Chapter

Sustainable and Effective Management Strategies in Cotton Cultivation

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Abstract

Cotton, which is one of the leading fiber and oilseed crops, consumes 16% of the total pesticides and about 24% of insecticides in the world. In arid climatic regions such as Turkey, most of the plant water consumption is met by surface irrigation methods, while a significant part of it infiltrates deep. During cultivation, a significant portion of pesticides and chemical fertilizers are consumed incorrectly, or unconsciously due to socioeconomic and cultural reasons such as the lack of education of farmers and low economic income. For this reason, it is necessary to understand the correct cultivation techniques from planting to harvest and to manage critical periods in practice. Owing to this, it is necessary to re-evaluate and sustain high-productivity and quality cotton cultivation together with human and environmental requirements. Especially for this purpose, the charts and figures prepared to give direction to experts are a tool for a correct and complete understanding of the topics covered. Considering the objectives and needs of agricultural production, the analysis of the most critical issues required for cotton cultivation from a different perspective will be an important stage for the next steps.

Keywords: sustainable management, cotton cultivation, irrigation, nutrient management, cotton yield

1. Introduction

Cotton (*Gossypium spp.*) is used to obtain fiber, oilseeds animal feed, cellulose, and biofuel [1]. It is among the plants that provide employment and income to millions of people for its production, processing, and marketing besides having an important share in the economy. The annual contribution of cotton to the textile industry is 600 billion dollars. More than 80% of the total cotton production of 25 million tons per year is produced in the top 10 countries, mainly India, China, the United States, Pakistan, Brazil, Pakistan, Uzbekistan, Turkey, Australia, Benin, and Greece [2]. Cotton is grown on almost 2.5% of the world's arable land by nearly 26 million farmers in 75 countries [3]. It meets 27% of the world's textile requirements and provides employment and income to almost 100 million families. Two-thirds of the total cotton produced in the world is obtained from 53% of the irrigated lands [4]. Cotton cultivation meets 27% of worldwide textile needs and supports jobs and income for roughly

100 million people. By 2030, it is estimated that world cotton production will reach 28 million tons with an annual increase of 1.5%. This growth is expected to come from global yield growth (1%) in addition to expanding the cotton field (0.5%) [5]. Where it is grown, cotton is an attractive environment for numerous insects, pests such as aphids, thrips, and spider mites [6]. The only solution that farmers use to fight pests is to use insecticides. About 16% of the pesticides consumed globally are used for cotton growing lands [7]. Chemical pesticides used on cotton are linked to everything from cancer to infertility to birth defects. With excessive irrigation, it is carried to groundwater, rivers, and oceans, but also threatens the ecosystem by polluting the soil, air, food, and drinking water [8]. It is 300 times stronger than the greenhouse gas CO_2, which is formed because of the conversion of nitrate-containing chemical fertilizers as nitrogen source, used per hectare, in cotton-grown lands [9]. Excessive use of chemicals threatens environmental resources as well as agricultural production. When the future production style is arranged according to the wishes and needs of ecology, progress will be made in the direction of sustainability.

2. Cotton cultivation

2.1 Climatic requirements

Cotton is a plant that needs temperature above freezing, a humid climate, and sunbathing during its growing period. In general, the seed sowing depth (4–5 cm) should be above 15°C for germination to occur [10]. It is desirable that the soil temperature in sowing is at least 18°C. According to the developmental periods, the optimum temperatures are around 21–27, 27–32, and 21–32°C in vegetative, reproductive, and maturity periods, respectively [11].

2.2 Phenological development

The development of cotton during the growing period can be examined in five stages [12]. These are (1) germination and emergence, (2) seedling/root establishment, (3) leaf area expansion and canopy closure, (4) flowering and boll formation, and (5) boll and fiber maturation (**Figure 1**).

The number of days of development periods of cotton from sowing to harvest is given in **Table 1**.

