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Review Article

Pros and Cons of Different Irrigation Scheduling Approaches: A Review

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Abstract

Scheduling irrigation involves making a decision of how much water to apply and when. Three factors enter into the decision: water needs of the plants, water availability, and storing capacity of the soil around the roots. When to irrigate should be greatly influenced by water needs of the plants. Irrigation scheduling (IS) aims to give plants the right amount of water at the right times in order to promote plant growth and achieve high yield and/or quality. The four most popular ways of operating irrigation scheduling includes: evapotranspiration and water balance (ET-WB), soil moisture status, plant water status, and models based irrigation scheduling. When the four types of irrigation scheduling systems are thoroughly examined, it becomes clear that they are all centered on soil moisture, which serves as a link or bridge between crop water needed for growth and irrigation management). A few studies have been accomplished on pros and cons of different irrigation scheduling approaches. The purpose of this review was to provide some information on pros and cons of four selected irrigation scheduling methods, viz: evapotranspiration and water balance (ET-WB), soil moisture status, plant water status, and models based irrigation scheduling. When the four types of irrigation scheduling systems are thoroughly examined, it becomes clear that they are all centered on soil moisture, which serves as a link or bridge between crop water needed for growth and irrigation management. Plant-based techniques can need professional oversight since farmers may find it difficult to understand the tracked data, which reduces the dependability of irrigation. When built software or a procedure is based on a well-calibrated model, model-based methods are simpler for users. When compared to the soil moisture sample irrigation scheduling approach, the evapotranspiration losses irrigation scheduling method uses less irrigation water regardless of the minimal yield difference.

Keywords

Irrigation Scheduling, Evapotranspiration, Water Balance, Soil Moisture

1. Introduction

Approximately 11% of the Earth's total land area is made up of the 1.55 × 109 ha of arable land that is now under cultivation worldwide. By 2050, this proportion is expected to rise to 13% [2]. About 17% of these arable lands are managed by irrigation in some way. But according to [27] this very tiny portion of land that is suitable for irrigation could account for as much as 30% to 40% of global total agricultural production. The lack of water has long been a barrier to agricultural activity. It could be suggested to schedule irrigation to conserve applied water while preserving ideal yield. Choosing the most effective irrigation method is essen-

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tial to overcoming water scarcity and increasing water productivity, as it is a significant obstacle to food production, especially in arid and semi-arid regions [11].

However, a variety of innovative ways to irrigation scheduling has been presented recently and have not yet gained widespread acceptance. Many of these strategies rely on monitoring the plant's response to water deficiencies rather than directly sensing the soil moisture condition [19].

There is a growing focus on creating irrigation techniques that minimize water consumption (maximize water use efficiency) due to global water shortages and irrigation expenses. The development of precision irrigation techniques like trickle irrigation has significantly decreased the amount of water needed for horticultural and agricultural crops, but it has also brought attention to the need for new approaches to precise scheduling and management of irrigation. Recent research has demonstrated that maintaining a small plant water deficit can enhance the distribution of carbohydrates to fruit and other reproductive structures while also reducing excessive vegetative growth [7].

The goals of the irrigator and the available irrigation system play a major role in the method of irrigation scheduling that is selected. Even less complex systems, such flood irrigation scheduling, can profit from the irrigation scheduling advances discussed here. Generally speaking, more complex scheduling techniques call for higher-precision application systems. Increased precision in irrigation control is necessary to maintain the soil moisture status within fine bands and meet specific crop management goals, as indicated by the pressures to increase irrigation use efficiency and use irrigation for precise control of vegetative growth, as in regulated deficit irrigation. Only precision irrigation systems, like trickle irrigation, which can apply precise amounts of water at regular intervals (sometimes multiple times per day) may achieve such goals [18].

Irrigation scheduling (IS) aims to give plants the right amount of water at the right times in order to promote plant growth and achieve high yield and/or quality. The four most popular ways of operating irrigation scheduling includes: evapotranspiration and water balance (ET-WB), soil moisture status, plant water status, and models based irrigation scheduling. Irrigation scheduling (IS) aims to supply plants with moisture at specific levels in order to enhance plant growth and attain high yield and/or quality. Soil moisture-affecting elements in the soil-crop-atmosphere system need to be taken into account throughout the scheduling process.

