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Irrigation Scheduling and Cultivar Management for Increasing Water Productivity under Dryland Condition: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

In Dryland environments with limited water resources, irrigation scheduling and cultivar management are play pivotal roles in enhancing water productivity. Effective irrigation scheduling involves the judicious timing and amount of water application, considering factors such as soil moisture levels and crop growth stages. Utilizing advanced technologies, such as soil moisture

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sensors and remote sensing, facilitates precise irrigation management. This approach not only conserves water but also prevents waterlogging and salinity issues, promoting optimal plant growth. Cultivar selection is another critical aspect, focusing on identifying and cultivating crops that are well-adapted to arid conditions. Drought-resistant cultivars with traits like deep root systems and efficient water use contribute significantly to water productivity. Integrating modern breeding techniques and genetic engineering enhances the development of cultivars with improved drought tolerance, ensuring resilience in dryland agriculture. Furthermore, the implementation of agro ecological practices, such as conservation tillage and organic farming, complements irrigation scheduling and cultivar management. These practices enhance soil structure, water retention, and overall ecosystem health, fostering a more sustainable and resilient agricultural system. Adopting a comprehensive approach that combines precise irrigation scheduling, resilient cultivar selection and agro ecological practices holds great potential for increasing water productivity in dryland conditions. This integrated strategy not only addresses the challenges posed by water scarcity but also contributes to the long-term viability of agriculture in arid regions.

Keywords: Cultivar; dryland; efficiency; irrigation scheduling and water productivity.

1. INTRODUCTION

“Water is most limiting factor for crop production in dryland agriculture. Dryland ecosystems and their biodiversity are uniquely adapted to these twin features of water scarcity and climatic variability. The main problem of these regions is low rainfall and meagre availability of irrigation water. A major portion of rainfall is lost in unproductive losses like evaporation, deep drainage and seepage, thereby leaving a very small amount of water for crop production. 68% area and 44% contribution of the nation’s total food production comes under Dryland agriculture. The area under drylands in India is in a declining rate and is expected to be stabilized by 2050 at 75 million ha” [1]. “Dryland agriculture is the practice of crop production entirely with rain-water received during the crop season and on conserved soil moisture in low rainfall areas of arid and semi-arid climates and the crop may face mild to very severe moisture stress during their life cycle. Without water people do not have a means of watering their crops and, therefore, to provide food for the fast growing population. Major factor of less productivity are inadequate & uneven distribution of rainfall, late onset & early cessation of rains, prolonged dry spell during the crop period, low moisture retention capacity, low fertility of soils, effective storage of rain water and selection of limited crops in Dryland areas. Irrigation scheduling and cultivar management are essential strategies for enhancing water productivity in dryland conditions. Soil moisture in a specified root zone depth is depleted to a particular level (which is different for different crops), it is to be replenished by irrigation”. Rizk and Sherif. [2]. “Water scarcity is a pressing issue in arid and semi-arid regions, and efficient water management is crucial to sustain agricultural productivity and ensure food security. Due to the scarcity and unavailability of irrigation water, production of Mustard is lower than average productivity of the country” [3]. “Irrigation scheduling involves the judicious application of water to crops, considering their growth stages, soil moisture levels, and climatic conditions. Implementing techniques such as drip irrigation, rainwater harvesting, and soil moisture monitoring can optimize water usage and minimize wastage, leading to increased water-use efficiency. To get the best crop yield, irrigation water must be applied at the right time and in the right amount [4].

