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Approaches to Efficient Water Management and Use in Rice Cultivation

Enfoques para la gestión y uso eficiente del agua en el cultivo de arroz

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ABSTRACT: In the current context of climate change and instability where the availability of water is reduced over the years, the rice sector faces the challenge of making rational use of water, while at the same time needing to mitigate the effects of rice production in the face of a changing climate. Of particular interest in this regard are water-saving irrigation methods and climate-smart agricultural practices such as conservation agriculture that has begun to gain acceptance in rice cultivation. The objective of this work is to review the main approaches for the management and efficient use of water in rice cultivation, reported in the specialized scientific literature.
***Keywords*:** Agriculture, Water, Sustainability, Climate Change, Irrigation Management.

RESUMEN: En el contexto actual de cambio e inestabilidad climática donde la disponibilidad de agua se reduce con el paso de los años, el sector arrocero enfrenta el desafío de hacer un uso racional del agua, a la vez que necesita mitigar los efectos de la producción arrocera ante un clima cambiante. En este sentido, son de particular interés métodos de riego que ahorren agua y prácticas agrícolas climáticamente inteligentes como la agricultura de conservación que ha comenzado a ganar aceptación en el cultivo de arroz. El presente trabajo tiene como objetivo revisar los principales enfoques para la gestión y uso eficiente del agua en el cultivo de arroz, informados en la literatura científica especializada.
Palabras clave: agricultura, agua, sostenibilidad, cambio climático, manejo del riego.

INTRODUCTION

Rice is the staple food of 75 % of the world's population and one of the most important crops in the world (Vijayakumar *et al.*, 2022a; Gharsallah *et al.*, 2023). But in most countries, rice is grown under flooded conditions, which involves the use of large volumes of water and the emission of greenhouse gases (Gharsallah *et al.*, 2023; Meriguetti *et al.*, 2023). It is estimated that rice cultivation consumes 43 % of the irrigation water used globally (Majumdar *et al.*, 2023). However, increasing water scarcity in rice-producing countries is a cause for concern and threatens the sustainability of rice production under irrigated conditions Shukla *et al.* (2021), por lo que, en las últimas décadas, los investigadores se han enfocado en la búsqueda de nuevos métodos de riego que, which is why, in recent decades, researchers have focused on the search for new irrigation methods that save water without significantly affecting rice production.

In Cuba, rice cultivation has historically depended on the flood irrigation method (which consumes large volumes of water), making it the largest consumer of water in the agricultural sector. In addition, it has established a strong dependence on flooding as a method for weed control. But the current conditions of climate change, the degradation of soils expressed in low contents of organic matter, nitrogen, phosphorus and potassium, the change in climatic patterns (intense precipitation in some periods and prolonged droughts), and the scarcity of resources, they force farmers to implement profitable cultivation methods that contribute to the improvement and conservation of soils and at the same time save water.

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In response to these challenges, several cropping systems have been implemented internationally in which fields are not flooded and less irrigation water is used, while reducing the negative effects of rice production on climate change (Mallareddy *et al.*, 2023). For example, irrigation alternating periods of flooding and drying Gharsallah *et al.* (2023) and no-till cultivation applying the AC principle Gangopadhyay *et al.* (2023), among others. However, each method has its particularities, which may constitute advantages or disadvantages depending on local production conditions, availability of labor and factors such as soil type, field characteristics (topography or leveling) and field dimensions of the farms. The objective of this work is to review the main approaches for the management and efficient use of water in rice cultivation, reported in the specialized scientific literature.

DEVELOPMENT OF THE TOPIC

Rice cultivation is currently facing problems such as water scarcity and soil health degradation (Arouna *et al.*, 2023; Mallareddy *et al.*, 2023) Factors associated with the traditional method of continuously flooding the fields throughout the crop cycle, being the most practiced irrigation strategy worldwide for rice production (Luo *et al.*, 2022; Meriguetti *et al.*, 2023). As well as, traditional tillage based on the use of implements that break and decompose the soil structure, particularly with humid soils (Domínguez *et al.*, 2024). In this context, the application of new cultivation approaches in which fields are not permanently flooded and minimal soil disturbance as part of CA emerge as an important step for the efficient use of water, soil conservation and the environment.

The demand for irrigation water in rice cultivation is influenced, among other factors, by irrigation management practices such as: irrigation methods, irrigation regimes, irrigation scheduling, irrigation technologies, etc.), and practices agronomic aspects such as soil preparation and irrigation scheme patterns (Arouna *et al.*, 2023). Therefore, the demand for irrigation water can be reduced by adopting irrigation methods that save water and implementing agronomic practices that contribute to the efficient use of water, such as CA. In this sense, Arouna *et al.* (2023). suggest that water-saving technologies for rice cultivation can be classified into three groups: water-saving irrigation systems, water-saving irrigation methods, and water-saving agronomic practices.

Water-saving irrigation methods in rice production

The surface irrigation method is the most used in the world (Mubangizi *et al.*, 2023; Meriguetti *et al.*, 2023). In this method, surface irrigation, including basin irrigation, edge irrigation and furrow irrigation, is characterized by inefficient irrigation that causes water losses. Sprinkler irrigation and drip irrigation are a better alternative than surface flood irrigation to save irrigation water and increase agronomic water productivity, even with higher agricultural yield (Merza *et al.*, 2023; Saikumar *et al.*, 2023).

Modernization of surface irrigation

In Cuba, where rice cultivation irrigation systems were designed superficially (engineered, semi-engineered and traditional irrigation systems), it does not seem economical to introduce more expensive specialized irrigation systems or transform existing irrigation systems. One option, to improve the efficiency of water conduction, could be the use of polytubes of a certain diameter that extend throughout the field and have spaced holes for the outlet of an established flow rate (known as multiple-inlet irrigation).

This method is used in 32 % of the rice growing areas in Arkansas, with savings of 30 % of the volume of water Hardke *et al.* (2021) and in Mississippi, it has allowed us to reduce the volume of water traditionally used by 22 % (Massey *et al.*, 2022) Likewise, in Uruguay, savings of up to 50 % in water volume and 30 % in labor costs have been reported (González y Alonso, 2016). Also, in Cuba it has been tested with good results in the province of Camagüey and in the Los Palacios municipality, in Pinar del Río.

Another alternative could be the adoption of furrow irrigation, a practice that has increased significantly in recent years in the Hardke & Hardke (2021) and manages to significantly reduce water and labor consumption, compared to traditional flooding (Stevens *et al.*, 2018). Hussein *et al.* (2023) reported that the furrow irrigation technique outperformed the continuous flood irrigation technique, reducing water use by 33 % and increasing grain yield by 12,37 %. Similar results were obtained by Massey *et al.* (2022) with a saving of 23 % of the water volume. Abdallah *et al.* (2018), reported a significant reduction in water consumption and increased yield in transplanted rice, and concluded that furrow irrigation is a good option to optimize water use in surface irrigation systems in rice. Also, Hang *et al.* (2022) demonstrated that the adoption of furrow irrigation contributes to higher water productivity and yield of rice cultivation, and therefore recommended its implementation for sustainable water-saving rice production in northern China.

On the other hand, Carnevale *et al.* (2023) suggest that raised bed furrow irrigation is the best way to grow rice and other crops under aerobic conditions, in lowlands with heavy clay soil. *This method is compatible with CA principles of minimal soil disturbance and maintenance of permanent soil biomass cover*. In this regard, it has been proven that the supply of water through lateral furrows to the crop in raised beds under AC conditions saves irrigation water Sharif *et al.* (2014) and reduces the consumption of energy carriers (Saharawat *et al.*, 2022). Furthermore, when there is excess rainwater in the field, it can be drained through the furrows to avoid unwanted flooding and its consequences (Lv *et al.*, 2019).

