in sufficient quantities and quality on a local, regional, national, and global scale to meet the needs of humans and ecosystems now and in the future to sustain life and protect humans from natural and human-caused disasters that threaten life.

"Water usage that supports human society's potential to persist and thrive indefinitely without jeopardizing the integrity of the hydrological cycle or the biological systems that rely on it" is what sustainable water use means.

9. Sustainability concerns in irrigated agriculture

Irrigation is a considerable change in the physical, environmental, and social aspects of the area. Existing equilibriums are disrupted in the process, and new ones emerge over time. Fact, the essential principle of irrigation development is that new conditions meet mankind's goals better than old ones. This premise has proven to be correct in many ways. Irrigation was a major driving force in the growth of many ancient civilizations, and it continues to be so today. While just approximately a 6th of the world's agricultural land is irrigated, this part produces about a third of the world's food. The irrigated area of the world is not uniform. Different locations are afflicted by various sustainability issues. Many of the sustainability challenges raised by irrigated agriculture in affluent countries are like those raised by modern high-input agriculture, which places a heavy demand on natural resources and often exceeds the capacity for environmental assimilation. Many of the concerns about irrigated agriculture's sustainability in emerging countries, on the other hand, stem from the general development problems that these countries face, such as a lack of public capital, macroeconomic reliance on agricultural commodity exports, widespread poverty, population pressure, insufficient management, and human resource development, institutional and regulatory shortcomings, and so on [22].

9.1 Water resources

Many countries, particularly those in the dry climatic zone with high rates of population growth, urbanization, and industry, are finding water to be a precious resource. Increased water competition in these nations will have a considerable influence on irrigated agricultural water supply [23]. The competing industries' water demand will always be a modest proportion of the naturally accessible supply in most countries. In most nations, the need to use water more efficiently will steadily rise. Most occurrences of groundwater mining are caused by a lack of sufficient legislation and enforcement, as well as a lack of awareness of the environmental implications.

9.2 Land resources

The deterioration of land resources because of agricultural usage is a major cause of worry across the world. Irrigation development has worsened this problem by generating conditions that have led to deforestation and soil erosion accidentally. This is especially true of land degradation in river diversion schemes upstream catchment regions [24].

9.3 Waterlogging and salinity

Irrigation has resulted in waterlogging and salinization of irrigated land on a huge scale. The incidence of this dual issue is usually limited to dry regions. About half of the world's already irrigated territory, or 270 million hectares, is thought to be desert.

10. A long-term irrigation system for small landholdings in rain-fed agriculture Punjab Pakistan

The drip irrigation system plays a vital role for fruits and vegetables in Pakistan, but the primary hindrance to the widespread acceptance is for small landowners. Because the drip system was obtained from local merchants, it was also less expensive. In 2015 and 2016, field trials were conducted on vegetables (potato, onion, and chilies) and fruits to analyze the productive and economic effects of low-cost drip irrigation (olive, peach, and citrus). While comparing with other systems this system saved 50% on water expenditures and created 27–54% net revenue. Drip and furrow irrigation systems have obtained water use efficiency (WUE) of 3.91–13.30 kg/m^3 and 1.28 4.89 kg/m^3, respectively. According to the current study, low-cost drip irrigation increased yield by more than 20% [25].

11. Sustainability enhancement and management

There are no obvious flaws in this technology that make irrigation development unsustainable in the long run. Salt accumulation/mobilization and accompanying downstream water deterioration, as well as the development of waterborne infections, are the only two sustainability issues organically linked to irrigation technology. Careful planning and the implementation of mitigation measures can help solve these issues.

The most typical causes of water logging and salinity are poor planning, inadequate irrigation efficiency, and development issues. The consequences of planned interventions can be better predicted with the development of comprehensive model-based planning and design approaches. This will help in the battle against flooded and saline regions throughout the world.