“Variety of the crop decides its growth and yield potential under specific agro-climate along with efficient resource utilization. Therefore, exploring appropriate varieties for higher yield in dryland condition is also having tremendous scope. Improved varieties have higher moisture use efficiency as compared to local varieties and can be adopted for efficient moisture use. The old and degenerated varieties due to their low yield potential and other factors like maturity, shattering habit, poor response to fertilizers and irrigation and susceptibility to insect-pest and diseases have poor productivity as compared to improved varieties of the region” [5]. “Selection of improved varieties are important for producer to achieve high crop yield by improving the fertilizer use efficiency and water use efficiency. Improved cultivars and hybrids offers better genetic makeup, ensures uniform germination and emergence maintaining optimum plant stand, higher survival under temperature stress during vegetative phase, resistance to major pests and diseases and efficient translocation and assimilation of assimilates which ultimately results in improved growth, yield contributing characters and productivity of mustard" Rana *et al.* By combining effective irrigation scheduling and suitable cultivar management, farmers can significantly enhance water productivity in dryland regions. These sustainable practices not only conserve water but also improve crop yields, farm incomes, and overall agricultural resilience in the face of climate change-induced challenges. Emphasizing such approaches is essential to achieve food security and environmental sustainability in water-scarce regions.

2. IRRIGATION SCHEDULING AND CULTIVAR AS A SOLUTION

2.1 Irrigation Scheduling

"Irrigation scheduling has been described as the primary tool to improve water use efficiency, increase crop yields, increase the availability of water resources, and provoke a positive effect on the quality of soil and groundwater" [7]. Effective irrigation scheduling optimizes water use in dryland conditions, maximizing crop yield while minimizing wastage [8]. It considers soil moisture, weather data, and crop water requirements to deliver precise amounts of water when needed. This approach enhances water productivity by ensuring efficient water distribution and fostering sustainable agricultural practices [9]. "The quantity of water applied and the timing of its application are both of significant importance in irrigation scheduling whether in landscape or agricultural applications" [10,11].

2.2 Approaches for Irrigation Scheduling

2.2.1 Soil moisture depilation approach

Soil moisture in a specified root zone depth is depleted to a particular level (which is different for different crops), it is to be replenished by irrigation. Irrigation applied the available water (100%, 80%, 60% and 40%) the highest value of water use Efficiency (grain) when applied at 40%, available soil moisture and the significant effect of at 100% available soil moisture on growth and yield of wheat [2]. Enhance dry land water productivity via soil moisture depilation for efficient water use, fostering sustainable agriculture in arid environments. Shtewy *et al.* [12] reported that "irrigation at 66% ASMD was the most effective in terms of grain yield in wheat". "Seasonal evapotranspiration (ETC) of sunflower and water use efficiency WUE decreased by increasing available soil moisture depletion (ASMD) percentage" [13].

2.3 Deficit Irrigation

"Deficit irrigation is applying water less than the requirement. In this method interval of irrigation schedule is the same but the quantity of irrigation is reduced so as increase efficiency though some yield loss occur. The application of full irrigation as compared to the farmers practices reduced water application by 640 and 460 m3/ha with yields decreases of 7 and 8% in the first and second seasons, respectively" [14]. "Deficit irrigation and raised bed techniques resulted in savings of 1600 m^3 water/ha in maize and 1500 m3 water/ha in wheat. Water saving due to DI was accompanied by a yield reduction of 8.8% in maize, but with no effect on wheat. Deficit irrigation treatments significantly reduced plant growth parameters, yield attributes and seed yield of sunflower compared to full irrigation. DI-60 at vegetative and pre-flowering stages highest water productivity, irrigation water productivity, and net financial return" [15]. "Moisture deficit under conventional, alternate and fixed furrow irrigation systems with three irrigation levels and observed the significant effect of moisture deficit irrigation on growth and yield of maize" [16].

2.4 Irrigation Water (IW) / Cumulative Pan Evaporation (CPE) Approach

Prihar et al. [17] suggested "relatively simple IW/CPE approach for scheduling crop irrigation. Evapotranspiration mainly depends on climate. In this approach amount of irrigation water is applied when cumulative pan evaporation (CPE) reaches a predetermined level". "Significant effect of irrigation (0.7 IW: CPE ratio) on growth and yield of mustard" [18]. "Application of (I4)1.0 IW/CPE ratio moisture regime found to be more suitable higher yield of wheat variety PBW -154" [19]. It balances the Irrigation Water (IW) applied to fields with the Crop Water Requirement (CPE), ensuring efficient water utilization, reducing waste, and enhancing crop yield while considering factors like climate and soil conditions. Barick *et al.* [20] founded that irrigation levels (IW: CPE of 1.0) recorded maximum growth and yield of rape-seed. Maximum plant height, leaf area index and yield per hectare of green gram application irrigation IW: CPE 1.0 while maximum WUE recorded with IW: CPE ratio 0.6 [21]. The highest potato yield obtained with irrigation systems when irrigation

