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13. Water Management in Millets

Shambhu Chouhan

Assistant Professor,
Department of Agronomy,
B.R. College of agriculture,
Sahawa, Churu (SKRAU BIKANER, Rajasthan).

Abstract:

Millets, ancient grains cultivated for centuries, are crucial to global food security, especially in arid regions of Africa and Asia. This chapter explores the significance of millets as climate-resilient crops, their nutritional benefits, and their role in ensuring sustainable agriculture. Focusing on India, the world's largest millet producer, the chapter discusses water management techniques, emphasizing the importance of efficient irrigation systems such as drip and sprinkler irrigation. The analysis delves into the advantages and disadvantages of these systems, considering factors like water savings, soil health, and crop productivity. Additionally, the chapter addresses irrigation scheduling, highlighting the importance of adapting water supply to varying plant growth stages. Mulching, another key aspect discussed, emerges as a strategy to enhance soil conditions, conserve moisture, and improve crop quality. The types and benefits of mulching, both organic and synthetic, are explored, along with potential drawbacks. Overall, the chapter aims to provide insights into maximizing millet yield through sustainable water and soil management practices.

Keywords:

Millets, water management, irrigation, micro-irrigation.

13.1 Introduction:

Millets distinguish themselves as one of the earliest foods acknowledged in human history, potentially taking the lead among cereal grains cultivated for human consumption [1]. Millets serve as a primary cereal crop in the developing world, especially in the arid and semi-arid tropical regions of Africa and Asia. These regions heavily rely on millets for both human and cattle food [2].

Millets, considered ancient food crops, boast high nutritional value and adaptability to marginal environmental conditions. They stand out as a significant energy source and nutritious staple foods crucial for sustenance. Categorized as 'miscellaneous or coarse cereals,' millets belong to a group of small edible grasses within the Poaceae family [4]. Millets fall under a collective term used to describe a diverse group of small-seeded annual C4 Panicoid grasses. This category includes barnyard millet (*Echinochloa frumentacea*), finger millet (*Eleusine coracana*), foxtail (*Setaria italica*), pearl millet (*Pennisetum glaucum* (L.), kodo millet (*Paspalum scrobiculatum* L.), little millet (Panicum sumatrense Roth ex Roem. & Schult.), and proso millet (*Panicum miliaceum*) [5].

Millets play a crucial role in sustaining communities residing in mountainous regions. Beyond addressing global food security concerns, it is imperative to focus efforts on indigenous crops that thrive in the face of water scarcity.

The anticipated impact of climate change on crop cultivation in the coming century underscores the need for resilient alternatives. Millets, known for their climate-resilient attributes, exhibit adaptability to diverse ecological conditions.

They demand reduced irrigation, demonstrate enhanced growth and productivity in low-nutrient environments, minimize dependence on synthetic fertilizers, and display resilience to environmental stresses.

As the world contends with changing climates, millets emerge as potential climate-smart crops, surpassing the adaptability of current major global crops [3].

Millets are predominantly cultivated in states like Rajasthan, Maharashtra, Gujarat, Uttar Pradesh, and Haryana, relying mostly on rainfed practices as a monocrop.

To optimize productivity per unit area and time, there is also a trend toward high-intensity cultivation, involving double cropping when water resources permit. Irrigation plays a pivotal role in augmenting millet yield, and judicious use at critical growth stages can be more beneficial than irrigation at unnecessary stages, preventing potential yield losses.

Given the inelastic nature of agricultural land area, the primary avenue for improvement lies in enhancing productivity.

Therefore, there is a pressing need for focused efforts to increase and stabilize agricultural production in moisture-deficient regions. The availability of soil moisture emerges as a critical determinant for successful crop production in arid lands [6-7].

13.2 What Is Millets:

Millets encompass a diverse group of small-seeded grasses commonly referred to as the grass family [8]. Renowned for their nutritional richness, these ancient grains have gained popularity owing to their health benefits, environmental sustainability, and versatility in cooking [9].

Various types of millets exist, such as pearl millet (bajra), sorghum (jowar), finger millet (madua), foxtail millet (kangni), little millet (kutki), barnyard millet (jhangora), kodo millet (kodra), and proso millet (barri), each boasting unique characteristics and culinary uses [10].