Improving irrigation efficiency is a requirement that will be pushed upon the irrigation industry, gladly or unwillingly, for the welfare of the sector. Many of the above-highlighted sustainability issues are directly or indirectly connected to the already permitted irrigation water waste.

- Government policy changes aimed at improving cost recovery, as well as regulatory and legal frameworks.

- Irrigation department institutional reforms to improve performance and water conservation, as well as make them more responsible to end-users.

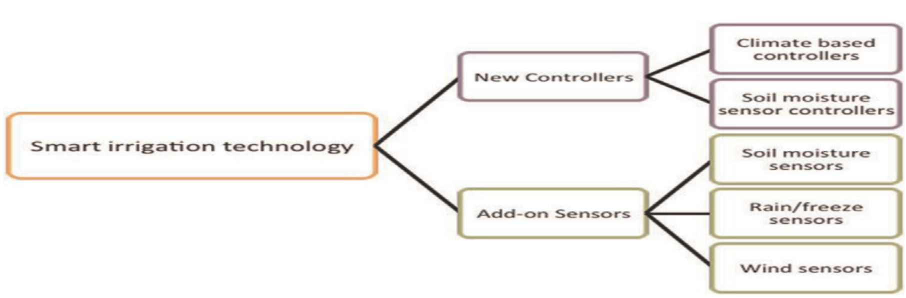
- Water pricing incentives to discourage over-irrigation

- Improved water supply reliability and equity through more decentralized water management and expanded engagement of (groups of) end users in system design and real water management.

- Improving the abilities of operational people and providing an extension to farmers to help them understand and make better decisions.

12. Smart irrigation system

Smart irrigation technology uses weather data or soil moisture data to determine the irrigation need of the landscape. Smart irrigation technology includes: These products maximize irrigation efficiency by reducing water waste while maintaining plant health and quality. Using intelligent irrigation devices, outdoor water savings are possible. In contrast to conventional effective automated timers, which irrigate according to a user-determined set schedule, smart irrigation control systems and sensors have been created to reduce external water usage by irrigation depending on plant water needs. This technology can be used to construct a smart controller by attaching a sensor to an existing water distribution timer or as a whole controller. Utilizing smart irrigation systems in the landscape may help to cut back on water usage outside. Both tiny, private landscapes and huge, professionally managed landscapes can increase productivity. The functions of each product, as well as their benefits and drawbacks, are covered in the sections that follow.



13. Irrigation system

Irrigation is the technique of artificially delivering water to agricultural fields to produce crops. If the amount of water available to the plants from rainfall is insufficient, irrigation water is used to supplement it. To accomplish this goal, an irrigation system must be created, which includes the planning, design, building, operation, and maintenance of numerous irrigation works:

- Source: River, Reservoirs, Alternate sources (groundwater, treated wastewater)
- Control structures: Barrages, Head Regulators
- Distribution system: Irrigation Canals and Tertiary Irrigation System

Each irrigation system has unique advantages and disadvantages depending on different factors such as:

1. Initial installment cost
2. Filed architecture
3. Soil texture and structure
4. Nature and availability of the water supply
5. Climate
6. Cropping patterns
7. Social preferences and structures
8. Historical experiences

Let us have a look at different types of irrigation and the methods used for irrigation.
Surface Irrigation.
Sprinkler Irrigation.
Localized Irrigation.
Drip Irrigation.
Centre Pivot Irrigation.
Sub Irrigation.
Manual Irrigation.

Irrigation may be used in a variety of ways to increase agricultural productivity. Irrigation systems are used in different ways depending on the soils, climates, crops, and resources available. Farmers use a variety of irrigation methods, including:

13.1 Surface irrigation

There is no irrigation pump in this system. Gravity distributes water throughout the terrain here. Water is ponded on an enclosed level field and allowed to penetrate basins, borders, or furrows in surface irrigation.

Water is applied to the field in either a controlled or uncontrolled manner.