2.3 Planting

The ideal planting depth is 4–5 cm. Planting depth should be 2–3 cm when the soil temperature is low in early sowing and when tempering is high. As the sowing date progresses, the planting depth should be increased up to 5–6 cm to ensure germination by taking advantage of the soil moisture [14]. The harvestable number of plants for cotton should be between 70.000 and 140.000 per hectare. When determining the number of plants in sowing, 80–85% seed germination rates should be considered in order to obtain the number predicted to be harvested. Accordingly, for the conditions where the distance between rows is 70–76 cm, the ideal plant density for machine harvesting is 10 cm. The number of plants in the harvest should be around 140,000, and for this, the distance between the row spaces should be adjusted to 8–8.5 cm in the planter settings. If the harvest is done by hand, the ideal in-row distance after

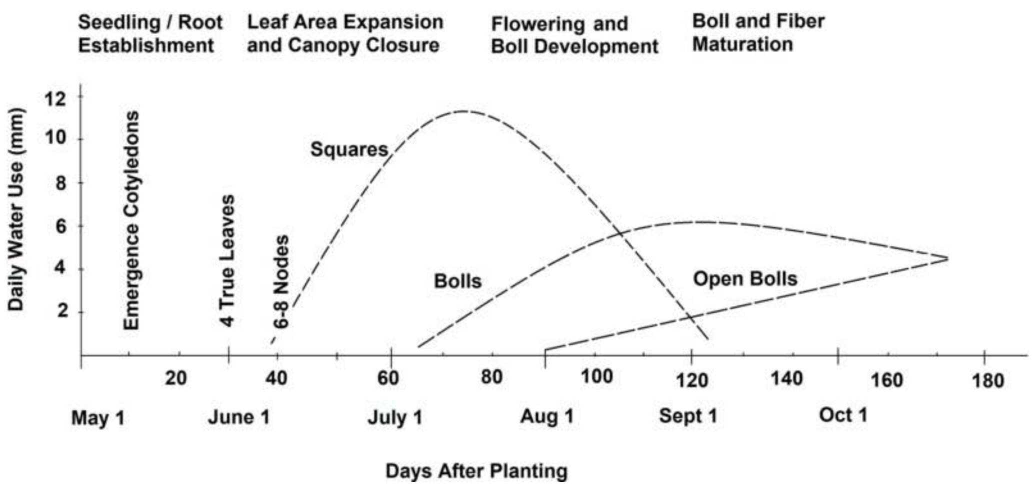

Figure 1.
Growth stages of cotton [12].

Event	Time required (days)	Average time required (days)	Cumulative duration (days)	Average date
Planting	0	1	1	May 1
Planting to emergence	4–14	7	7	May 7
Planting to first square	35–45	39	40	June 17
Planting to first bloom	55–70	62	62	July 6
Cut-out	8–10	9	71	July 28
Pinhead square to white flower	20–35	23	94	August 6
White flower to pink flower	1	1	95	July 29
Pink flower to open boll	50–60	55	112	July 30
Planting to 10% opening bolls	10–12	10	122	August 20
10% opening bolls to Harvest	160–180	51	170	August 30

**Assuming 20 main-stem nodes and 10–12 active fruiting branches.*

Table 1.
Growth and development periods of cotton [13].*

thinning is 17–20 cm. Cotton harvest starts when 60–65% of the bolls open (around September 15) and lasts until mid-December in Turkey.

3. Crop rotation

The purpose of the rotation is to provide sustainable management of the soils. Crop rotation also has purposes such as weed and pest control, disease management, utilizing the remaining nutrients from the previous plant, and improving the accumulation of organic matter in the soil. The biggest problem with rotation in cotton cultivation is finding the rotation product that can generate the income of the main product. Other determining factors in this regard are the climatic conditions as well as how much the rotation product is affected by price changes. In addition to the market value of the product, farmer habits also affect the rotation.

In terms of sustainable management, organic matter accumulation is generally a major problem, especially in arid climatic regions where rainfall is insufficient, and irrigation is made. In such places, it is vital to adopt practices that will ensure the accumulation of organic matter in the soil in double, triple, and quadruple rotation applications. Prior cultivation of legume crops (such as soybean, peanut, beans, kidney beans, chickpeas, lentils) or legume fodder crop (such as Hungarian vetch, fodder pea, or vetch, broad bean) is an excellent choice for cotton planted land. In this way, since the physical, chemical, and biological characteristics of the soil will be enhanced, the organic matter content will also increase. More favorable soil conditions will be provided, especially in terms of plant nutrient intake, weed control, disease, and pest management.