These cereals, abundant in nutrients, are broadly categorized into two groups:

- **Major Millets:** Sorghum, Pearl Millet, Finger Millet
- **Minor Millets:** Little Millet, Proso, Kodo, Foxtail Millet, Barnyard Millet, etc.

Figure 13.1: Types of Millets

Millets find their primary cultivation in dryland areas, notably in the arid and semi-arid regions of Maharashtra, Rajasthan, Gujarat, Karnataka, Andhra Pradesh, and Tamil Nadu [8].

These grains have long served as a staple food source in numerous regions worldwide, with a particular stronghold in Asia and Africa [11]. India stands as the largest global producer of millets, predominantly cultivating them in economically challenging agroclimatic regions, especially rainfed areas of the country.

In 2022, India achieved a total millet production of 17.60 million metric tons, comprising 4.40 million metric tons of sorghum and 13.20 million metric tons of other millets [12].

13.2.1 Nutritional Benefits of Millets and Their Role in Food Security:

The nutritional benefits of millets position them as a viable alternative to major cereals, offering a rich source of protein, micronutrients, and phytochemicals. Various processing methods, including soaking, malting, decortications, and cooking, can influence the antioxidant content and activity of millets [13].

While sorghum and most millets typically contain around 10% protein and 3.5% lipids, finger millet stands out with 12-16% protein and 2-5% lipids. Sorghum and millets are excellent reservoirs of micronutrients such as vitamins and minerals [14].

Table 13.1: Proximate Composition and Dietary Fibre (Per 100 g)

Millets and Cereals	Moisture (g)	Protein (g)	Ash (g)	Total Fat (g)	Dietary Fibre (g)			Carbo hydrates (g)	Energy (KJ)
					Total	Insoluble	Soluble		
Bajra (*Pennisetum typhoideum*)	08.97 ± 0.60	10.96 ± 0.26	1.37 ± 0.17	5.43 ± 0.64	11.49 ± 0.62	9.14 ± 0.58	2.34 ± 0.42	61.78 ± 0.85	1456 ± 18
Sorghum (*Sorghum vulgare*)	09.01 ± 0.77	09.97 ± 0.43	1.39 ± 0.34	1.73±0.31	10.22± 0.49	8.49 ± 0.40	1.73 ± 0.40	67.68 ± 1.03	1398 ± 13
Ragi (*Eleusine coracana*)	10.89 ± 0.61	07.16 ± 0.63	2.04 ± 0.34	1.92 ± 0.14	11.18 ± 1.14	9.51 ± 0.65	1.67 ± 0.55	66.82 ± 0.73	1342 ± 10
Little Millet (*Panicum miliare*)	14.23 ± 0.45	08.92 ± 1.09	1.72 ± 0.27	2.55± 0.13	06.39 ± 0.60	5.45 ± 0.48	2.27 ± 0.52	65.55 ± 1.29	1449 ± 19
Kodo Millet (*Setaria italica*)	14.23 ± 0.45	08.92 ± 1.09	1.72 ± 0.27	2.55 ± 0.13	06.39 ± 0.60	4.29 ± 0.82	2.11 ± 0.34	66.19 ± 1.19	1388 ± 10
Foxtail Millet *	-	12.30	-	4.30	-	-	-	60.09	331
Barnyard Millet *	-	06.20	-	2.20	-	-	-	65.55	307
Proso Millet *	-	12.50	-	1.10	-	-	-	70.04	341

Table 13.2: Mineral and Trace Elements Compared to Fine Cereals (mg/g of N)