- Uncontrolled: Wild flooding and Flood Irrigation
- Controlled:

Water is applied from the water channel outlet and controlled by borders and/or furrows. Surface irrigation is only used when there is plenty of water. The cheap initial design expense is countered subsequently by the high labor cost for water application.

- Water is delivered directly to the soil surface from a channel or open ditch at the field's upper reach.
- Water moves due to gravity force in surface irrigation
- It is the oldest method of irrigation (from 4000 years)
- Highly adopted method in the world
- In most countries, about 90% area is under surface irrigation
- In the USA, about 60% of the area is under surface irrigation

Following are some advantages and disadvantages of surface irrigation methods.

Advantages	Disadvantages
It is really simple to manage. Easily adapts to flat topography. It is necessary to keep costs down. It's possible to use it even if there aren't any drainage outlets. Allows for quick salt leaching. Allows for full use of rainfall. It is possible to attain high application efficiency. Adapts effectively to infiltration rates ranging from moderate to low. The short-term water supply works well. Small landholdings do not bother it.	To obtain high efficiency, the land must be flat (the greatest land elevation fluctuation should not exceed half the administered irrigation depth). Small field sizes are required for soils with high infiltration rates, which problems with automation. It's tough to get rid of extra water, especially when there's a lot of it. Plants that are partially submerged in water can occasionally provide longer periods (in low infiltration rate soils). Small irrigations are difficult to apply.

13.2 Sprinkler irrigation

Sprinklers from the movable platform or overhead high-pressure sprinklers deliver water from a central point. Water is sprayed over the area to be watered by pressurized water flowing via pipes to outlets.

Advantages	Disadvantages
By this method, we can increase efficiencies. Land leveling is not a mandatory method and can easily use on uneven land Can be used on all types of infiltration rates soils require less labor to operate this system and reduce labor costs.	The high initial cost to install the system consumes more energy as compared to other systems. Requires moderately high technology.

13.3 Localized irrigation

Water is delivered to each facility through a network of pipes at low pressure in this system. Water is continually delivered at very low rates to points or small areas in the field through small holes in plastic tubing or from emitters in this system. Only a portion of the field has been soaked.

Advantages	Disadvantages
It has many of the same benefits as sprinklers, but it can attain extremely high-water efficiency and can be used successfully in highly salty conditions.	It needs a large initial investment. It needs a high level of technological expertise. Saline soils may cause problems

13.4 Drip irrigation

Drops of water are provided at the roots of the plants in this style. Because it takes more upkeep, this method of irrigation is only utilized in orchards and high-value crops. Fertigation can also be done through this system.

13.5 Centre pivot irrigation

A sprinkler system that moves in a circular pattern distributes the water. This approach is most employed in commercial cooperative farms with a lot of acreages to grow. It aids in the attainment of precision agricultural aims. This technology can also be used for fertilization. Sub Irrigation Water is dispersed by raising the water table through a network of pumping unit valves, ditches, and canals.

13.6 Manual irrigation

This is a laborious and time-consuming irrigation technique. Manual labor is used to supply water using watering cans at this location. We can characterize irrigation in other ways also. Irrigation can be done by two different techniques:

Conventional Methods.

Modern Methods.

13.6.1 Conventional methods of irrigation

This method involves hand irrigation. A farmer brings water to farming areas by hand, with the aid of livestock, or from wells or canals. Depending on the localization strategy. The main advantage of this technique is its affordability. Its effectiveness is nonetheless minimal due to the uneven dispersion of water. Additionally, there is a substantial chance of water loss. Examples of typical systems are the chain pump, the lever system, and the pulley system. The most popular and commonly used of these is the pump system.

