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SUSTAINABLE USE OF SOIL AND WATER RESOURCES FOR IRRIGATION: IRRIGATION EFFICIENCY AND WATER PRODUCTIVITY

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ABSTRACT
Agriculture plays a vital role in the economies of many countries and irrigation make it a crucial actor to increase crop production. In the world, 70% of available water resources are used for agricultural irrigation. However, it is almost 90% in some countries in the world. The main and common problems and challenges in agricultural irrigation are observed as excessive water use by farmers in some areas with surface irrigation, insufficient land leveling, no use of appropriate furrow and border length according to water flow and soil texture, irrigation water application without volumetric measurement of water, low irrigation water use efficiency and water productivity, drainage and salinity issues, alkalinization, impact of climate change (drought), the low effectiveness of the water user associations, improper crop pattern (monoculture), insufficient design and management of pressurized irrigation systems, inadequate irrigation pricing policies, weak cooperation among the instittutions and political instability in some countries. Irrigation efficiency (IE) (35-40%) and irrigation water productivity (WP) are very low and use of gross irrigation water is more than 10,000 m^3 ha^{-1} in some Middle East countries. IE (%) WP (kg m^{-3} and \$ m^{-3}) are the most important indicators for evaluation criteria of irrigation schemes and farms, irrigation authorities and decision makers. Thus, the importance of IE and WP for sustainable use of soil and water resources, some actual and experimental data regarding those issues, problems and recommendations considering technical and institutional approaches are discussed.

Key words: global water use, irrigation efficiency, sustainability, water productivity, food security.

INTRODUCTION
It is estimated that the world population will reach 9.8 billion people by 2050 and more than half of this population will live in urban areas. The economic and population growth will continue and production demand for more food will, thus, increase in the future. Depending on the population growth, the demand for food will be double (Nangia and Yadava, 2016). This implies that water demand will go up by more than 40%. Therefore, water scarcity is to become a major challenge in the near future.

The two most serious problems of climate change are, thus, food security and the other one is water supply. Providing safe and sustainable water (water cycle) is the most important priority for the continuation of life. Since food and crop production is directly dependent on water use, water security is a prerequisite for food security (Ortaş, 2022). Countries under food and water stress around the world are shown in Figures 1 and 2. Food scarcity and/or hunger appears almost to be increasing in areas of water stress at the same time.

On the other hand, irrigation is a very important practice to prevent drought risks. Because it makes continuous and stable agriculture possible. In other words, irrigation is an insurence in agricultural production especially in drought periods for food security (Orta, 2022). For this reason, although approximately 20% of the agricultural lands in the world are irrigated, 40% of the total production is provided from irrigated lands (OECD, 2021).

Depending on the climate, soil conditions, agronomy practices, crop species and variety, irrigation can lift up the yield per unit area from once through five times compared with dry farming (rainfed). This situation, on the other hand, leads to a rise in regional and national income, especially of farmers, and thus a rise in the welfare of the region and the country. The growth in income driven by irrigation can also create a multiplier effect for other sectors (industry, agricultural industry, transportation, service, education etc.) (Çetin et al., 2013).

Recent studies show that one-third of the developing countries' populations live in areas with absolute water scarcity. The levels of water scarcity per country are shown in Figure 1 globally. Accordingly, the most severe water scarcity is in Middle East countries meaning that most of the countries in the region will not have sufficient water resources for industry, domestic use, environmental and agricultural needs by 2025 (Seckler et al., 2003). On average, more than 75% of the available water resouces in the Middle East countries is consumed for agriculture while this ratio is 70% on the global level (OECD, 2021). However, agricultural water use is near almost to 90% in some countries in the Middle East (FAO, 2008; Nazari et al., 2018). On the other hand, in the same countries, the use of agricultural irrigation water per unit area is above 10 000 m^{-3} ha^{-1} and the irrigation efficiency (IE) is quite low such as 35-40% (SUEN, 2022). In addition, climate change is expected to exacerbate the negative effects on irrigated agriculture and associated water-dependent ecosystems.