Table 1. Moisture sensitive stages in different crops

Crops	Moisture sensitive stages
Rice	Panicle initiation, flowering
Wheat	Crown-root initiation (CRI), jointing, milking
Maize	Silking, tasseling
Sugarcane	Formative stage
Rapeseed & Mustard	Rosette stage and pod formation
Cotton	Flowering and boll development
Soybean	Flowering and seed formation
Potato	stolen and tuber formation
Pearl millet	Panicle initiation, flowering
Groundnut	Rapid flowering, pegging, early pod formation
Red gram, Greengram, Blackgram	Flowering and pod formation

Source: Reddy, T. Y., & Reddy, G. H. [31]

scheduled at 1.20 IW/CPE while highest water-use efficiency recorded with 0.80 IW: CPE [22]. Generally, irrigation is given at 0.75 to 0.8 ratios with 5 cm of irrigation water and irrigation can also be scheduled at fixed level of CPE by varying amount of irrigation water. Irrigation scheduling at IW: CPE 1.2 recorded significantly highest grain yield and water use efficiency recorded at IW: CPE 1.0 [23]. Application of irrigation at 0.8 IW: CPE to mustard hybrid PAC 432 resulted in increment in dry matter accumulation at different growth stages as well as harvest [24].

2.5 Can Evaporimetry Methods

In this method using one liter capacity cans is installed in the mid of field at the crop height. An indicator pointer is fixed 1.5 cm below the brim. Crop is well irrigated till the field capacity obtained. The can is filled with water up to the brim [25]. Water is losses through can due to the evaporation is directly related to the water losses from the field due to the evapo-transpiration [26]. When the water is loses in the can up to a predetermined level, irrigation is scheduled accordingly.

2.6 Critical Growth Stage

In each crop, among these stages, there are some growth stages when the deficiency of water causes irrevocable yield losses, these stages are called critical stages. When the irrigation water is limited, this approach is more useful. Under limited water supply conditions, water is applied only at the moisture sensitive stages and skipped at non sensitive stages Mohamed et al. [27] For example in potato water is applied at the stolen and tuber formation and tuber enlargement stages. Singh et al. [28] studied the effect of irrigation on mustard + chickpea intercropping system. Irrigation levels (viz., no irrigation, one irrigation at pre-flowering, one irrigation at grain filling and two irrigations at pre-flowering + grain filling stage of mustard). Applied two irrigations at pre-flowering + grain filling stage of mustard significantly increased growth and yield attributing characters. Uddin *et al.* [29] reported from the experiment with four irrigation levels of wheat growth stages and result observed the effect of irrigation at (crown root initiation stage + pre-flowering stage) significantly better response on growth and yield attributes of wheat. Irrigation scheduling with two irrigations (first at rosette stage and second during pod formation stage) improves the growth attribute, yield and B: C ratio of Indian mustard [30].

3. SIMPLE TECHNIQUE FOR IRRIGATION SCHEDULING

3.1 Soil-Cum-Sand Miniplot Technique

In this approach, 1 m^3 pit dug in the mid of the field about 5 to 10% sand is well mixed in this soil. The pit is filled with sand mixed soil. In the field, sowing is done as usual and due to the presence of sand, plants of pit express wilting symptoms earlier than the rest of the field [32]. This shows the need of irrigation scheduling.

3.2 Sowing High Seed Rate

Select some elevated area of one meter square in the field. Than in this selected area, seed rate is increased by four times. Due to high seed rate and elevation, plants of this 1 m^2 area expressed wilting symptoms than rest of the field, indicating the need of scheduling of irrigation.