13.6.2 Modern methods of irrigation

The current technique compensates for the limitations of previous methods and so aids in proper water consumption. The significance of irrigation may be described as follows:

Agriculture suffers from insufficient and unpredictable rainfall. Droughts and famines are caused by insufficient rainfall. Irrigation improves efficiency even in areas with minimal rainfall. The productivity of irrigated land is higher than unirrigated land. Multiple cropping is not feasible in Pakistan because the rainy season varies by area. However, the climate allows for agriculture all year. In most areas of the region, irrigation infrastructure allows for the cultivation of more than one crop. Irrigation has contributed to the cultivation of the majority of the fallow land. Irrigation has helped to maintain productivity and yield levels. Irrigation enhances the availability of water supply for crops, which boosts farmer income.

GRAVITY OR SURFACE IRRIGATION.

Suitability of Surface Irrigation Methods

- Soils with a low to moderate rate of infiltration
- Leveled lands
- Lands with a slope less than 2–3%
- Accommodate all types of crops
- Labor intensive but nowadays equipment is available for automation

14. Irrigation resource constraints and climate change

Freshwater availability has an impact on almost all social and environmental elements of climate and demographic change, and also their implications for sustainability. Water scarcity is already a significant problem in many parts of the globe and is predicted to get worse as the population increases, the nutrition quantity is demanded, temperatures are rising, and rainfall pattern change. It also affects energy projects, anthropogenic water usage, and ecological use.

The world's freshwater resources are under tremendous pressure due to population growth, changing land uses brought on by agricultural development, and deforestation [26]. The future availability of freshwater for industrial use, agricultural production, and human consumption become more uncertain as global climate change intensifies. Depending on greenhouse emissions, the predicted range of global temperatures is comparable to 1980–1999 even by end of the 21st century anywhere between 1.1 and 6.4°C [27].

The size and sign of potential impacts are still up for debate, and the extent of predicted precipitation changes varies substantially relying on geographical region and spatial extent [28]. Even in certain locations where mean precipitation is expected to decrease, daily heavy precipitation occurrences are likely to increase [27]. Even though atmospheric CO2 seems to have the potential to increase photosynthesis by close to 30%, such changes are anticipated to have a greater negative impact on

	Feel or appearance of soil and moister deficiency			
Available soil moisture remaining	Loamy Sand	Sandy Loam	Loam and Silt Loam	Clay Loam or Silty
				Clay Loam
	Course Quality	Reasonably Course Texture	Medium Texture	Fine and Very Fine Texture
0 to 25 out of a hundred	Waterless, moveable, solo-grained, flows through fingers	Waterless, moveable, flows through fingers	Powdered dry, sometimes a little covered but easily broken down into powdered condition.	Unbreakable baked, split, and sometimes has loose crumbs on the surface.
25 to 50 out of a hundred	Seems to be dehydrated and will not form a ball with density. [1*]	Seems to be dry and will not form a ball. [1*]	Rather crumbly but holds together from pressure.	Somewhat flexible will ball under pressure. [1*]
50 to 75 out of a hundred	Seems to be waterless and will not form a ball with gravity.	Tends to the ball under pressure but seldom holds it together.	Forms a ball somewhat plastic and will sometimes slick slights with pressure.	Forms a ball, ribbons out between thumb and forefinger.
75 percent to field capacity (100 out of a hundred).	Tends to switch together somewhat, and sometimes forms a very weak ball under pressure.	Forms a weak ball, breaks easily, and will not slick.	Forms a ball, is very pliable, slicks readily, and is relatively high in clay.	Effortlessly ribbons out between fingers, have a slick feeling.
At field capacity (100 out of a hundred).	Upon pressing, no free water seems on the soil but the wet framework of the ball is left on hand.	Upon pressing, no free water seems on the soil but the wet framework of the ball is left on hand.	Upon pressing, no free water seems on the soil but the wet framework of the ball is left on hand.	Upon pressing, no free water appears on the soil but a wet framework of the ball is left on hand.