All four types of irrigation scheduling methods concentrate on soil water content, which acts as a link between crop water requirements for growth and irrigation management. Therefore, future scheduling techniques should manage soil moisture based on a deeper comprehension of its effects on crop growth, either by integrating current irrigation scheduling methods or creating new models with the help of intelligent algorithms. These methods should be used to create more accurate, useful, and flexible irrigation scheduling applications for farming operations that take place in real time [15]. A few studies have been accomplished on pros and cons of different irrigation scheduling approaches. The purpose of this review was to provide some information on pros and cons of four selected irrigation scheduling methods.

2. Fundamentals of Irrigation Scheduling

Scheduling irrigation involves making a decision of how much water to apply and when. Three factors enter into the decision: water needs of the plants, water availability, and storing capacity of the soil around the roots. When to irrigate should be greatly influenced by water needs of the plants. The two conventional techniques used to determine whether irrigation is necessary are "soil water measurement," which measures the soil moisture status (either in terms of water content or water potential) directly, or "soil water balance calculations," which use a water balance approach to calculate the soil moisture status. The difference between the inputs (irrigation plus precipitation) and the losses (runoff plus drainage plus evapotranspiration) over time determines the change in soil moisture. Numerous books and studies have addressed soil moisture measurement methods. Likewise, the comprehensive techniques for determining crop water requirements and evapotranspiration [24] conducted a thorough analysis of the precise techniques for estimating evapotranspiration and calculating crop water requirements for various crops and climates, which are necessary for the water balance calculation. The water balancing strategy has been demonstrated to be sufficiently durable across a wide range of situations, despite its lack of accuracy. However, there is a significant issue with inaccuracies compounding over time. Because of this, it is frequently required to periodically recalibrate the computed water balance using actual soil measurements, or occasionally plant response measurements.

All soil-water based techniques may have a drawback in that many aspects of plant physiology react directly to variations in water status inside plant tissues, such as the roots or other tissues, as opposed to variations in the overall water content (or potential) of the soil. As a result, the way a plant reacts to a specific level of soil moisture varies depending on a variety of factors including evaporative requirement. Therefore, it has been proposed [18] that, the use of "plant "stress" sensing," may be able to achieve more accuracy in the administration of irrigation. Using this method, rather of using precise measurements of the soil water status, irrigation schedule decisions are made based on plant responses.

2.1. Evapotranspiration–Water Balance Based Method Irrigation Scheduling (ET-WB)

The ET-WB method, which is a popular irrigation scheduling technique, first estimates the crop's evapotranspiration (ETc), the primary consumptive factor, and the daily soil water content using the Food and Agriculture Organization's

[3, 4] guidelines. Irrigation events are scheduled when the total amount of water withdrawn exceeds the amount of water that is easily available [15]. Since crop requirements (ETc) are assessed while the crop is developing, the ET-WB approach is a fundamental and important irrigation scheduling methodology. The estimation of ETc is a crucial step in the ET-WB approach, and it can be completed by a range of computations based on different remote sensing measurements [14].

Under various management systems, ET-based irrigation scheduling approaches operate differently. According to [9], an ET-based irrigation system greatly decreased irrigation water consumption while preserving turf grass quality. However, because ET-based irrigation allows for a lower allocation of soil water content during the growing season, it has occasionally failed to produce the same crop production [17] or grass quality [20] as traditional experience-based irrigation regimes, Similarly to utilize ET-based scheduling, a reliable source of ET data is required [6].