3.3 Feel and Appearance Methods

Moisture content can be roughly estimated by taking the soil from root zone into hand and making into small ball. By squeezing the soil between the thumb and forefinger or by squeezing the soil in the palm of a hand, a fairly accurate estimate of soil moisture can be determined. Let's look at clay loam. At a 0.4 in./ft deficit, a ribbon can be easily made when the soil is squeezed between the thumb and forefinger. Since the wilting point occurs at about 1.8 in./ft., a 0.4 deficit would equate to a 22% deficit [33]. Sandy loam soil makes a good ball at 0.6 in./ft deficit (about 40% deficit), but will not make a ball at all and only sticks together at 1.0 in./ft (about 66% deficit). Once you become familiar with the feel of the soil, it becomes easier to estimate soil moisture content. However, it takes time to become familiar with the feel of the soil and this method requires a great deal of experience [34].

3.4 Plant Indices

There are some plants sensitive to soil-water variations. They may be used for detecting the water stress in crops that do not show symptoms of water stress easily or exhibit the same when they have already suffered seriously. For instance, plant wilting, curling and rolling of leaves is used as indicators for scheduling irrigation.

3.5 Tensiometer

Irrigation can be scheduled on the basis of soil moisture tension. Tensiometer is installed in the field at specified depth. Irrigation is scheduled at predetermined level of soil moisture tension like 0.5, 0.75 and 1.0 bar [35].

3.6 Infrared Thermometer

Canopy temperature is measured with infrared thermometer. It is also measured canopy temperature (Tc) and air temperature (Ta) Noguera et al. [36]. Tc–Ta values can be used for scheduling irrigation. When transpiration is normal, due to its cooling effect, canopy temperature is less than air temperature [37]. The negative value of Tc –Ta indicate that plant have sufficient amount of water. Canopy temperature is measured during mid –day when air temperature is maximum. The use of infrared thermometry and thermal imaging may be a very promising option for stress monitoring in trees and vines [38].

Fig. 1. Rolling of leaves in maize
Source: http://www.angrau.ac.in/media/7380/agro201.pdf

3.7 Remote Sensing

Single crop is grown on a large area irrigation scheduling can be done with the help of remote sensing data, with the following sensors being used-

3.7.1 Radiometric sensors

Irrigation scheduling using radiometric sensors optimizes water usage in agriculture. These sensors measure crop water stress and soil moisture levels, enabling precise irrigation timing and amount. This data-driven approach improves crop health, conserves water, and enhances overall agricultural productivity and sustainability [39].

3.7.2 Hyperspectral sensors

Irrigation scheduling using hyperspectral sensors involves employing advanced remote sensing technology to assess plant health and moisture levels in crops. These sensors detect specific wavelengths of light reflected by plants, allowing precise monitoring of their water needs [40]. This data-driven approach optimizes irrigation timing, leading to water conservation and improved agricultural productivity.

3.7.3 Thermal sensing

Irrigation scheduling using thermal sensing involves monitoring plant temperatures to determine their water needs accurately (Khanal *et al.* 2017). Thermal sensors measure temperature variations in crops, helping optimize irrigation timing and frequency. This data-driven approach enhances water efficiency, minimizes wastage, and promotes sustainable agricultural practices.

3.7.4 Multispectral sensors

Irrigation scheduling with multispectral sensors involves using advanced remote sensing technology to monitor crop health and soil moisture levels. These sensors analyze various wavelengths of light reflected by the vegetation, enabling precise assessment of plant stress and water requirements. By gathering real-time data, farmers can optimize irrigation schedules, conserve water resources, and enhance overall crop productivity [41].