Sprinkler irrigation

Mechanized sprinkler irrigation systems (center pivot and mechanical lateral movement or front feed) are gaining attention among farmers in several countries, due to easy irrigation management, combined with greater water use efficiency and greater productivity productividad (Brito *et al.*, 2020; Singh *et al.*, 2021). Furthermore, sprinkler irrigation makes it easier for farmers to adopt soil conservation practices, such as no-till farming and crop rotation (Pinto *et al.*, 2020; Rato *et al.*, 2023).

A two-year field study developed by Spanu *et al.* (2020) under Mediterranean climatic conditions and for 26 rice genotypes, found that the average yields of rice irrigated by flooding and sprinklers were never statistically different from each other. Also, Hussein *et al.* (2023) in clay soil of Egypt managed to grow rice under the sprinkler irrigation system, with higher values of grain yield, water use efficiency and water productivity, compared to furrow irrigation and irrigation continuous flooding. Similar results were reported by Brito *et al.* (2020) in temperate climate of southern Brazil.

In this regard, it is proposed that the yields of aerobic rice irrigated by sprinkler can be equivalent or higher than those of continuously flooded rice, when irrigation was activated with a soil tension between ≤15 and ≤30 kPa (Champness *et al.*, 2023). However, these soil tension thresholds determined in studies of other environments may not be ideal in tropical climates such as that of Cuba. Taking into account that Brito *et al.* (2020) observed in Southern Brazil that a soil water tension of 10 kPa was adequate to manage sprinkler irrigation in rice, especially in the reproductive stage, using cultivars developed for flooded environments.

On the other hand, the transition from flood irrigation to sprinkler irrigation could bring important environmental advantages. As water needs are halved, it is not essential to use specific agricultural machinery for soil leveling and raising dikes, it may be possible to reduce the number and intensity of weed treatments (Peña *et al.*, 2023). Furthermore, adopting sprinkler irrigation for rice can be an economically viable option for farmers (Hussein *et al.*, 2023).

Localized irrigation in rice

Drip irrigation is a water-saving technology that is used in rice production with mainly dry direct sowing (Mallareddy *et al.*, 2023), although it has also been used with good results in transplanted rice and in combination with the practices of the Rice Intensification System (Rao *et al.*, 2017; Padmanabhan, 2019). Drip irrigation consists of adding water to the soil slowly and at frequent intervals to maintain the moisture content in the soil close to field capacity (Merza *et al.*, 2023).

In drip irrigation, water losses due to evaporation, deep percolation, runoff and filtration decrease, compared to flood irrigation, which increases water productivity in the crop (Mallareddy *et al.*, 2023). In addition, it improves tillering and the development and functioning of the root system (Rao *et al.*, 2017; Parthasarathi *et al.*, 2018; Merza *et al.*, 2023). Likewise, it can provide better salinity control Ikramov *et al.* (2023) and allow the expansion of rice cultivation to mountainous areas (Gonçalves *et al.*, 2020). However, the effect of drip irrigation on rice yield may vary depending on local and environmental conditions (Mallareddy *et al.*, 2023).

Ikramov *et al.* (2023) in Uzbekistan report water savings of 26,4 % to 37,6 % with drip irrigation, but with a significant decrease in yield, which coincides with what was reported by Hang *et al.* (2022) in northern China. In contrast, Sasmita *et al.* (2022) in Indonesia obtained agricultural yield similar to the traditional flooding system, and suggest that fertigation through drip irrigation can increase crop yield by applying adequate fertilizer. In this sense, Padmanabhan (2019) y Soman (2021) in India observed that the drip system with fertigation saved between 50 and 61 % of water, increased rice yield (13-28 %) in all varieties in comparison with the yields recorded with the conventional flooding method, with better efficiency of the use of N, P and K under drip fertigation. Similar results are described by Merza *et al.* (2023) in Iraq.

However, drip irrigation systems require specialized installation and maintenance, including checking emitters for leaks or blockages, adjusting water flow, and monitoring soil moisture levels. This implies a greater need for labor and high production costs, making them not feasible for poor farmers and areas with labor shortages (Mallareddy *et al.*, 2023).

Irrigation management that saves water

Although experiments on rice production with drip and sprinkler irrigation systems are promising, traditional surface irrigation with continuous flooding practices is the most widely implemented in the world for rice cultivation (Meriguetti *et al.*, 2023; Arouna *et al.*, 2023). Given this situation, an alternative may be to develop and adopt irrigation practices that improve water use efficiency without affecting yield (Arouna *et al.*, 2023).

Among the irrigation management methods that save water in rice cultivation, the following stand out internationally: the alternative wetting and drying (AWD) method, the aerobic rice system, saturated soil cultivation (SSC) and intelligent irrigation with sensors and internet of things (IoT) (Mallareddy *et al.*, 2023). However, each management has its own peculiarities and must be adopted taking into account the type of soil, climatic suitability, the irrigation technique traditionally used, the characteristics of the fields (topography or leveling), the dimensions of the farms, the conditions economics and farmers' familiarity with digital technologies (Mallareddy *et al.*, 2023).

Alternate Wetting and Drying

The AWD is the most used water-saving management in rice production (Bwire *et al.*, 2023). It is based on intermittent flooding of rice fields and consists of alternating aerobic and anaerobic soil conditions, except during the stages of rooting (transplant rice), panicle formation and flowering (Bwire *et al.*, 2023). It can be applied after sowing in water or dry Gharsallah *et al.* (2023) and 1-2 weeks after transplanting (Bwire *et al.*, 2023).

In AWD, irrigation is interrupted for days and when the water content in the soil layer explored by plant roots falls below a threshold value, the field is flooded again to a depth of 5-12 cm (Bwire *et al.*, 2023; Mallareddy *et al.*, 2023; Wichaidist *et al.*, 2023). This technique is being implemented in countries such as India, Philippines, Myanmar, Vietnam, Bangladesh, China, Italy, Nepal, Indonesia and the United States of America (Mallareddy *et al.*, 2023; Wichaidist *et al.*, 2023). In Cuba it is known as replacement irrigation (MINAG, 2020).

According to Carrijo *et al.* (2017) research has shown that maintaining a soil water potential (SWP) of ≥ 20 kPa or ensuring that the water level in the field does not fall below 15 cm from the soil surface, ensures that plants do not suffer drought stress and yields are not significantly affected, regardless of the planting method (transplanting or direct sowing) and the type of cultivar (hybrid or genetic). Recent research also agrees that a 15 cm threshold guarantees that there is no significant reduction in performance (Bwire *et al.*, 2023; Mallareddy *et al.*, 2023; Wichaidist *et al.*, 2023)., which may represent a challenge for farmers to track optimal irrigation threshold variations.

The threshold soil water content can be monitored using soil water status sensors or devices (such as tensiometers or observation wells) (Bwire *et al.*, 2023; Mallareddy *et al.*, 2023). Likewise, automating the practice of AWD through Internet of Things (IoT)-based smart sensors and real-time alerts that apply soil, crop, and climate information, can optimize water use efficiency (Pham *et al.*, 2021).

AWD irrigation has been shown to save irrigation water, improve water use efficiency, reduce greenhouse gas emissions, save fertilizers and pesticides. Based on a meta-analysis of 56 studies, Carrijo *et al.* (2017) established that this AWD irrigation method saved 25,7 % of water input, with higher rice productivity. But Mallareddy *et al.* (2023) suggest that it can reduce water use by up to 37 % without affecting production, because it stimulates root growth (deeper root system). This behavior of the roots allows better absorption of water and nutrients from the deeper layers of the soil, and also makes plants more tolerant to water stress (Singh & Chakraborti, 2019). Likewise, (Bouman & Lampayan, 2009), noted that intermittent irrigation with AWD decreased insect pests by 92 % and diseases by 100 %.

On the other hand, numerous studies on AWD have highlighted additional benefits, such as: reduction in irrigation frequency; fuel savings; reducing greenhouse gas (GHG) emissions, particularly methane; greater efficiency in the use of nitrogen and phosphorus, and lower accumulation of contaminants such as arsenic (As) and mercury (Hg) in the grain grano (Islam *et al.*, 2022; Bwire *et al.*, 2023; Wichaidist *et al.*, 2023).