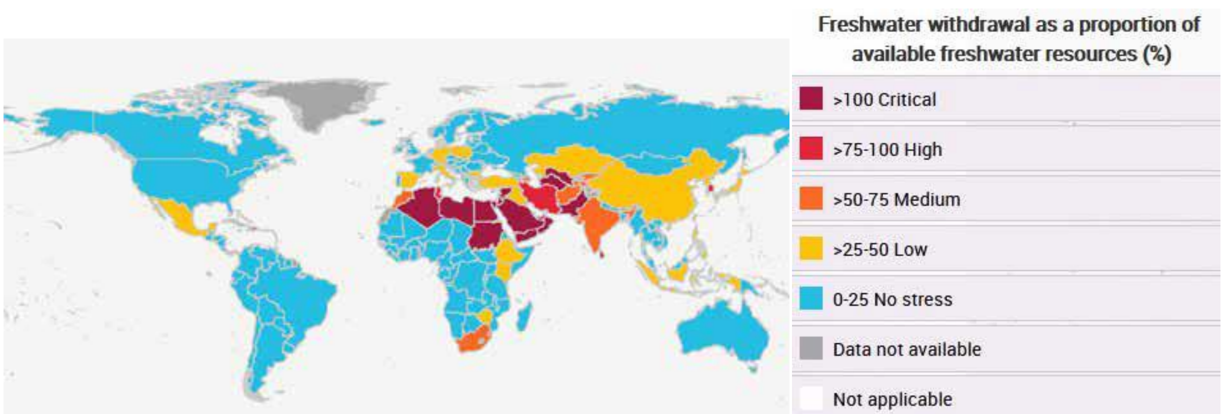

Figure 1. Water stress levels by country (FAO; UN Water, 2021)

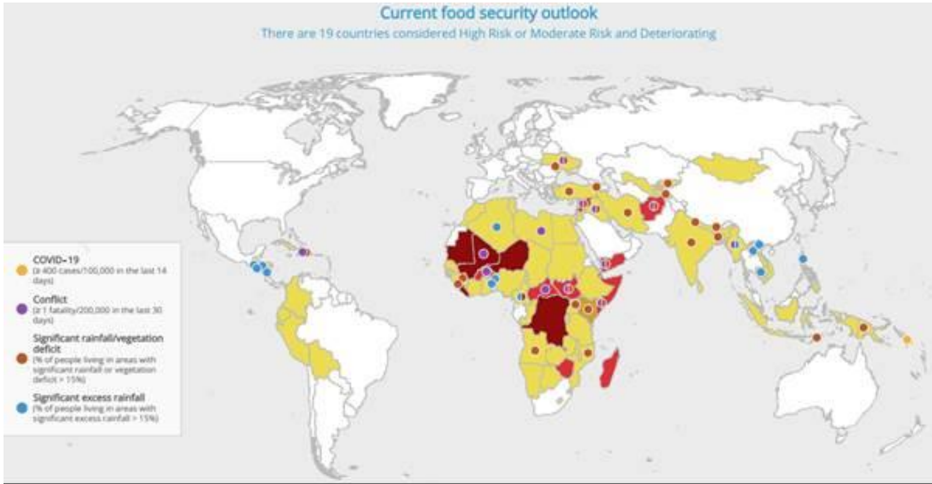

Figure 2. Current food security outlook and relation to water deficiency (HungerMap, 2022)

Considering the food and water stress in the world, it has become necessary to use soil and water resources more effectively and efficiently for sustainability. It has, thus, become inevitable to increase or improve irrigation efficiency and water productivity in the irrigation sector which the largest amount of global water is used.

IRRIGATION EFFICIENCY (IE) AND WATER PRODUCTIVITY (WP) FOR SUSTAINABLE IRRIGATION MANAGEMENT

Agricultural irrigation engineers and irrigation scientists have used the term of irrigation efficiency (IE) and/or water use efficiency to describe how effectively water is delivered to crops and to indicate the amount of water wasted at a farm, system or command level and defined it as "the ratio of irrigation water used by the crops in a farm or irrigation district area during the crop growth period to the water diverted from a reservoir or a river. Irrigation efficiency is, thus, an indicator of what percentage of water diverted from the source is used in irrigation. This gives an idea on efficiencies of irrigation schemes, irrigation management and how water is used in the field. It is understood that the higher the irrigation efficiency, the more effectively the water is used depending on the purposes.

Pressures on irrigation shemes and the farmers are continuing to achieve higher water productivity and improve irrigation efficiency, and use less water. A discussion on differences of perception of water management and efficiency objectives exists between farmers and policy- and decision-makers (Pereira et al., 2012).

Water productivity (WP, kg m^{-3} and/or \$ m^{-3}) is the ratio of the amount of crop production obtained per unit area to the water used in the same unit area. Water productivity can be calculated based on crop evapotarnspiration, irrigation water, irrigation water plus rainfall and only rainfall. These can be evaluated differently depending on the purpose of the users. Water economic productivity (WEP) is the ratio of the net income obtained from the unit area to the irrigation water applied to the same unit area (Paredes et al., 2014; Cetin and Kara, 2019).