Millets and Cereals	Aluminium (mg)	Arsenic (mg)	Cadmium (mg)	Calcium (mg)	Chromium (mg)	Cobalt (mg)	Copper (mg)	Iron (mg)	Lead (mg)	Lithium (mg)
Bajra (*Pennisetum typhoideum*)	2.21 ± 0.78	0.97 ± 0.24	0.003 ± 0.001	27.35 ± 2.16	0.025 ± 0.006	0.030 ± 0.015	0.54 ± 0.11	6.42 ± 1.04	0.008 ± 0.002	0..003 ± 0..001
Sorghum (*Sorghum vulgare*)	2.56 ± 0.59	1.53 ± 0.04	0.002 ± 0.002	27.60 ± 3.71	0.010 ± 0.003	0.012 ± 0.007	0.45 ± 0.11	3.95± 0.94	0.008 ± 0..003	0.001 ± 0.001
Ragi (*Eleusine coracana*)	3.64 ± 0.69	-	0.004 ± 0.004	364 ± 58	0.032 ± 0.019	0.022 ± 0.009	0.67± 0.22	4.62 ± 0.36	0.005 ± 0.002	0.003 ± 0.003
Little Millet (*Panicum miliare*)	-	0.49 ± 0.15	0.001 ± 0.000	16.06 ± 154	0.016 ± 0.006	0.001 ± 0.00	0.34± 0.08	1.26± 0.44	-	-
Kodo Millet (*Setaria italica*)	1.07 ± 0.83	-	-	15.27 ± 1.28	0.021 ± 0.027	0.005± 0.003	0.26± 0.05	2.34 ± 0.46	-	0.027 ± 0.003
Foxtail Millet *	-	-	-	-	0.030	-	1.40			
Barnyard Millet *	-	-	-	-	0.090	-	0.60			
Proso Millet *	-	-	-	-	0.020	-	1.60			

Source: Indian Food Composition Tables, NIN – 2017. *Nutritive value of Indian foods, NIN – 2007 and [14]

13.3 Water Management and Requirements of Millets:

In agronomic terms, millet crops exhibit an advantage over major cereals due to their lower water requirements. With reduced water needs, it is advisable to provide 2–3 light irrigations at critical stages, including pre-flowering, post-flowering, and grain-filling stages [15]. Effective water management techniques, specifically low-water-use methods, are employed in dry areas for millet production. Therefore, the implementation of micro-irrigation practices becomes crucial, especially in the context of water scarcity conditions.

13.3.1 Micro Irrigation Methods:

The rise in the global population, accompanied by swift urbanization and industrialization, has intensified the competition for accessible water resources, leading to a decline in the availability of fresh water for agricultural purposes. The scarcity of freshwater is exacerbated by the increasing frequency of droughts attributed to climate change. Despite experiencing moderate rainfall in certain global regions, it is concerning that more than half of the irrigation requirements for crop production rely on extracting water from underground aquifers. This practice is alarming as it contributes to the rapid depletion of these aquifers. Consequently, achieving food security becomes a critical imperative. This objective not only demands high crop yields but also underscores the need for the efficient utilization of water resources. To address these challenges, there is an urgent call for the implementation of innovative and sustainable approaches to agricultural water management, aiming to mitigate the growing competition and depletion of crucial water sources [16].

To address water deficits and optimize food production per unit of water, irrigation techniques emphasizing pressure over gravity have been developed. Pressurized irrigation systems involve supplying water with the application of pressure, designed for enhanced efficiency compared to conventional methods.

These techniques enable precise quantification of the required water or nutrient supply at specific times. The selection of a pressurized irrigation system hinges on factors such as plant type, soil composition, landscape characteristics, required flow rate, operating pressure, and cost considerations. Notable examples of pressure-driven irrigation systems include drip irrigation and sprinkler irrigation.

13.3.2 Drip Irrigation System:

Drip irrigation stands out as an efficient system employed for row cropping, where water is directly delivered to the soil surrounding the root region using drip tubes. These tubes may be laid on the soil surface (surface drip) or buried a few centimeters below ground level (subsurface). The advantages and efficiency of drip irrigation have led to its widespread acceptance and usage by agriculturists globally, particularly in arid and semi-arid regions where freshwater availability is limited. The precision in applying water solely to the root region without saturating the entire farm plots makes drip irrigation an effective water-saving technique when compared to alternative methods. In a drip irrigation system, only a portion, typically ranging from 15% to 60%, of the soil surface is wetted [17]. The gradual, drop-by-drop watering sequence in drip irrigation is instrumental in reducing surface runoff and percolation, thereby contributing to improved disease management and salinity control [18].

Beyond these advantages, drip irrigation offers a range of other benefits, including enhanced crop quality, efficient utilization of fertilizers and other chemicals, minimized weed growth, and improved agronomic practices [19]. In a drip irrigation system, the spacing of emitters is crucial to ensure the accurate delivery of irrigation water, and this spacing is largely dependent on planting distance or vice versa. The effectiveness and efficiency of a drip emitter are pivotal factors influencing water distribution and the overall performance of the drip irrigation system. The rate of water delivery by emitters varies, and their selection is based on soil types and the water-use efficiency of the crop. Emitter clogging is predominantly linked to the quality of irrigation water. Turbidity, stemming from physical factors like sand particles, biological elements such as bacteria, and chemical components like inorganic fertilizer and salts, can lead to emitter clogging. Over time, these compounds settle around the water passage, forming clusters that impede further water passage.