However, AWD may not be the most suitable approach for growing rice on sandy soils as water drains away quickly resulting in minimal water savings. Similarly, in heavy clay soils and shallow water tables, it may not be necessary, since in these soils the water table never falls below the lowest roots (Mallareddy *et al.*, 2023). Likewise, studies conducted by Gharsallah *et al.* (2023) in Italy, indicated that the total variable costs applying AWD were approximately 71 euros higher compared to continuous flooding, which they attributed to a greater need for labor for irrigation management.

A promising agricultural practice that, associated with AWD, can offer superior options in terms of water savings, rice productivity and GHG emissions reduction is conservation agriculture (Gangopadhyay *et al.*, 2023). The application of CA principles based on minimal soil disturbance, residue retention on the field surface and crop rotation, improves soil health and the water retention capacity of rice soils Domínguez *et al.* (2024), which contributes to reducing GHG emissions and increasing water efficiency.

Aerobic rice system

Aerobic rice cultivation is an approach to growing rice in well-drained, non-flooded and unsaturated soils without standing water (Mallareddy *et al.*, 2023; Saikumar *et al.*, 2023). Generally, rice is planted on dry soil, without any flooding, and the field is irrigated intermittently. Although, sometimes water management consists of short dips, which can last a few days, alternated with longer dry periods Monaco *et al.* (2016), so specific aerobic rice cultivars must be used. This system is compatible with System of Rice Intensification (SRI) practices and irrigation technologies such as wetting and drying (AWD) Kumar *et al.* (2023) and drip irrigation (Sasmita *et al.*, 2022) can be used.

Among the main advantages of this cultivation system are water savings, the reduction of greenhouse gas emissions and the potential for global warming (Kumar *et al.*, 2023). In addition, it can facilitate the traffic of agricultural machinery and facilitate the harvest-transport process. Also, it favors the rotation of rice with legumes and legumes that provide nitrogen to the soil Saikumar *et al.* (2023), but the change from conventional flooded rice cultivation to an aerobic rice system has generally resulted in lower yields (Champness *et al.*, 2023; Meriguetti *et al.*, 2023). In aerobic rice cultivation, there may be greater weed infestation and it may be necessary to use intensive weed control measures, such as the application of herbicides or manual weeding (Mallareddy *et al.*, 2023). Research conducted by Champness *et al.* (2023) in temperate areas of Australia demonstrates that aerobic rice requires more than 20 irrigation events per season, which implies high demand for labor, so the adoption of aerobic rice on a commercial scale is unlikely without the use of automated irrigation technology.

Saturated soil cultivation (SSC)

Is a water management alternative in which shallow irrigation is applied to achieve about 1 cm of water depth for one or two days after standing water has disappeared (Bwire *et al.*, 2023; Mallareddy *et al.*, 2023). Generally, SSC involves watering the field to a depth of approximately 1 cm per day after standing water has dissipated (Wichaidist *et al.*, 2023). In SSC, the soil is kept as close to saturation as possible, which reduces hydraulic loading and decreases losses through filtration and percolation (Bwire *et al.*, 2023). The depth of water above ground is kept below 3 cm (Mallareddy *et al.*, 2023).

According to Matsue *et al.* (2021) SSC irrigation can significantly increase grain yield by increasing the percentage of filled grains compared to the traditional flooding system. In Australia, SSC used about 32 % less water compared to traditional flooded rice production in both seasons (wet and dry), with no effect on grain yield and quality (Mallareddy *et al.*, 2023). A similar result was obtained by Borja *et al.* (2018) in Brazil.

SSC facilitates maximum utilization of rainfall and reduces the number of irrigations required for crop development, thereby reducing irrigation cost, energy required for irrigation, and irrigation water (Mallareddy *et al.*, 2023). Furthermore, it can improve the nitrogen and phosphorus utilization efficiency of the rice plant, and consequently reduce the need for fertilizers (Wichaidist *et al.*, 2023). At the same time, it has the potential to mitigate greenhouse gas (GHG) emissions, particularly methane emissions (Wichaidist *et al.*, 2023).

Smart Irrigation

This technology is based on the use of smart irrigation sensors, the Internet of Things (loT), wireless communications, networks of automatic weather stations, improved measurement of crop evapotranspiration, aerial and satellite images, and cloud computing technology. Wireless networks are used to collect data from soil moisture sensors, which can then be accessed via a web browser or smartphone application (Mallareddy *et al.*, 2023; Zeng *et al.*, 2023).

The IoT-based smart irrigation system enables real-time remote monitoring of moisture content and precise irrigation management in rice fields, through mobile devices (Mallareddy *et al.*, 2023; Zeng *et al.*, 2023). Irrigation systems can be automated to adapt to different crops, soil, climate and other factors with the help of humidity and temperature sensors, IoT devices and machine learning algorithms (Vijayakumar *et al.*, 2022b). In addition, they can be integrated with other technologies, such as weather forecasting or images taken by drones, to optimize the irrigation process (Mallareddy *et al.*, 2023).

Automation of irrigation systems increases production without requiring labor, improves the quality and efficiency of crop water use, while reducing water consumption, time, cost and energy expenditure of irrigation (Vijayakumar *et al.*, 2022a; Zeng *et al.*, 2023). IoT systems are particularly useful in regions with a limited workforce due to a shrinking rural population, an aging population, or rising labor wages in agricultural activities, as it reduces the need for labor by 19,1 % to 24,5 %, compared with the conventional irrigation system (Lee, 2022; Zeng *et al.*, 2023). Additionally, farmers can increase water-saving benefits if combined with technologies such as AWD, SRI, or intermittent irrigation (Pham *et al.*, 2021; Zeng *et al.*, 2023).

However, the adoption and dissemination of automated irrigation systems based on IoT sensors in rice fields may be slow due to factors such as lack of technical expertise of farmers and the high cost of the sensors used to intelligent automatic irrigation, which is fundamentally inaccessible to small farmers (García *et al.*, 2020; Mallareddy *et al.*, 2023). Furthermore, for its use it is necessary that there is a quality Internet connection so that the data can be sent from the sender to the receiver, which, in the rice-growing areas of Cuba, is still a problem.

AGRONOMIC PRACTICES THAT SAVE WATER

In irrigated rice cultivation, the multiple agronomic solutions that can be adopted to save water include:

- A change in the crop mix, introduction of new rice cultivars with genetically improved characteristics that require less water Surendran *et al.* (2021) and short cycle (Monaco *et al.*, 2016; Hussein *et al.*, 2023).
- The use of vegetal covers Wei *et al.* (2019); Singh *et al.* (2021) or plastic mulch Zhang *et al.* (2022), especially in conditions of unsaturated aerobic soil (Singh *et al.*, 2021).
- Dry sowing and intermittent irrigation, known as aerobic rice (Monaco *et al.*, 2016).
- Application of organic matter (Chen *et al.*, 2022).
- Practice no-till cultivation and direct sowing Gangopadhyay *et al.* (2023), which implies eliminating traditional tillage and the practice of fangueo (Carnevale *et al.*, 2023).
- The implementation of efficient weed control methods (Monaco *et al.*, 2016; Farooq *et al.*, 2019).
- Proper leveling of fields (Haji, 2023; Mallareddy *et al.*, 2023).
- Reuse excess or drainage water (Haji, 2023).
- Adjust the crop planting date to make more effective use of rain (Luo *et al.*, 2022).
- Direct dry sowing and delayed flooding, which eliminates water consumption for soil preparation. Strategy that in Italy implies a reduction in total variable costs of 215,50 euros per hectare, with respect to traditional cultivation and permanent flooding (Gharsallah *et al.*, 2023).
- Construct and line field canals and waterways (Mallareddy *et al.*, 2023), which can be done through the use of polyethylene materials (Rau *et al.*, 2020).