[1]Ball is formed by squeezing a handful of soil very firmly.*
Source: https://sanangelo.tamu.edu/extension/agronomy/agronomy-publications/how-to-estimate-soil-mois ture-by-feel/

Table 2.
Guide for judging how much moisture is available for crops.

agricultural output [29]. The impact of climate change on agriculture water usage especially changes in net irrigation demands, demand, and agricultural water consumption has been the subject of several studies (**Table 2**).

15. Irrigation scheduling

It is the ability with which the farmer decides the amount and time of irrigation. It includes the Time of irrigation when irrigation is needed, Amount of irrigation (how much water should be applied?). What should be the response of the crop (seed yield or forage yield) to the irrigation applied? There are two alternative aims for scheduling irrigation. 1 For achieving maximum output per unit of land area 2.For Maximizing land area utilized in crop production.

15.1 Methods of irrigation scheduling

Fixed interval application: In the warabandi system there is a fixed interval for irrigation application.

Apply irrigation when your neighbor is doing so. A visual sign of crop-based upon their experience farmers apply irrigation when they observe the sign of starvation of water, it is only descriptive. The determination of moisture content of the soil: Gravimetric method, Gypsum block method, Tensiometer method and Neutron probe method.

15.2 Irrigation scheduling benefits

It enables the farmer to plan a water rotation schedule between fields to lessen agricultural water stress and boost yields. For the farmer, it cuts the cost of labor and water. Because it collects surface runoff, fertilizer costs are reduced. It raises net profits by enhancing agricultural quality and productivity. Water logging risk is decreased. It helps to control problems with root zone salinity. Using the "saved" water to irrigate non-cash crops, creates additional revenue.

15.3 Strategies for irrigation scheduling

15.3.1 Certain

Climate variables that have been measured; Average soil parameters were measured. Irrigation water quality. The amount of water used and when it was used Irrigation technique and a few crop parameters (crop height, development stage, DAP, LAI, root depth).

15.3.2 Uncertain

Reference evapotranspiration and Kc values are estimated. Estimation of crop water needs. Crop water uptake pattern, and crop response function to shortfall irrigation and/or excessive salt accumulation.

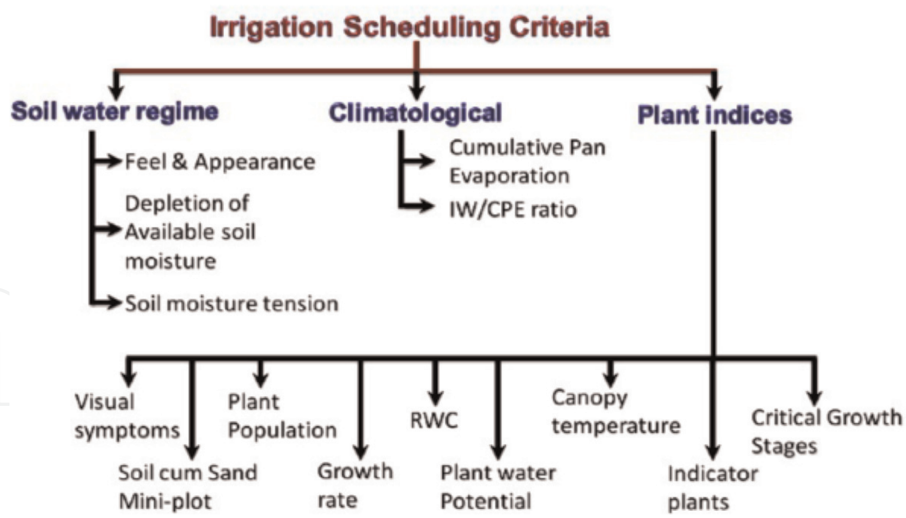
Irrigation Scheduling Approaches, Fixed Scheduling, Flexible Scheduling, and Flexible Scheduling Incorporating Rainfall are the three types of irrigation scheduling. Each category is described in detail below.

1. By taking the soil samples from the field and estimating the required depth of irrigation and net depth of water needed.