Clogging adversely affects the productivity of crops surrounding the affected emitters, resulting in reduced yield. To prevent emitter clogging, it is advisable to treat water and reduce turbidity before application. Employing a combination of strategies, such as installing a filtration system, utilizing sedimentation tanks and tube settlers, regularly flushing the irrigation system, and implementing chlorination, can effectively mitigate the risk of emitter clogging and maintain the efficiency of the drip irrigation system.

Source: https://images.app.goo.gl/DSKiLzMYYpnu5D5W7.

Figure 13.2: Drip Irrigation System

A. Advantages of Drip Irrigation:

a. **Wind Resistance:** Despite its lower operating cost compared to sprinklers, drip irrigation is less affected by wind speed.
b. **Increased Yield:** Enhances crop yield by efficiently utilizing water and nutrients.
c. **Weed and Herbicide Cost Reduction:** Helps decrease weeding and herbicide costs, especially when used in conjunction with film mulch.
d. **Suitable for Difficult Topography:** Well-suited for use in challenging terrains.
e. **Environmental Benefits:** Reduces environmental contamination and soil compaction, particularly when mineral nutrients are supplied through fertigation.
f. **Reduced Water Contact with Leaves:** Minimizes water contact with leaves, lowering the risk of plant diseases.

B. Disadvantages of Drip Irrigation:

a. **High Initial Installation Cost:** One major drawback is the significant initial cost of installing a drip irrigation system.
b. **Maintenance Expenses:** The cost of maintaining drip irrigation pipes can pose a challenge for low-income farmers.
c. **Vulnerability to Damage:** Susceptible to damage from farm equipment, sunlight, rodents, wildlife, etc.

d. Corrosion and Emitter Clogging: Fertigation (nutrient and fertilizer application) through drip irrigation may lead to system corrosion and emitter clogging.

e. Frequent Replacement: Drip irrigation systems need more frequent replacement compared to other irrigation methods.

13.3.3 Sprinkler Irrigation System:

Sprinkler irrigation mimics natural rainfall by distributing water over plants through a process that involves spraying it into the air in droplet form. This water then lands on leaves and surrounding areas. The distribution is achieved through a series of pipes and a high-pressure sprinkler or guns. Although applicable on varied land slopes, it is most commonly employed on flat surfaces like lawns, golf courses, crops, landscapes, and level terrains. Various types of sprinkler irrigation systems exist, including the centre pivot system, rain gun system, side roll system, perforated pipe system, and rotating head system. Regardless of the type, each system comprises essential components: a pump unit, mainline, laterals, and sprinklers. The pump unit draws water from the source, and the laterals distribute it from the pump unit to the sprinklers. To ensure efficient water delivery, multiple sprinklers need to operate closely together, facilitating an overlap of distribution patterns, with the heaviest water application occurring near the sprinkler. In a central pivot system, the machinery moves in a circular pattern, spraying water onto the crops situated beneath the circular path. The rain gun system involves the use of a high-pressure machine that propels water into the sky, creating a rain-like effect as it descends onto the farmland. Side roll systems consist of pipes affixed to the center of a wheel, perforated to release water onto the crops as the wheel traverses the field. Perforated drain pipe systems employ pipes with perforations, enabling water drainage, while a rotating head system utilizes a pipe with spraying head nozzles to irrigate the field. The application rates of sprinklers vary based on factors such as nozzle size, spray radii, and operating pressure. Sprinkler irrigation proves adaptable to a range of soil types, although it is particularly well-suited for sandy soil with low water-holding capacity. The water droplets not only moisten both the soil and the crops but also become accessible through absorption by the roots and foliar penetration. It is essential to use sediment-free water to prevent nozzle blockage.

Source: https://images.app.goo.gl/gunxbdbKNRbwR7Sw9,
https://images.app.goo.gl/92MV 3gjawzNnVxQg6.