In Cuba, according to several research works, the exposure of the crop to controlled stress conditions due to water deficit, mainly in the tillering phase, has favored increased yield and decreased water consumption (Ruiz *et al.*, 2016; Polón *et al.*, 2019). Other global studies show that reducing the height of the water table, as well as strengthening extension, training and demonstration programs in farmers' fields, to conserve water and increase irrigation efficiency, can be strategies that contribute to water savings (Mallareddy *et al.*, 2023). Also, it is essential to provide encouragement, support and incentives to farmers to adopt these methods in practice (Wichaidist *et al.*, 2023). which constitutes important elements to consider when adopting alternative cropping systems that contribute to water savings.

System of Rice Intensification (SRI)

It consists of the application of four fundamental rules, related to each other: early, agile and solid planting; decrease in plant density; improve the soil through organic supplements; and controlled and reduced application of water (Singh *et al.*, 2021). However, adjustments are frequently adopted to address changing soil conditions, climate designs, water control, accessibility to work, access to natural resources, and the choice to rely entirely on organic farming (Uddin y Dhar, 2020). This is a system fundamentally designed for sowing by transplant with seedlings between 8 and 12 days old.

SRI has demonstrated positive results in China and India and in more than 60 countries in Asia, Africa and Latin America (Kumar *et al.*, 2023). In general, SRI can reduce the amount of seed required from 120 to 10 $kg \cdot ha^{-1}$. Additionally, on-farm evaluations from major rice-producing countries (Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Vietnam) indicate that on average, it increases yield by 47 %, saves 40 % water, increases income per hectare by 68 % and reduces costs per hectare by 23 % (Mubangizi *et al.*, 2023). Also, it can reduce greenhouse gas emissions by 21% Mubangizi *et al.* (2023) and its technology is more accessible to small and medium-sized producers (Valdiviezo *et al.*, 2023).

However, rice seedlings must be planted with greater care and precision, which is still done primarily manually in many countries. Additional weeding may also be necessary, so increased labor requirements have prevented its adoption in several countries (Kaur *et al.*, 2023). However, there are currently self-propelled machines for mechanized rice transplanting Miranda *et al.* (2022) and mechanical weeders that can contribute to the implementation of SRI, even on large farms.

It has also been reported as a drawback for its greater diffusion that there is no custom of transplanting very small and individual seedlings, being necessary to improve the construction of seedbeds. Weed control problems due to greater transplant distances and dispensing with the use of irrigation with a constant sheet of water (Valdiviezo *et al.*, 2023).

Use of hydrogel or superabsorbent polymer

Hydrogel is defined as a three-dimensional polymeric network that can retain a significant amount of water within its structure and swell without dissolving in water (Guilherme *et al.*, 2015). The particles (hydrogel or superabsorbent polymer), when in the soil, act as water reservoirs, from which plant roots can absorb water, which is why the application of hydrogel has been identified as a possible solution to increase the efficiency in water use in irrigation (Prakash *et al.*, 2021b).

The main advantages of using hydrogels may vary depending on soil conditions. However, these advantages include increased seed germination, increased growth of seedlings and their roots, which contributes to a denser plant population and higher yields. Hydrogels also facilitate better absorption of excess water, allowing its gradual release during periods of water stress, which delays the appearance of permanent wilting point. Additionally, hydrogels significantly increase water use efficiency by reducing water loss through evaporation and leaching, decreasing irrigation frequency, the need for crop fertilizers, and the costs associated with irrigation. Likewise, these materials can resist salt concentrations in the soil, improving their physical, chemical and biological attributes (Vedovello *et al.*, 2024).

Hydrogels provide versatile solutions to address water scarcity and soil degradation in agriculture (Vedovello *et al.*, 2024). Recent research shows that water availability in clay loam soil increased from 56 % to 125 % with the addition of the hydrogel. With an ideal application rate of 0,2 %, the hydrogel decreased the need for irrigation water by 29 % compared to bare soil (Saha *et al.*, 2021).

Rehman *et al.* (2011) found that hydrogel application improved the moisture content of sandy loam soil, compared to soil without hydrogel, which increased the number of germinated seeds and achieved better crop establishment. With significant improvement of yield components (plant height, number of fertile tillers, number of grains per panicle and 1000 grain weight) and rice yield in hydrogel-amended soil, in all planting techniques. Furthermore, planting rice in beds with hydrogel amendment improved the growth and yield of aerobic rice more than other planting techniques.

Also, El-Naby *et al.* (2024) observed that the application of hydrogel polymer conserved approximately 14,8 % of the applied water and improved rice grain yield by 16,5 %, as well as increased water productivity by 0,32 $kg \cdot m^{-3}$ to 0,48 $kg \cdot m^{-3}$ compared to the treatment without hydrogel.

In general, the effects found in rice cultivation may be due to the improvement of soil moisture content, moisture retention curve, apparent density, particle density, total porosity, pore diameter, organic matter and biological activity in the soil (Solieman *et al.*, 2023), as well as the reduction of leaching of nutrients from the soil through runoff and infiltration (Prakash *et al.*, 2021a). Although studies have indicated that hydrogel in agriculture does not present risks to the environment Vedovello *et al.* (2024) and its application is identified as a possible solution to increase the efficiency of water use in irrigation (Prakash *et al.*, 2021b). Large-scale hydrogel implementation may be hampered by issues such as cost-effectiveness and stability of many traditional agricultural practices (Kaur *et al.*, 2023). On the other hand, the use of most hydrogels is still based on synthetic polymers, which raises concern about their role in long-term applications Vedovello *et al.* (2024), therefore, they should be used with caution. in rice cultivation.

Research work carried out by (Cisneros *et al.* (2018, 2020, 2021) on the use of polymers in Cuban agriculture in tomato, corn and bean crops have shown that in all trials when the polymer was applied, the number of irrigations was reduced. Consequently, the total net standard was also reduced in the range of 19 and 27 %, water productivity increased with respect to the control treatment in the range of 24 and 40 %, also achieving the best benefit-cost ratios when used the polymer.

Conservation Agriculture (CA)

As the vulnerability of agricultural production systems to the effects of climate change increases, the world needs new farming approaches that are more resilient and productive (Carnevale *et al.*, 2023). CA has demonstrated global relevance for improving crop production, poverty alleviation, food security, and climate change adaptability and mitigation (Kassam et al., 2022). This agricultural production technology is characterized by three fundamental principles: maintaining the soil permanently covered with crop residues or plant covers at least 30 %, minimal disturbance of the soil and diversification of the species grown in rotation (Kassam *et al.*, 2022).

Globally, CA is used with good results on approximately 205,4 M ha worldwide, mainly in countries such as the United States, Brazil, Argentina, Canada and Australia, and has begun to gain acceptance in rice cultivation (Kassam *et al.*, 2022). However, to sustain optimal factor productivity and ecosystem services, basic CA practices must be combined with other complementary practices for the integrated management of crops, soil, nutrients, water, pests, labor, energy and land cultivation (Kassam *et al.*, 2022). In this sense, the combination of CA with the application of irrigation methods and alternatives that save water could contribute to the sustainability of rice production under irrigated conditions.

In a CA system, planting is done directly into untilled soils Domínguez *et al.* (2021) and water can be managed by keeping the soil in mostly moist conditions without continuous flooding (Carnevale *et al.*, 2023). Taking into account that AC conditions improve soil health and promote root development of the crop, so plants can better tolerate water stress. Additionally, minimal soil disturbance and increased organic matter improve soil infiltration and water retention capacity, allowing longer periods between irrigation events (Singh, 2018).

Maintaining moist soil conditions in AC systems can be accomplished through water management. Either with drip irrigation or frequent irrigation (surface or sprinkler), or through AWD cycles in surface irrigation (pulse flooding), can increase water use efficiency by more than 50 % and reduce emissions of CH_4 by 30-70 % (Carnevale *et al.*, 2023).

CA has also shown good results in the cultivation of rice in permanent raised beds, without tillage, covered with biomass residues, and irrigation is applied in the furrows between the beds through flood irrigation (Sharif *et al.*, 2014).This method reduces water and labor requirements for rice cultivation by 70 %, with a yield of 12 $t \cdot ha^{-1}$ in Pakistan (Sharif *et al.*, 2014). A similar result has been obtained by Chappell in Arkansas, USA in a sandy loam soil, not suitable for flooded cultivation (Carnevale *et al.*, 2023).