ET-WB-based irrigation scheduling demonstrated benefits in certain situations. When field weather data and FAO recommended Kc curves for the crop are available, the ET-WB method is comparatively simple to apply and has been shown to be effective when a scientific (as opposed to experience-based) irrigation scheduling method is initially used across a growing season. Even in cases when soil parameters are unknown, the ETWB approach can still be implemented as long as the cumulative daily soil water deficit determined by ET calculations is promptly quenched. But increasing the accuracy of estimating the reference evapotranspiration (ET0), enhancing the crop coefficient (Kc) curve during the growing season, assessing soil characteristics to ascertain the soil's water-holding capacity, and measuring site-specific rainfall are all crucial to the ET-based irrigation scheduling method. But the main challenge of the ET-WB based approach is measuring site-specific rainfall, and the ET-based irrigation scheduling method depends heavily on improving the accuracy of estimating the reference evapotranspiration (ET0), improving the crop coefficient (Kc) curve over the growing season, evaluating soil properties to determine the soil's water holding capacity, and measuring these factors [8, 5]. Long-term adjustments to leaf area and root extension, as well as short-term adjustments to leaf angle, stomata conductance, and the hydraulic characteristics of the transport system, are used to accomplish this control. The relative sensitivity of each plant-based metric to water deficits determines which one to use. Generally speaking, reference or threshold values that indicate when irrigation is required must be defined before using any plant-based or comparable signal for irrigation scheduling.

These reference values are frequently established for plants that are grown in soil with an unrestricted supply of water [12]. However, gathering comprehensive data on how these reference values behave in changing environmental conditions is a crucial step in the development and validation of such techniques. Another common drawback of plant-based techniques is that they typically only indicate whether or not irrigation is necessary, not "how much" to apply at any given time. As alternatives to direct measurement, a number of indirect techniques have been developed for monitoring or measuring water status. The general behavior of a number of such methods has been compared by [28].

Although these indirect approaches have occasionally been developed into commercial systems, they often share the same drawbacks as direct monitoring of leaf water status. Generally Plant-based sensing provides a number of potential benefits over soil-based measurements, such as a higher relevance to plant functioning. However, they have been outweighed by a number of implementation-related challenges that have so far prevented the creation of systems that are profitable.

However, the need for more precise irrigation scheduling and for increased water efficiency will probably provide a significant push for the creation of new precision irrigation scheduling systems that consider each plant's unique irrigation requirements. These systems may also make greater use of plant-based sensing technologies.

2.2. Soil-Moisture-Based

Calculating the soil parameters accurately is necessary before irrigating a field till the moisture content of the soil reaches field capacity. Among the techniques for determining irrigation amount, administering a fixed amount of irrigation is useful in reducing water stress; nevertheless, this approach has the danger of causing either deep percolation or inadequate irrigation, which can lead to nutrient and water loss or stunted crop growth. A unique irrigation time and depth determination approach was developed by [26], in which irrigation was started and stopped based on whether the wetting front was activating or not. The Soil-Moisture based method has the advantage of allowing variable rate irrigation scheduling due to its capacity to measure spatial and temporal moisture variability in the field. Accordingly, the spatial differences in irrigation quantity required for different blocks of the field can be considered. However, the major weakness of a soil moisture based irrigation scheduling approach resides in the inaccuracy of moisture measurements using sensors [10] Practically, moisture sensors are used to track soil water trends and then coupled with other irrigation scheduling approaches. Because the soil-moisture based approach can monitor both the temporal and spatial variability of moisture in the field, it has the advantage of permitting variable rate irrigation scheduling. As a result, the spatial variations in the amount of irrigation needed for various field blocks can be taken into account. However, the primary flaw in an irrigation scheduling strategy based on soil moisture is the imprecision of sensor-based moisture measurements [10]. In reality, soil water trends are monitored by moisture sensors, which are then combined with other methods of irrigation scheduling.

2.3. Plant-Based Methods For Irrig tion Scheduling

It is crucial to think about which plant-based metrics would be best suited for irrigation scheduling if soil water-based measures are to be replaced. Aspects of plant water status that may be directly measured as well as some plant activities that are known to react negatively to water deficiencies can be measured. Though it's still unclear exactly where in the plant that quantity should be measured, one may anticipate that a direct measurement of plant water status should be the most exacting and, therefore, the most helpful predictor of irrigation requirement.

In reality, most plants have some degree of autonomous control over the water state of their shoots or leaves, As the soil dries out or evaporative demand rises, these plants tend to minimize fluctuations in shoot water status [5]. Long-term adjustments to leaf area and root extension, as well as short-term adjustments to leaf angle, stomata conductance, and the hydraulic characteristics of the transport system, are used to accomplish this control. The relative sensitivity of each plant-based metric to water deficits determines which one to use. Generally speaking, reference or threshold values that indicate when irrigation is required must be defined before using any plant-based or comparable signal for irrigation scheduling.