3.8 Cultivar

Cultivar management plays a vital role in adapting crops to water-limited environments. Selecting drought-tolerant cultivars that exhibit higher water-use efficiency and better stress tolerance is paramount. Breeding and genetic engineering techniques have paved the way for developing drought-resistant crop varieties that thrive under limited water availability. Improving water productivity in dryland conditions necessitates strategic cultivar management. Selecting drought-tolerant varieties is crucial, as demonstrated by recent studies [42]. These cultivars exhibit enhanced water-use efficiency, mitigating the impact of water scarcity [43]. Additionally, incorporating conservation tillage practices further optimizes water utilization, as evidenced by recent on-field trials [44]. Employing a comprehensive approach to cultivar management, integrating genetics and agronomic practices, is imperative for sustainable water use in arid environments.

4. ADVANCES IN BREEDING FOR DROUGHT RESISTANCE

Advances in breeding for drought resistance have revolutionized cultivar management, addressing the pressing challenges posed by climate change. Researchers focus on identifying and enhancing traits associated with water use efficiency, such as deep root systems, reduced stomatal conductance, and osmotic adjustment. Precision breeding techniques, including marker-assisted selection and genomic editing, expedite the development of drought-resistant cultivars [45]. Integration of diverse germplasm sources and the utilization of wild relatives contribute to broadening the genetic base for enhanced adaptability. Advances in breeding for drought resistance involve selecting and developing cultivars with improved water-use efficiency and stress tolerance traits. This enhances crop productivity under water scarcity [46]. The success stories of drought-tolerant cultivars, such as those in major cereal crops, underscore the impact of these advancements on global agriculture. Continuous innovation in breeding methodologies offers a sustainable approach to bolstering crop resilience amidst changing environmental conditions [47].

5. DEVELOPMENT OF HIGH-YIELDING, WATER-EFFICIENT CULTIVARS

Cultivar management is crucial for sustainable agriculture, emphasizing the development of high-yielding, water-efficient cultivars [48] This involves the integration of advanced breeding techniques to enhance crop performance under varying water availability. Researchers focus on identifying and selecting genetic traits that promote water-use efficiency and yield stability. The development of cultivars with improved drought resistance, optimized root systems, and efficient water utilization contributes to sustainable resource management in agriculture. Incorporating molecular and genomic tools accelerates the breeding process, ensuring timely release of resilient cultivars [49]. Such advancements not only address water scarcity challenges but also enhance overall crop productivity. This approach aligns with the goal of achieving food security while minimizing the environmental impact of agriculture [50].

6. ROLE OF BIOTECHNOLOGY IN CULTIVAR IMPROVEMENT

Cultivar management is enhanced through the pivotal role of biotechnology in cultivar improvement [51]. Biotechnological tools, such as genetic engineering and molecular breeding, enable precise manipulation of plant genomes to develop improved cultivars with desirable traits. This includes enhanced yield, resistance to pests and diseases, and improved nutritional content. Biotechnology expedites the breeding process by identifying and incorporating specific genes responsible for desired traits. Additionally, it facilitates the development of cultivars tailored to diverse environmental conditions, ensuring resilience in the face of climate change [52,53].

7. DISCUSSION AND CONCLUSION

In dryland conditions, optimizing water productivity is vital for sustainable agriculture. Effective irrigation scheduling, based on soil moisture monitoring and weather forecasts, ensures efficient water use. Cultivar management, selecting drought-tolerant varieties and employing crop-specific practices, enhances resilience to water scarcity. Integrating these strategies not only conserves water but also maximizes crop yield, promoting agricultural sustainability in arid regions. Balancing water availability with crop needs through meticulous scheduling and cultivar choices becomes imperative for mitigating the impact of water scarcity, fostering agricultural resilience, and securing food production in dryland environments. Cultivar management and efficient irrigation scheduling are essential tactics for raising water productivity in dryland region. Implementing optimized irrigation schedules tailored to specific cultivars can significantly conserve water resources while maximizing water productivity. The synergy between efficient water management and cultivar selection ensures sustainable agricultural practices, mitigating the impact of water scarcity. These integrated approaches contribute to increased overall water productivity, promoting resilience in dryland agriculture and fostering environmental sustainability.

CONFERENCE DISCLAIMER

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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