Figure 13.3: Sprinkler and Central Pivote Irrigation System

A. Advantages of Sprinkler Irrigation:

- This system facilitates the efficient utilization of water, reducing the need for additional labor in the application of fertilizers, pesticides, and herbicides.
- It proves more effective in irrigating plants with a higher concentration per unit area, such as cereals and vegetables.
- Particularly suitable for shallow-rooted plants, it stands as the sole irrigation form capable of supplying water to depths less than 1 inch [20].
- It boasts a longer lifespan compared to drip irrigation.
- Applicable for a variety of purposes, including agricultural, landscape, and nursery irrigation.

B. Disadvantages of Sprinkler Irrigation:

- The initial setup cost is high.
- It demands higher pressure than drip irrigation, leading to increased energy costs.
- Owing to its intricate structure, there are elevated operating expenses.
- Wind's ability to influence water movement may result in uneven water distribution.
- Foliar application of water and nutrients may adversely affect leaves (leading to leaf rot, senescence, and leaf burn) and fruit (resulting in fruit rot).
- Inefficient water delivery to understorey crops may occur.
- The rate of water evaporation is high in a sprinkler irrigation system.
- There is a potential risk of runoff and erosion compared to drip irrigation.

13.4 Irrigation Scheduling:

Plants exhibit varying water requirements at different growth stages, emphasizing the need for irrigation scheduling to supply optimal water at specific times. Irrigation scheduling involves determining when and how much water should be applied to plants [21-22]. This can be achieved by monitoring soil water status and crop water requirements. Common methods for irrigation scheduling include soil moisture-based, evaporation-based, and plant-based measurements to enhance water utilization and crop productivity. Soil moisture content serves as a basis for determining an irrigation schedule. Instruments such as the FDR soil moisture meter [23-24] measure soil moisture, and irrigation is initiated when the moisture falls below a critical level.

This approach considers soil type and composition, with sandy, loam, and clay soils having low, medium, and high-water availability, respectively.

The evapotranspiration schedule accounts for soil evaporation and plant transpiration rates, helping to balance water input and loss for optimal plant growth. Understanding the water needs of actively growing plants is facilitated by evapotranspiration data. Observing plant characteristics is another method for determining irrigation schedules. Morphological symptoms, such as chlorosis, dried leaves, leaf curling, and stunted growth, indicate plant stress or water deficit. Instruments like the chlorophyll meter and chlorophyll fluorometer [23] are used to assess chlorosis and water stress for effective irrigation scheduling.

13.5 Mulching:

Mulching is a soil enhancement strategy involving the application of various materials to cover the soil surface. This technique includes the placement of a protective layer around the root zone of plants, shielding them from adverse micro-climatic conditions. Mulching has gained widespread acceptance in agriculture due to its immediate economic advantages, including enhanced yields, earlier harvests, improved fruit quality, and reduced water consumption. Additionally, it promotes increased microbial activity in the soil. The practice of mulching establishes an optimal environment for plant growth by improving soil temperature, preserving soil moisture, minimizing weed pressure, deterring certain insect pests, and optimizing the utilization of soil nutrients, among other advantages [25]. An important benefit of mulching is the reduction of the impact of raindrops on the soil surface [26-27], thereby enhancing the hydrothermal regime of the soil and improving key soil physical properties such as texture, porosity, and infiltration rate.

Source: https://images.app.goo.gl/4EwGUo8wH823S1tR9,
https://images.app.goo.gl/KpVPHSg nx1PoqkPF9

Figure 13.4: Stuble and Plastic Mulch

13.5.1 Types of Mulching:

a. **Organic Mulches:** These mulches are readily degradable and commonly found on farms. The gradual decomposition of organic mulches enhances organic matter and soil fertility (Figure 5A). They provide a habitat for beneficial soil organisms like bacteria, fungi, insects, and worms. Importantly, their residues in the soil pose no disposal issues. Examples include leaves, paddy straw, grasses, sawdust, and sugarcane trash.
b. **Paddy Straw:** Paddy straw possesses a unique characteristic of not absorbing water, making it beneficial for water availability to plants. Among organic mulches, paddy straw has an extended lifespan. It functions as a nutrient reservoir, releasing nutrients gradually into the soil.
c. **Sawdust:** Sawdust, a small granular chip wood obtained as a finished product in sawmills, is easy to apply, cost-effective, and has a high C/N ratio. It retains moisture for prolonged periods.

d. **Sugarcane Trash:** Sugarcane trash, the residue from sugar cane after juice extraction, helps conserve moisture, reduces weed growth, and should be avoided in termite-prone areas.