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2.4. Model-Based Method of Irrigation Scheduling

The model-based irrigation scheduling methods reviewed are limited to those intended for determining irrigation Among these model-based irrigation scheduling methods, the utilization of process-based models Using the previously mentioned irrigation scheduling methods, scheduling can be done on the basis of crop/plant responses to moisture, and is therefore subject to the influence of the atmosphere, the growth stages of the crop, and the soil type. To obtain a more precise and dependable irrigation schedule, models founded on a theoretical study of the crop's growth process and considering the effects of the soil crop-atmosphere system in a holistic manner have been tested. Among these models, CROPWAT and AquaCrop models are highlighted in this review.

The model-based irrigation scheduling techniques examined are restricted to those meant to ascertain the quantity and timing of irrigation for a particular field, as opposed to figuring out how to divide water resources across multiple fields and/or crops [30] Using process-based models is one of these model-based irrigation scheduling techniques. The soil type, crop growth stages, and atmosphere can all have an impact on irrigation scheduling, which can be done based on crop/plant responses to moisture using the previously listed methods. Models based on a theoretical analysis of the crop's growth process and taking the influences of the soil crop-atmosphere system into account holistically have been developed in order to produce a more accurate and reliable watering schedule. These models [1, 16] can reliably simulate crop responses to varied atmospheric and soil conditions after proper calibration.

It was demonstrated that soil moisture monitoring and irrigation scheduling based on the Penman Montieth evapotranspiration model (NDCW) were more and less cost-effective, respectively. When compared to conventional irrigation management, the penman monthieth and soil moisture measurement methods among other irrigation scheduling techniques conserved applied water by 23% and 40%, respectively [25, 15].

Many factors are involved in irrigation planning, management and irrigation scheduling, which integrates the effects of soil evaporation and plant transpiration rates. Therefore, choosing when and how much water to apply is part of scheduling irrigation. The selection is influenced by three factors: the plants' water requirements, the availability of water, and the soil's ability to store water around the roots [21-23].

Table 1. Applied water, yield and water productivity of the orange irrigation scheduling treatments sources.

Irrigation scheduling	Yield (kg/ha)	Applied water (m^3/ha)	Saved water compared to conventional	Irrigation water productivity (kg/m^3)
Conventional irrigation scheduling	27854^a	9979^a	0	2.86^c
Penman monthieth	24792^a	7688^b	23 3.21^{bc}	2.58^{bc}
Soil moisture	23708^a	6021^b	40 4.36^{ab}	3.27^{ab}

Sources: [25]

3. Conclusion

When the four types of irrigation scheduling systems are thoroughly examined, it becomes clear that they are all centered on soil moisture, which serves as a link or bridge between crop water needed for growth and irrigation management. Put another way, the goal of irrigation management techniques is to regulate soil moisture to a point where crop development can be ensured with enhanced irrigation water usage efficiency, all while preserving water. Determining a range of moisture levels (target level) that encourage crop growth during the whole growing season is crucial. Prior to using soil moisture-baed or plant-based scheduling approaches, distinct target levels should be established for different growth phases by implementing different irrigation treatments in the field.

Final Thoughts and Upcoming Prospects Benefits and Drawbacks of Information Systems Approaches Each of the four types of IS approaches has benefits and drawbacks; while they can be useful in some situations, they can also produce less than optimal results when used improperly or improperly executed.

Plant-based techniques can need professional oversight since farmers may find it difficult to understand the tracked data, which reduces the dependability of irrigation. When built software or a procedure is based on a well-calibrated model, model-based methods are simpler for users. When compared to the soil moisture sample irrigation scheduling approach, the evapotranspiration losses irrigation scheduling method uses less irrigation water regardless of the minimal yield difference. By switching from the traditional (farmer practice) irrigation scheduling method to the water-saving irrigation scheduling method, adoption of this technology implies the tremendous potential of doubling the cultivable acreage and productivity utilizing the current irrigation water supply.

Abbreviations

IS	Irrigation Scheduling
ET-WB	Evapotranspiration and Water Balance
ETc	Evapotranspiration
FAO	Food and Agricultural Organization

Conflicts of Interest

The authors declare no conflicts of interest.

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