On the other hand, raised bed cultivation and furrow irrigation can benefit the rotation of rice with other crops that do not tolerate flooding. Furthermore, it has been shown that no-till systems induce a reduction in the weed seed bank present in the soil (Hossain *et al.*, 2021). This approach of growing rice under CA principles in raised beds and furrow irrigation is compatible with other cropping systems such as the SRI Carnevale *et al.* (2023) and can enhance the application of hydrogel in agriculture.

CONCLUSIONS

In the world, different irrigation methods and water management alternatives are adopted in rice cultivation, all aimed at the efficient and sustainable use of the water resource as a measure to mitigate the effects of climate variability and change.

There are different irrigation methods with greater or lesser efficiency in the use of water that can be used to irrigate rice. The study carried out in this work shows that the trend is towards the combination of these methods, with different strategies that reduce the volumes of water necessary to apply for the control of weeds and the good physiological development of the rice crop.

The adoption of agricultural systems that combine the advantages of conservation agriculture with the Rice Intensification System and the application of hydrogels or super absorbent polymer, may offer promising solutions for the future of agricultural innovations and technologies that address the challenges to improve the efficiency in the use of irrigation water in rice cultivation.

REFERENCES

ABDALLAH, A.; ALZOHEIRY, A.; BURKEY, K.: "Comparison of flooded and furrow-irrigated transplanted rice (Oryza sativa L.): Farm-level perspectives", *Journal of Irrigation and Drainage Engineering*, 144(9): 04018022, 2018, ISSN: 0733-9437, DOI: https://doi.org/10.1061/(ASCE)IR.1943-4774.0001337.

AROUNA, A.; DZOMEKU, I.K.; SHAIBU, A.-G.; NURUDEEN, A.R.: "Water management for sustainable irrigation in rice (Oryza sativa L.) production: A review", *Agronomy*, 13(6): 1522, 2023, ISSN: 2073-4395, DOI: https://doi.org/10.3390/agronomy13061522.

BORJA, R.A.F.; ALMEIDA, R.E.; LAGO, B.C.; TRIVELIN, P.C.; LINQUIST, B.; FAVARIN, J.L.: "Aerobic rice system improves water productivity, nitrogen recovery and crop performance in Brazilian weathered lowland soil", *Field Crops Research*, 218: 59-68, 2018, ISSN: 0378-4290, DOI: https://doi.org/10.1016/j.fcr.2018.01.002.

BOUMAN, B.A.M.; LAMPAYAN, R.M.: *Rice Fact Sheet-Alternate Wetting Drying (AWD)*, Inst. International Rice Research Institute: Los Baños, Philippines, Los Baños, Philippines, 2009.

BRITO, M.A.; BARBAT, J.M.; TIMM, L.C.; COLLAZOS--ROMO, L.: "Concenço G, Stumpf L, Gomes B. Sprinkler irrigation in lowland rice: Crop yield and its components as a function of water availability in different phenological phases", *Field Crops Research*, 248: 107714, 2020, DOI: https://doi.org/10.1016/j.fcr.2020.107714.

BWIRE, D.; SAITO, H.; SIDLE, R.C.; NISHIWAKI, J.: "Water Management and Hydrological Characteristics of Rice-Paddy Catchments Under AWD Irrigation Practice: Asia and Sub-Saharan Africa", 2023, DOI: 10.20944/preprints202311.1677.v1.

CARNEVALE-ZAMPAOLO, F.; KASSAM, A.; FRIEDRICH, T.; PARR, A.; UPHOFF, N.: "Compatibility between Conservation Agriculture and the System of Rice Intensification", *Agronomy*, 13(11): 2758, 2023, ISSN: 2073-4395, DOI: 10.20944/preprints202309.1689.v1.

CARRIJO, D.R.; LUNDY, M.E.; LINQUIST, B.A.: "Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis", *Field Crops Research*, 203: 173-180, 2017, ISSN: 0378-4290, DOI: https://doi.org/10.1016/j.fcr.2016.12.00.

CHAMPNESS, M.; BALLESTER, C.; HORNBUCKLE, J.: "Effect of soil moisture deficit on aerobic rice in temperate Australia", *Agronomy*, 13(1): 168, 2023, ISSN: 2073-4395, DOI: https://doi.org/10.3390/agronomy13010168.

CHEN, K.; YU, S.; MA, T.; DING, J.; HE, P.; DAI, Y.; ZENG, G.: "Effects of water and nitrogen management on water productivity, nitrogen use efficiency and leaching loss in rice paddies. Water 14 (10): 1596", *Water*, 14(10): 1596, 2022, DOI: https://doi.org/10.3390/w14101596.

CISNEROS, Z.E.; CUN, G.C.; HERRERA, P.J.; GONZÁLEZ, R.F.; CUN, R.S.; SARMIENTO, G.O.: "Efecto de los polímeros en la economía del agua.", *Revista Iberoamericana de polímeros*, 21(1): 1-13, 2020.

CISNEROS, Z.E.; CUN, G.R.; ROSALES, N.L.; GONZÁLEZ, M.D.: "Lluvia sólida, para un uso eficiente del agua. Resultados preliminares", *Ingeniería Agrícola*, 8(1): 13-20, 2018, ISSN: 2227-8761.

CISNEROS-ZAYAS, E.; GONZÁLEZ-ROBAINA, F.; CUN-GONZÁLEZ, R.; HERRERA-PUEBLA, J.; MATOS-CREMÉ, H.; SARMIENTO-GARCÍA, O.: "Los polímeros súper absorbentes y su influencia sobre la productividad del agua en el frijol", *Revista Ingeniería Agrícola*, 11(2): 10-17, 2021, ISSN: 2306-1545.

DOMÍNGUEZ, V.C.; DE ARAÚJO, A.G.; MIRANDA, C.A.; DÍAZ, L.G.; RODRÍGUEZ, G.A.: "Machinery for direct sowing of rice in agricultural conditions", *International Journal of Food science and Agriculture*, 5(3): 471-481, 2021, DOI: 10.26855/ijfsa.2021.09.018.

DOMÍNGUEZ, V.C.; MIRANDA, C.A.; DÍAZ, L.G.; DOMÍNGUEZ, P.D.; DUARTE, D.C.; RUIZ, S.J.; RODRÍGUEZ, A.: "Properties of a cultivated soil of irrigated rice under conservation agriculture principles", *Net Journal of Agricultural Science*, 12(1): 9-16, 2024, DOI: 10.30918/NJAS.121.24.011.

EL-NABY, A.; EL-GHANDOR, A.; ABOU EL-DARAG, I.; MAHMOUD, M.: "Impact of Hydrogel Polymer on Water Productivity, Weed Control Efficiency and Yield of Broadcast-Seeded Rice", *International Journal of Plant & Soil Science*, 36(2): 9-27, 2024, ISSN: 2320-7035, DOI: 10.9734/IPSS/2024/v36i2435.

FAROOQ, M.; HUSSAIN, M.; UL-ALLAH, S.; SIDDIQUE, K.: "Physiological and agronomic approaches for improving water-use efficiency in crop plants", *Agricultural Water Management*, 219: 95-108, 2019, ISSN: 0378-3774, DOI: https://doi.org/10.1016/j.agwat.2019.04.010.

GANGOPADHYAY, S.; CHOWDHURI, I.; DAS, N.; PAL, S.C.; MANDAL, S.: "The effects of no-tillage and conventional tillage on greenhouse gas emissions from paddy fields with various rice varieties", *Soil and Tillage Research*, 232: 105772, 2023, ISSN: 0167-1987, DOI: https://doi.org/10.1016/j.still.2023.105772.