2. Estimate ET by multiplying it with Kc by the pan evaporation method.

3. Calculate the total crop water need (CWR) for the whole crop period, considering the duration of the growing season or the number of growing days.

4. Calculate the irrigation interval by the ratio between total CWR and net irrigation depth. 5. Adjust irrigation depth according to the irrigation interval set up in step.



Author details

Fahd Rasul[1*], Hassan Munir[1], Aftab Wajid[1], Muhammad Safdar[2,3], M. Salman Ayub[1,4], Sobia Shahzad[5], Rehan Mehmood[2,3], M. Adnan Shahid[2,3], Abid Sarwar[3], M. Danish Majeed[2,3], Umair Gull[1], Wajid Nasim Jatoi[5], Muhammad Mubeen[6], Summera Jahan[7] and Shakeel Ahmed[8]

1 Department of Agronomy, University of Agriculture Faisalabad, Pakistan

2 Agriculture Remote Sensing Lab (ARSL), University of Agriculture Faisalabad, Pakistan

3 Department of Irrigation and Drainage, University of Agriculture Faisalabad, Pakistan

4 Valley Irrigation Systems Pakistan (Valley – California, USA)

5 Department of Botany, Islamia University of Bahawalpur, Pakistan

6 Department of Environmental Sciences, Comsats University, Vehari Campus, Pakistan

7 Department of Botany, University of Gujrat, Pakistan

8 Department of Agronomy, Bahauddin Zakariya University Multan, Pakistan

*Address all correspondence to: drfahdrasul@uaf.edu.pk; drfahdrasul@gmail.com

References

[1] Green PA, Vörösmarty CJ, Harrison I, Farrell T, Sáenz L, Fekete BM. Freshwater ecosystem services supporting humans: Pivoting from water crisis to water solutions. Global Environmental Change. 2015;**34**:108-118. DOI: 10.1016/j.gloenvcha.2015.06.007

[2] Rockström J, Falkenmark M, Allan T, Folke C, Gordon L, Jägerskog A, et al. The unfolding water drama in the anthropocene: Towards a resilience-based perspective on water for global sustainability. Ecohydrology. 2014;**7**:1249-1261. DOI: 10.1002/eco.1562

[3] Chartzoulakis K, Bertaki M. Sustainable water management in agriculture under climate change. Agriculture and Agricultural Science Procedia. 2015;**4**:88-98. DOI: 10.1016/j.aaspro.2015.03.011

[4] Food and Agriculture Organization. Food and Agriculture Data. USA: FAOSTAT; 2019

[5] Sullivan C. Calculating a water poverty index. World Development. 2002;**30**:1195-1210. DOI: 10.1016/S0305-750X(02)00035-9

[6] D'Odorico P, Davis KF, Rosa L, Carr JA, Chiarelli D, Dell'Angelo J, et al. The global food-energy-water nexus. Reviews of Geophysics. 2018;**56**:456-531. DOI: 10.1029/2017RG000591

[7] Alcamo J, Döll P, Henrichs T, Kaspar F, Lehner B, Rösch T, et al. Global estimates of water withdrawals and availability under current and future "business-as-usual" conditions. Hydrological Sciences Journal. 2003;**48**:339-348. DOI: 10.1623/hysj.48.3.339.45278

[8] Rock Strom J, Williams J, Daily G, Noble A, Matthews N, Gordon L, et al. Sustainable intensification of agriculture for human prosperity and global sustainability. Ambio. 2017;**46**:4-17. DOI: 10.1007/s13280-016-0793-6

[9] Savenije HHG, van der Zaag P. Water as an economic good and demand management: Paradigms with pitfalls. Water International. 2002;**27**:98-104. DOI: 10.1080/02508060208686982

[10] ADB (Asian Development Bank). Water Resources Strategy Study. Draft Report Vol. 1. Islamabad, Pakistan: ADB; 2002