Farmers and water user associations should consider farm net income and irrigation water productivity for optimum and sustainable irrigation management (Uygan et al., 2021)

MAIN CONSIDERATIONS ON IRRIGATION EFFICIENCY AND WATER PRODUCTIVITY

The main issue water use must be more effective use it for agriculture. For achieving of this, some applications and practices on sustainable water use strategies can be considered such as scheduling irrigation events, modifying agricultural practices, improving irrigation systems, deficit irrigation, shifting planting date etc. Thus WP could be increased (Figure 3).

Water productivity is a fundamental evaluation criterion in irrigation management. There is no single manner to enhance irrigation water productivity. In addition to use of irrigation systems such as drip irrigation, agronomic and other agricultural applications such as soil cultivation, use of seeds with high yield potential and drought-resistant, selection of appropriate crop patterns, use of mulch, appropriate fertilization, etc. are also to be considered.

For a sustainable water management in irrigation and agricultural water management, it should be a joint effort together with farmers, authorities on water and/or irrigation and government considering equity, efficiency, reliability and timeliness (Figure 4).

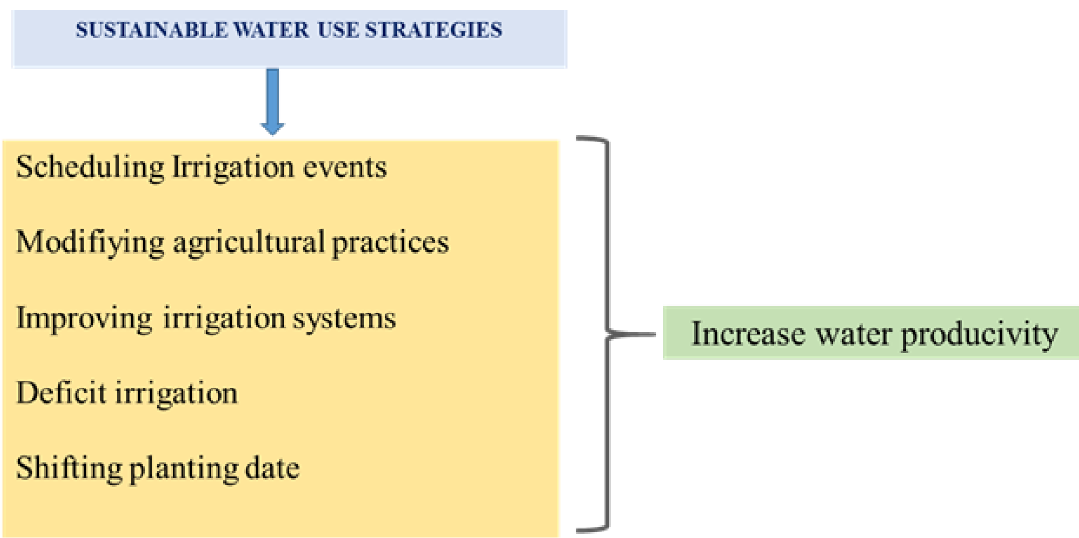

Figure 3. Some applications and practices on sustainable water use strategies and increasing WP

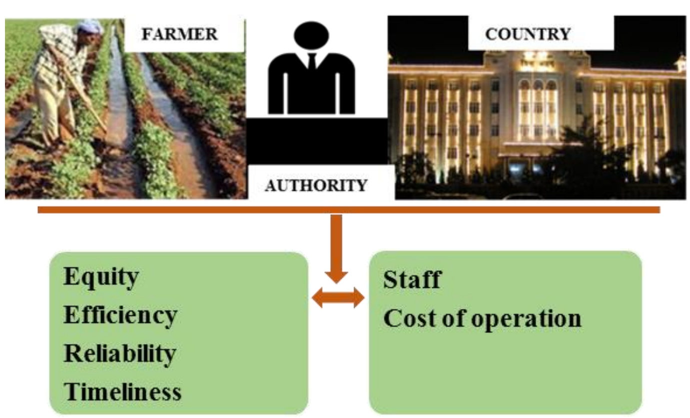

Figure 4. The stakeholders and components of irrigation and irrigation management

The balance between water resources, climate change, environmental pollution and agricultural demands plays a key role in terms of sustainability. The sustainability of water resources can be achieved if efficient river basin management strategies that incorporate efficient use and reuse of water are adopted. A rational, planned and effective water management strategy, which involves participatory management and environmental sustainability, should be developed in order to meet future demands (Figure 5)

Figure 5. The balance between agricultural demand and water resources (SUEN, 2022)

Ways or approaches to increase and/or improve IE and WP are summarized as below.