GARCÍA, L.; PARRA, L.; JIMENEZ, J.M.; LLORET, J.; LORENZ, P.: "IoT-based smart irrigation systems: An overview on the recent trends on sensors and IoT systems for irrigation in precision agriculture", *Sensors*, 20(4): 1042, 2020, ISSN: 1424-8220, DOI: https://doi.org/10.3390/s20041042.

GHARSALLAH, O.; RIENZNER, M.; MAYER, A.; TKACHENKO, D.; CORSI, S.; VUCITERNA, R.; ROMANI, M.; RICCIARDELLI, A.; CADEI, E.; TREVISAN, M.: "Economic, environmental, and social sustainability of Alternate Wetting and Drying irrigation for rice in northern Italy", *Frontiers in Water*, 5: 1213047, 2023, ISSN: 2624-9375, DOI: 10.3389/frwa.2023.1213047.

GONÇALVES, J.M.; FERREIRA, S.; NUNES, M.; AGRAWAL, R.; AMADOR, P.; FILIPE, O.; DUARTE, I.M.; TEIXEIRA, M.; VASCONCELOS, T.; OLIVEIRA, F.: "Developing irrigation management at district scale based on water monitoring: study on Lis valley, Portugal", *AgriEngineering*, 2(1): 78-95, 2020, ISSN: 2624-7402.

GONZÁLEZ, M.; ALONSO, A.M.: "Tecnologías para ahorrar agua en el cultivo de arroz", *Nova*, 14(26): 63-78, 2016, ISSN: 1794-2470.

GUILHERME, M.R.; AOUADA, F.A.; FAJARDO, A.R.; MARTINS, A.F.; PAULINO, A.T.; DAVI, M.F.T.; RUBIRA, A.F.; MUNIZ, E.C.: "Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review", *European Polymer Journal*, 72: 365-385, 2015, ISSN: 0014-3057.

HAJI, W.S.: “Adoption of technology to improve self-sufficiency in paddy plantations in Brunei: Challenges and mitigation strategies for intermediate stakeholders.”, En: *IOP Conference Series: Earth and Environmental Science*, Ed. IOP Publishing, vol. 1182, p. 012011, 2023, DOI: 10.1088/1755-1315/1182/1/012011, ISBN: 1755-1315.

HANG, X.; DANSO, F.; LUO, J.; LIAO, D.; ZHANG, J.; ZHANG, J.: “Effects of water-saving irrigation on direct-seeding rice yield and greenhouse gas emissions in north China”, *Agriculture*, 12(7): 937, 2022, ISSN: 2077-0472, DOI: https://doi.org/10.3390/agriculture12070937.

HARDKE, J.; SHA, X.; BATEMAN, N.: “BR Wells Arkansas rice research studies 2020. Arkansas Agricultural Experiment Station Research Series”, 2021, *Disponible en:* https://scholarworks.uark.edu/aaesser/200.

HARDKE, J.T.; HARDKE, J.L.: *Arkansas Furrow-Irrigated Rice*, Inst. University of Arkansas System: Little Rock, AR, USA, Little Rock, AR, USA, 42 p., 2021.

HOSSAIN, M.; BEGUM, M.; HASHEM, A.; RAHMAN, M.M.; HAQUE, M.E.; BELL, R.W.: “Continuous practice of Conservation Agriculture for 3-5 years in intensive rice-based cropping patterns reduces soil weed seedbank”, *Agriculture*, 11(9): 895, 2021, ISSN: 2077-0472, DOI: https://doi.org/10.3390/agriculture11090895.

HUSSEIN, N.; EL ANSARY, M.; AWAD, M.; MOSTAFA, H.M.S.: “Effect of sprinkler and furrow irrigation systems on rice yield and its water productivity”, *Misr Journal of Agricultural Engineering*, 40(4): 319-330, 2023, ISSN: 1687-384X, DOI: 10.21608/mjae.2023.229501.1113.

IKRAMOV, R.; GAPPARO, S.; DZHUMAEV, Z.; ABDUKHOLIK, U.: “Results of application of water-saving technologies in rice farming”, En: *E3S Web of Conferences*, Ed. EDP Sciences, vol. 401, p. 01041, 2023, DOI: https://doi.org/10.1051/e3sconf/202340101041, ISBN: 2267-1242.

ISLAM, S.; GAIHRE, Y.K.; ISLAM, M.R.; AHMED, M.N.; AKTER, M.; SINGH, U.; SANDER, B.O.: “Mitigating greenhouse gas emissions from irrigated rice cultivation through improved fertilizer and water management”, *Journal of Environmental Management*, 307: 114520, 2022, ISSN: 0301-4797, DOI: https://doi.org/10.1016/j.jenvman.2022.114520.

KASSAM, A.; FRIEDRICH, T.; DERPSCH, R.: “Successful experiences and lessons from conservation agriculture worldwide”, *Agronomy*, 12(4): 769, 2022, ISSN: 2073-4395, DOI: https://doi.org/10.3390/agronomy12040769.

KAUR, P.; AGRAWAL, R.; PFEFFER, F.M.; WILLIAMS, R.; BOHIDAR, H.B.: “Hydrogels in agriculture: Prospects and challenges”, *Journal of Polymers and the Environment*, 31(9): 3701-3718, 2023, ISSN: 1566-2543, DOI: https://doi.org/10.1007/s10924-023-02859-1.

KUMAR, R.M.; CHINTALAPATI, P.; RATHOD, S.; VIDHAN SINGH, T.; KUCHI, S.; MANNAVA, P.B.; LATHA, P.C.; SOMASEKHAR, N.; BANDUMULA, N.; MADAMSETTY, S.: “Comparison of System of Rice Intensification Applications and Alternatives in India: Agronomic, Economic, Environmental, Energy, and Other Effects”, *Agronomy*, 13(10): 2492, 2023, ISSN: 2073-4395, DOI: . https://doi.org/10.3390/ agronomy13102492.

LEE, J.: “Evaluation of automatic irrigation system for rice cultivation and sustainable agriculture water management”, *Sustainability*, 14(17): 11044, 2022, ISSN: 2071-1050, DOI: https://doi.org/10.3390/su141711044.

LUO, W.; CHEN, M.; KANG, Y.; LI, W.; LI, D.; CUI, Y.; KHAN, S.; LUO, Y.: “Analysis of crop water requirements and irrigation demands for rice: Implications for increasing effective rainfall”, *Agricultural Water Management*, 260: 107285, 2022, ISSN: 0378-3774, DOI: https://doi.org/10.1016/j.agwat.2021.107285.

LV, S.H.; DONG, Y.J.; JIANG, Y.; PADILLA, H.; LI, J.; UPHOFF, N.: “An opportunity for regenerative rice production: Combining plastic film cover and plant biomass mulch with no-till soil management to build soil carbon, curb nitrogen pollution, and maintain high-stable yield”, *Agronomy*, 9(10): 600, 2019, ISSN: 2073-4395.

MAJUMDAR, A.; KUMAR, V.D.P.; GIRI, B.; MOULICK, D.; SRIVASTAVA, A.K.; ROYCHOWDHURY, T.; BOSE, S.; JAISWAL, M.K.: “Combined effects of dry-wet irrigation, redox changes and microbial diversity on soil nutrient bioavailability in the rice field”, *Soil and Tillage Research*, 232: 105752, 2023, ISSN: 0167-1987, DOI: https://doi.org/10.1016/j.still.2023.105752.

MALLAREDDY, M.; THIRUMALAIKUMAR, R.; BALASUBRAMANIAN, P.; NASEERUDDIN, R.; NITHYA, N.; MARIADOSS, A.; EAZHILKRISHNA, N.; CHOUDHARY, A.K.; DEIVEEGAN, M.; SUBRAMANIAN, E.: “Maximizing water use efficiency in rice farming: A comprehensive review of innovative irrigation management technologies”, *Water*, 15(10): 1802, 2023, ISSN: 2073-4441, DOI: https://doi.org/10.3390/w15101802.