[11] Reinders FB. Micro irrigation: A world overview. In: Proceedings of the 6th International Micro Irrigation Congress, South Africa. Vol. 2000. Florida, USA: Apple Academic Press & CRC Press Taylor & Francis Group; 2000

[12] Keller J. Evolution of drip/micro irrigation: Traditional and non-traditional uses. In: Keynote Address at the International Meeting on Advances in Drip/Micro Irrigation, December 2002. Spain: Apple Academic Press & CRC Press Taylor & Francis Group; 2002

[13] Kiselev MV, Voropay NN, Dyukarev EA, Preis YI. Temperature regimes of drained and natural peatlands in arid and water-logged years. In: IOP Conference Series: Earth and Environmental Science. Vol. 386, No. 1. IOP Publishing; 2019. p. 012029

[14] Syre KD, Moreno Ramos OH. Application of Raised Bed Planting Systems to Wheat. Wheat Special Report No. 31. Mexico, D.F: CIMMYT; 1997

[15] Peries R, Chris B, Bruce W. Raised bed cropping leading to improved root

proliferation in heavy duplex soils prone to waterlogging. In: Proceedings of the 6th Symposium of the International Society of Root Research. Nagouya, Japan: Southern Victoria Australia; 2001, November 2001

[16] Fahong W, Xuquing W, Sayre KD. Comparison of conventional flood irrigated, flat planting with furrow irrigated, raised bed planting for winter whear in China. Field Crops Res. 2003; **87**:35-42

[17] Sands GR, Podmore TH. A generalized environmental sustainability index for agricultural systems. Agriculture, Ecosystems and Environment. 2000;**79**:29-41. DOI: 10.1016/S0167-8809(99)00147-4

[18] FAO. Sustainability Assessment of Food and Agriculture Systems. Guidelines Version 3.0. Rome, Italy: FAO; 2013

[19] Borsato E, Galindo A, Tarolli P, Sartori L, Marinello F. Evaluation of the grey water footprint comparing the indirect effects of different agricultural practices. Sustainability. 2018a;**10**:3992. DOI: 10.3390/su10113992

[20] FAO. Sustainable development and natural nesources management. In: Twenty-Fifth Conference, Paper C 89/2 —Sup. Vol. 2. Rome, Italy; 1989

[21] Konikov E, Likhodedova O. Global climate change and sea-level fluctuations in the black and Caspian seas over the past 200 years, in: Geology and geoarcheology of the black sea region: Beyond the flood hyphotesis. Geological Society of American. 2011;**473**:59-69. DOI: 10.1130/2011.2473(05)

[22] DGIS. Sustainable Land Use. the Hague, the Netherlands: Development Cooperation Information Department, Ministry of Foreign Affairs; 1992

[23] World Bank. Water Resources Management, a Policy Paper. Washington DC, USA: The World Bank; 1993

[24] ISRIC. The Extent of Human-Induced Land Degradation. Wageningen, the Netherlands: International Soil Reference and Information Centre; 1991

[25] Aziz M, Rizvi SA, Iqbal MA, Syed S, Ashraf M, Anwer S, et al. A sustainable irrigation system for small landholdings of Rainfed Punjab, Pakistan. Sustainability. 2021;**13**(20):11178

[26] Nejadhashemi AP, Wardynski BJ, Munoz JD. Large-scale hydrologic modeling of the Michigan and Wisconsin agricultural regions to study impacts of land use changes. Transactions of the ASABE. 2012;**55**(3):821-838

[27] Solomon S, Qin D, Manning M, Averyt K, Marquis M, (Eds.). Climate Change 2007-the Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC. Vol. 4. UK: Cambridge University Press; 2007

[28] Bates B, Kundzewicz Z, Shaohong W. Climate Change and Water. Geneva Switzerland: Intergovernmental Panel on Climate Change Secretariat; 2008

[29] Long SP, Ort DR. More than taking the heat: Crops and global change. Current Opinion in Plant Biology. 2010; **13**(3):240-247