e. **Synthetic Mulches:** These mulches are resistant to easy degradation (Figure 5B). They are synthesized materials requiring prior processing before use in the field. Termed non-biodegradable due to the natural decomposition of organic mulches, they come in various colors and thicknesses. They are more expensive than organic mulches and should be disposed of at the end of the growing season, e.g., plastic films.

f. **White Plastic Mulch:** Suitable for establishing crops in hot summer conditions, white plastic mulch has little effect on soil temperature. It repels some insects and reflects more light onto plants compared to black mulch.

g. **Black Plastic Mulch:** The most predominant colored mulch, black plastic acts as an opaque black body absorber and radiator. It prevents sunlight from reaching the soil, suppressing weed growth, increasing soil temperature, and enhancing mineralization and nutrient absorption. It promotes plant growth by warming the soil during the winter season.

h. **Transparent Plastic Mulch:** Also known as clear plastic mulch, it absorbs little solar radiation with a transmission of 85% - 95%. This significantly raises soil temperature and may adversely affect plant growth.

i. **Degradable Plastic Mulch:** Can be either biodegradable or photo-degradable, degradable plastic mulch breaks down through the action of microorganisms or sunlight.

j. **Biodegradable Plastic Mulch:** Made from plant starches like corn, wheat, and potatoes, this type of mulch can be broken down by microbes. It can be easily plowed into the ground after harvest.

k. **Photo-Degradable Plastic Mulch:** Formulated to break down after a specific period of sunlight exposure, it shares similar qualities with black or clear plastic film. Examples include plastigone and biolane.

13.5.2 Advantages of Mulching:

a. **Conservation of Soil Moisture:** Mulching helps retain soil moisture by reducing evaporation, benefiting plant hydration.

b. **Minimization of Soil Compaction and Erosion:** Mulch acts as a protective layer, minimizing soil compaction and preventing erosion caused by wind or water.

c. **Regulation of Soil Temperature:** Mulching moderates soil temperature, providing a more stable environment for plant growth.

d. **Reduction of Infiltration Rate:** Mulch helps control the rate of water infiltration, preventing rapid water loss from the soil.

e. **Reduced Fertilizer Leaching:** Mulching prevents the leaching of nutrients, ensuring that fertilizers remain available for plant uptake.

f. **Reduction of Weed Infestation:** By blocking sunlight and providing a physical barrier, mulch suppresses weed growth.

g. **Organic Matter Improvement:** Organic mulches gradually decompose, enhancing soil structure and fertility by increasing organic matter.

h. **Reduction in Harvesting Period:** Mulching can expedite harvesting by maintaining a cleaner and more accessible crop environment.

i. **Improvement in Quality and Yield:** Mulching contributes to improved crop quality and higher yields through optimal growing conditions.
j. **Reduction of Diseases:** Mulching helps prevent soil-borne diseases by acting as a barrier between plants and the soil.
k. **Remediation of Heavy Metals:** Some mulches have the potential to absorb and remediate heavy metals from the soil.

13.5.3 Disadvantages of Mulching:

a. **Competition for Resources:** Mulch may compete with plants for resources such as water and nutrients, especially if applied too close to plant stems.
b. **Allelopathic Effects:** Certain mulches may release chemicals that inhibit the growth of nearby plants, affecting their health.
c. **Weed Infestation:** Improperly applied mulch or the use of contaminated mulch may introduce weed seeds, leading to weed problems.
d. **Nitrogen Insufficiency:** Some types of mulch, particularly those high in carbon, may temporarily tie up nitrogen during decomposition, potentially affecting plant nutrient availability.

13.6 Conclusion:

Millets stand out as vital contributors to global food security, particularly in regions facing water scarcity and climate challenges. The analysis underscores the adaptability and resilience of millets, showcasing their potential to thrive under diverse ecological conditions. To harness their full potential, the chapter emphasizes the crucial role of efficient water management. Drip and sprinkler irrigation systems emerge as promising solutions, offering benefits such as water savings, improved crop quality, and enhanced nutrient utilization. The importance of irrigation scheduling tailored to specific growth stages is highlighted, ensuring optimal water supply for maximum productivity. Furthermore, the chapter explores the role of mulching in enhancing soil conditions, conserving moisture, and mitigating environmental challenges.

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