MASSEY, J.; REBA, M.; ADVIENTO-BORBE, M.; CHIU, Y.-L.; PAYNE, G.: “Direct comparisons of four irrigation systems on a commercial rice farm: Irrigation water use efficiencies and water dynamics”, *Agricultural Water Management*, 266: 107606, 2022, ISSN: 0378-3774, DOI: https://doi.org/10.1016/j.agwat.2022.107606.

MATSUE, Y.; TAKASAKI, K.; ABE, J.: “Water management for improvement of rice yield, appearance quality and palatability with high temperature during ripening period”, *Rice Science*, 28(4): 409-416, 2021, ISSN: 1672-6308, DOI: https://doi.org/10.1016/j.rsci.2021.05.011.

MERIGUETTI-PINTO, V.; BORJA-REIS, A.F.; ABREU, M.L.; REICHARDT, K.; SANTOS, D.; JONG, Q.: “Sustainable irrigation management in tropical lowland rice in Brazil”, *Agricultural Water Management*, 284: 108345, 2023, ISSN: 0378-3774, DOI: https://doi.org/10.1016/j.agwat.2023.108345.

MERZA, N.; ATAB, H.; AL-FATLAWI, Z.; ALSHARIFI, S.: "Effect of irrigation systems on rice productivity.", *SABRAO Journal of Breeding and Genetics*, 55(2): 587-597, 2023, DOI: http://doi.org/10.54910/sabrao2023.55.2.30.

MINAG: *Instructivo Técnico Instructivo Técnico del cultivo del arroz*, Ed. Ministerio de la Agricultura. La Habana, Cuba, La Habana, Cuba, 142 p., publisher: Ed. Instituto de Investigaciones del Arroz, Ministerio de la Agricultura …, 2020.

MIRANDA-CABALLERO, A.; DÍAZ-LÓPEZ, G.; RUIZ-SÁNCHEZ, M.; DOMÍNGUEZ-VENTO, C.; PANEQUE-RONDÓN, P.: "Evaluación de la calidad del trasplante mecanizado de arroz en Cuba", *Revista Ciencias Técnicas Agropecuarias*, 31(2), 2022, ISSN: 2071-0054.

MONACO, F.; SALI, G.; BEN HASSEN, M.; FACCHI, A.; ROMANI, M.; VALÈ, G.: "Water management options for rice cultivation in a temperate area: a multi-objective model to explore economic and water saving results", *Water*, 8(8): 336, 2016, ISSN: 2073-4441, DOI: 10.3390/w8080336.

MUBANGIZI, A.; WANYAMA, J.; KIGGUNDU, N.; NAKAWUKA, P.: "Assessing Suitability of Irrigation Scheduling Decision Support Systems for Lowland Rice Farmers in Sub-Saharan Africa-A Review", *Agricultural Sciences*, 14(2): 219-239, 2023, DOI: https://doi.org/10.4236/as.2023.142015.

PADMANABHAN, S.: "Drip irrigation technology for rice cultivation for enhancing rice productivity and reducing water consumption", En: *Proceedings of the 3rd World Irrigation Forum (WIF3), Bali, Indonesia*, pp. 1-7, 2019.

PARTHASARATHI, T.; VANITHA, K.; MOHANDASS, S.; VERED, E.: "Evaluation of drip irrigation system for water productivity and yield of rice", *Agronomy Journal*, 110(6): 2378-2389, 2018, ISSN: 0002-1962, DOI: https://doi.org/10.2134/AGRONJ2018.01.0002.

PEÑA, D.; MARTÍN, C.; FERNÁNDEZ-RODRÍGUEZ, D.; TERRÓN-SÁNCHEZ, J.; VICENTE, L.A.; ALBARRÁN, A.; RATO-NUNES, J.M.; LÓPEZ-PIÑEIRO, A.: "Medium-Term Effects of Sprinkler Irrigation Combined with a Single Compost Application on Water and Rice Productivity and Food Safety", *Plants*, 12(3): 456, 2023, ISSN: 2223-7747, DOI: https://doi.org/10.3390/plants12030456.

PHAM, V.B.; DIEP, T.T.; FOCK, K.; NGUYEN, T.S.: "Using the Internet of Things to promote alternate wetting and drying irrigation for rice in Vietnam's Mekong Delta", *Agronomy for Sustainable Development*, 41(3): 43, 2021, ISSN: 1774-0746, DOI: https://doi.org/10.1007/s13593-021-00705-z.

PINTO, M.A.B.; PARFITT, J.M.B.; TIMM, L.C.; FARIA, L.C.; CONCENÇO, G.; STUMPF, L.; NÖRENBERG, B.G.: "Sprinkler irrigation in lowland rice: Crop yield and its components as a function of water availability in different phenological phases", *Field Crops Research*, 248: 107714, 2020, ISSN: 0378-4290.

POLÓN-PÉREZ, R.; MIRANDA-CABALLERO, A.; DÍAZ-GARCÍA, R.; RUÍZ-SÁNCHEZ, M.; GUERRA-HERNÁNDEZ, G.; VELÁZQUEZ-PÉREZ, F.: "Effect of Water Stress on Rice Regrowth Crop. Second Part", *Revista Ciencias Técnicas Agropecuarias*, 28(3): 1-6, 2019, ISSN: 1010-2760.

PRAKASH, B.S.; VASUDEVAN, S.; MANI, S.K.; UPPALURI, S.; SUDAKAR, M.: "Drought mitigation through hydrogel application in rice (Oryza sativa L.) cultivation.", *Journal of Experimental Biology and Agricultural Sciences*, 9(6): 727-733, 2021a, DOI: http://dx.doi.org/10.18006/2021.9(6).727.733.

PRAKASH, S.; VASUDEVAN, S.; BANERJEE, A.; JOE, A.C.; REDDY, G.; KN, G.; MANI, S.K.: "Sustainable water consumption of rice (Oryza sativa L.) as influenced by superabsorbent polymer in water stressed conditions", *International Journal of Modern Agriculture*, 10(1): 857-866, 2021b, ISSN: 2305-7246.

RAO, K.; GANGWAR, S.; KESHRI, R.; CHOURASIA, L.; BAJPAI, A.; SONI, K.: "Effects of drip irrigation system for enhancing rice (Oryza sativa L.) yield under system of rice intensification management.", *Applied Ecology & Environmental Research*, 15(4): 487-495, 2017, ISSN: 1589-1623, DOI: http://dx.doi.org/10.15666/aeer/1504_487495.

RATO-NUNES, J.M.; MARTÍN-FRANCO, C.; PEÑA, D.; TERRÓN-SÁNCHEZ, J.; VICENTE, L.A.; FERNÁNDEZ-RODRÍGUEZ, D.; ALBARRÁN, A.; LÓPEZ-PIÑEIRO, A.: "Combined use of biochar and sprinkler irrigation may enhance rice productivity in water-stressed regions", *Annals of Agricultural Sciences*, 68(1): 48-59, 2023, ISSN: 0570-1783, DOI: http://doi.org/10.1016/j.aoas.2023.05.002.

RAU, A.; BEGMATOV, I.; KADASHEVA, Z.; RAU, G.: "Water resources management in rice irrigation systems and improvement of ecological situation in rice growing river basins", En: *IOP Conference Series: Earth and Environmental Science*, Ed. IOP Publishing, vol. 614, p. 012151, 2020, DOI: 10.1088/1755-1315/614/1/012151, ISBN: 1755-1315.

REHMAN, A.; AHMAD, R.; SAFDAR, M.: "Effect of hydrogel on the performance of aerobic rice sown under different techniques.", *Plant Soil Environ*, 57(7): 321-325, 2011.

RUIZ-SÁNCHEZ, M.; MUÑOZ-HERNÁNDEZ, Y.; POLÓN-PÉREZ, R.: "Manejo del agua de riego en el cultivo de arroz (Oryza sativa L.) por trasplante, su efecto en el rendimiento agrícola e industrial", *Cultivos Tropicales*, 37(3): 178-186, 2016, ISSN: 0258-5936.