1. One of the most important methods to reduce excess irrigation water is to apply closed pressurized irrigation systems in addition to the improvement of surface and furrow irrigation systems. An adequate system design as well as proper installation, operation and maintenance are necessary to reap the extra benefits of modern technologies. Drip irrigation saves, because, about 30-50% of water in comparison with surface irrigation methods (Cetin, 2019). Thus, the main approach of improvement of IE and WP are to improve surface irrigation systems and to use the pressurized irrigation systems such as drip irrigation.
2. Deficit irrigation strategy for crops is one of the options in irrigation management in case of insufficient irrigation water. The maximum yield per volumetric water can be taken into account instead of maximum yield per area of land. Each region and country should develop a guide on deficit irrigation strategies for different crops.
3. In light of the limited resources in the region, for a more effective track, a train-the-trainers approach should be adopted followed by farmers' training and extension services on a continuous basis.
4. Farmers' habits and customs play an important role in the adoption and use of new irrigation systems. As such, farmers' extension policies should be developed by considering this social reality.
5. The use of domestic wastewater and/or other marginal waters in irrigated agriculture has become inevitable in the face of diminishing water resources, growing population and irrigated land and climate change. The efffective use of blue water, higher use of gray water and more use of green water using water harvesting should be taken into account.

6. Water harvesting is one of the prominent practices in rain-fed agriculture. Conservative agriculture (no tillage, use of moisture-retaining materials, use of mulch, etc.), rainwater collection and use (water harvesting) and supplemental irrigation can be realized.
7. The increase in irrigation water prices and/or real cost of irrigation water resulted in a rise in the physical and economic productivity of irrigation water. It is necessary to measure the water used in irrigation correctly. As a scarce resource can not be managed without measuring it, irrigation water pricing should be based on volumetric measurement. Excessive use of water in irrigation cannot be prevented if the water pricing is based on irrigated land area.
8. The subsidizing has greatly lifted up the use of pressurized irrigation systems in recent years. Financial supports and/or subsidies to the benefit of farmers must be formulated in favor of water-saving modern irrigation technologies.

As a result, to improve IE and WP, the role of multiple and diverse applications and stakeholders is extremely important (Figure 6).

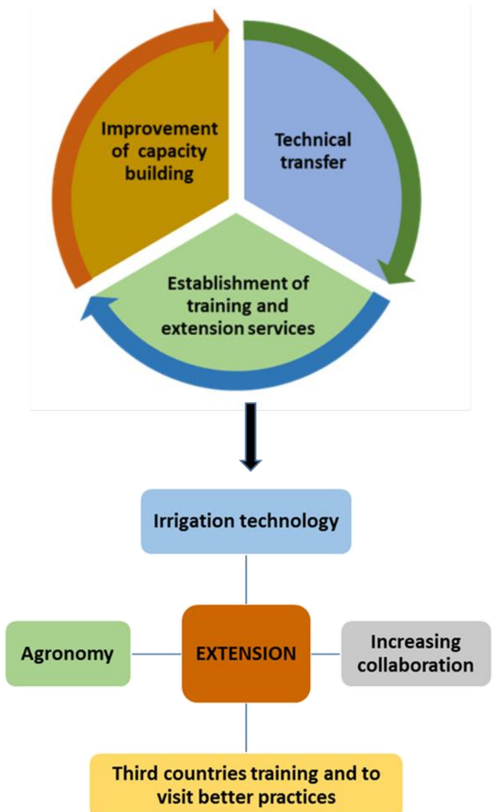

Figure 6. The dimensions of improvement of irrigation efficiency and water productivity

CONCLUSIONS

Irrigation efficiency and water productivity are the most important evaluation criteria which are affected by many different factors in irrigation management for the sustainability. Therefore, it is extremely important to consider and monitor those evaluation criteria for each irrigation scheme or irrigation basin. All institutions related to soil and water resources should use all data on soil and water and land use and crop production planning should be made for prevention use of excessive water and mismanagement. Organizations on land and water resources should link for and effective coordination between each other. Climate change mitigation and adaptation should be adopted as well. As aresult, a reform in irrigated agriculture is essential, involving a transformation to water use efficient crops, as well as water efficient farming techniques where all stakeholders adopt the more crop per drop.

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