SAHA, A.; GUPT, C.B.; SEKHARAN, S.: "Recycling natural fibre to superabsorbent hydrogel composite for conservation of irrigation water in semi-arid regions", *Waste and Biomass Valorization*, 12(12): 6433-6448, 2021, ISSN: 1877-2641, DOI: https://doi.org/10.1007/s12649-021-01489-9.

SAHARAWAT, Y.S.; GILL, M.; GATHALA, M.: *Conservation agriculture in south Asia*, Ed. Burleigh Dodds, Cambridge, UK, Kassam, A ed., vol. Advances in Conservation Agriculture, 3, Cambridge, UK, publisher: Cambridge University Press, 2022.

SAIKUMAR, G.; JINSY, V.; SUMESH, K.: "Agro-economic evaluation of aerobic rice+ legume intercropping system under varying levels of nitrogen.", *The Mysore Journal of Agricultural Sciences*, 57(3): 146-152, 2023.

SASMITA, P.; AGUSTIANI, N.; MARGARET, S.; ARDHIYANTI, S.D.; SUPRIHANTO, S.; NUGRAHA, Y.; SUHARTINI, S.: "Drip irrigation technology performance on rice cultivation", *Jurnal Teknik Pertanian Lampung*, 11(1): 130-145, 2022, DOI: http://dx.doi.org/10.23960/jtep-l.v11.i1.130-145.

SHARIF, A.: "Technical adaptations for mechanized SRI production to achieve water saving and increased profitability in Punjab, Pakistan", *Paddy and Water Environment*, 9(1): 111-119, 2011, ISSN: 1611-2490, DOI: https://doi.org/10.1016/j.agwat.2023.108345.

SHARIF, A.; KASSAM, A.; FRIEDRICH, T.; UPHOFF, N.; JOSHI, R.C.; SAHU, P.: "Towards the integration of the System of Rice Intensification (SRI) and Conservation Agriculture (CA) in the Indus Basin in Pakistan Punjab", *Fiji Agric. J*, 54: 48-52, 2014.

SHUKLA, M.K.; SHUKLA, A.K.; SINGH, S.: "Direct Seeded Rice: An Alternative Rice Establishment Method Over Conventional Transplanted Puddled Rice", *Recent Advances in Biology and Medicine*, 7(1): 1-6, 2021, ISSN: 2378-654X.

SINGH, A.; CHAKRABORTI, M.: "Water and nitrogen use efficiency in SRI through AWD and LCC", *The Indian Journal of Agricultural Sciences*, 89(12): 2059-2063, 2019, ISSN: 2394-3319, DOI: https://doi.org/10.56093/ijas.v89i12.96274.

SINGH, B.; MISHRA, S.; BISHT, D.S.; JOSHI, R.: "Growing rice with less water: Improving productivity by decreasing water demand", En: *Improving Productivity by Decreasing Water Demand. Rice Improvement, 2021*, *Growing Rice with Less Water*, pp. 147-170, 2021, DOI: https://doi.org/10.1007/978-3-030-66530-2_5.

SINGH, S.: *Profitable rice farming through system of rice intensification (SRI) under conservation agriculture*, Ed. ICAR Research Complex for Eastern Region, Patna, Conservation Agriculture Mitigating Climate Change Effects and Doubling Farmers' Income, Mishra, J.S. et al., eds ed., 233-237 p., 2018.

SOLIEMAN, N.Y.; AFIFI, M.M.; ABU-ELMAGD, E.; ABOU-BAKER, N.; IBRAHIM, M.M.: "Hydro-physical, biological and economic study on simply, an environment-friendly and valuable rice straw-based hydrogel production", *Industrial Crops and Products*, 201: 116850, 2023, ISSN: 0926-6690.

SOMAN, P.: "Drip Irrigation and Fertigation Technology for Rice Production Leading to Higher Water Productivity", *International Journal of Water Resources and Arid Environments*, 10(2): 70-77, 2021, ISSN: 2079-7079.

SPANU, A.; VALENTE, M.; LANGASCO, I.; LEARDI, R.; ORLANDONI, A.M.; CIULU, M.; DEROMA, M.A.; SPANO, N.; BARRACU, F.; PILO, M.I.: "Effect of the irrigation method and genotype on the bioaccumulation of toxic and trace elements in rice", *Science of The Total Environment*, 748: 142484, 2020, ISSN: 0048-9697, DOI: http://doi.org/10.1016/j.scitotenv.2020.142484.

STEVENS, G.; RHINE, M.; HEISER, J.: "Rice production with furrow irrigation in the Mississippi river delta region of the USA", *Rice Crop: Current Developments; Shah, F., Khan, ZH, Iqbal, A., Eds*, : 69-82, 2018.

SURENDRAN, U.; RAJA, P.; JAYAKUMAR, M.; SUBRAMONIAM, S.R.: "Use of efficient water saving techniques for production of rice in India under climate change scenario: A critical review", *Journal of Cleaner Production*, 309: 127272, 2021, ISSN: 0959-6526, DOI: https://doi.org/10.1016/j.jclepro.2021.127272.

UDDIN, M.T.; DHAR, A.R.: "Assessing the impact of water-saving technologies on Boro rice farming in Bangladesh: economic and environmental perspective", *Irrigation Science*, 38(2): 199-212, 2020, ISSN: 0342-7188.

VALDIVIEZO, E.W.; HERÁN, R.E.; VIVAS, M.L.: "Impacto del sistema intensivo de cultivar arroz (SICA) en el Ecuador", *Ciencia Latina Revista Científica Multidisciplinar*, 7(2): 11198-11213, 2023, ISSN: 2707-2215.

VEDOVELLO, P.; SANCHES, L.V.; DA SILVA, T.G.; MAJARON, V.F.; BORTOLETTO, S.R.; RIBEIRO, C.; PUTTI, F.F.: "An Overview of Polymeric Hydrogel Applications for Sustainable Agriculture", *Agriculture*, 14(6): 840, 2024, ISSN: 2077-0472, DOI: https://doi.org/10.3390/agriculture14060840.

VIJAYAKUMAR, S.; CHOUDHARY, A.K.; DEIVEEGAN, M.; THIRUMALAIKUMAR, R.; KUMAR, R.M.: "Android based mobile application for rice crop management", *Chronicle of Bioresource Management*, 6(Mar, 1): 019-024, 2022a.

VIJAYAKUMAR, S.; KUMAR, D.; RAMESH, K.; JINGER, D.; RAJPOOT, S.K.: "Effect of Potassium fertilization on water productivity, irrigation water use efficiency, and grain quality under direct seeded rice-wheat cropping system", *J. Plant Nutr.*, 45: 2023-2038, 2022b.

WEI, Q.; XU, J.; SUN, L.; WANG, H.; LV, Y.; LI, Y.; HAMEED, F.: "Effects of straw returning on rice growth and yield under water-saving irrigation", *Chilean journal of agricultural research*, 79(1): 66-74, 2019, ISSN: 0718-5839, DOI: https://doi.org/10.4067/S0718-58392019000100066.

WICHAIDIST, B.; INTRMAN, A.; PUTTRAWUTICHAI, S.; REWTRAGULPAIBUL, C.; CHUANPONGPANICH, S.; SUKSAROJ, C.: "The effect of irrigation techniques on sustainable water management for rice cultivation system-a review", *Applied Environmental Research*, 45(4), 2023, ISSN: 2287-075X, DOI: https://doi.org/10.35762/AER.2023024.

ZENG, Y.-F.; CHEN, C.-T.; LIN, G.-F.: "Practical application of an intelligent irrigation system to rice paddies in Taiwan", *Agricultural Water Management*, 280: 108216, 2023, ISSN: 0378-3774, DOI: https://doi.org/10.1016/j.agwat.2023.108216.

ZHANG, W.; TIAN, Y.; FENG, Y.; LIU, J.; ZHENG, C.: "Water-Saving Potential of Different Agricultural Management Practices in an Arid River Basin", *Water*, 14(13): 2072, 2022, ISSN: 2073-4441, DOI: https://doi.org/10.3390/w14132072.

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