In Şanlıurfa province in Turkey, the common practice in the rotation is wheat-corn in the first year and cotton in the second year. Farmers experience cotton yield decreases as high as 30–50% in wheat-cotton rotation in the same year. Another reason why wheat-cotton (Planting in May 15–30) rotation is not preferred is the increase in pest damage. In the same climatic region, an increase in cotton yield was observed in the lands of the farmers who preferred the first-year winter lentil (planting in October or November)—cotton (planting in June) rotation.

Another climatic region (İzmir and Muğla provinces) in the west of Turkey is wheat-silage corn or oat-silage corn in the first year and cotton in the second year of plant rotation. In the same area, it is silage maize for the first year consecutively and cotton for the second year. Some farmers in the region maintain a continuous cotton-cotton rotation. In Nazilli-Aydin province, first-year winter barley-cotton and second-year corn rations are maintained. In the alfalfa-cotton-wheat (W) rotation carried out by Nazilli Cotton Research Institute, a decrease in wilt loss disease was detected in cotton [15].

In rotation applications, corn-cotton and soybean-cotton are preferred in Mississippi, peanut-cotton in Arkansas, sorghum-cotton in Texas, and wheat-soybean-cotton rotations in Oklahoma. While practice yield increases range from 5 to 11%, research shows that rotation helps create a good balance and sustainability for farmers in matters related to disease and pest management, soil protection, soil, and plant health [13, 16].

It has been stated that the rotation of legumes with organic fertilizers is suitable for sustainable production in cotton and corn-growing areas in Burkina Faso [17]. In Pakistan, cotton-wheat rotation provided the highest yield, while sunflower-cotton rotation significantly reduced soil fertility and an allopathic effect [18]. Rotation schedules in India where cotton is grown in 10 states differ between states. In the north-western states of the country, Punjab, Haryana, and Rajasthan, there is a rotation of CW, C-Mustard, and C-Berseem (*Trifolium alexandrinum*), while most of them only cotton-wheat and Tamil Nadu Rice-C, Rice-Rice-C, C-GS. The states of Telangana and Andhra Pradesh practice C-Rice (Rank), C-Chilli, and C-Tobacco (two-year rotation).

4. Nutrient management

Dry matter formation in plants is the process of converting water and nutrients taken from the soil by photosynthesis [19]. Dry matter formation is adversely affected in cases where plant nutrients are insufficient in the soil for various reasons, their uptake is reduced, or it is not possible. Chlorosis, malformation, stunting, and poor plant growth are common symptoms due to nutrient deficiencies, improper soil management practices, or climatic factors [20]. Nitrogen, phosphorus, potassium, and boron deficiencies are common in cotton production [21]. In addition to their inadequacies, plant growth may be adversely affected by the imbalances between each other (such as Ca-Mg and K) [22], antagonistic effects (such as phosphorus and zinc) [23], soil pH, nutrient application time, method and amounts, climate and environmental factors.

4.1 Nutrient requirement

Coordination of factors such as climatic conditions, drought, pH, macro and micro plant nutrient deficiencies, pest, soil, and water management directly or indirectly affects yield and quality characteristics [24]. Especially in arid climatic regions, the inadequacy of precipitation that can provide organic matter development is an important problem in the uptake of plant nutrients [25]. Soil pH is a problem not only in the uptake of macronutrients, but also in micronutrients, which are generally available in the pH range of 5.5–6.5 [26]. Deficiencies in the early stages of plant development are not a big deal in terms of their effect on plant growth. These elements, constituting only 1% of a bale, are removed after ginning, along with the seed and litter, along with macro and micronutrients [27]. **Table 2** gives the macro and micronutrient needs removed from the soil when 2500 kg of lint is taken per hectare.

The average daily intake rate of plant nutrients is given in **Figure 2**.

4.2 Nitrogen

Nitrogen (N) is an important nutrient needed for the healthy progression and physiological improvement of cotton, increasing fiber and photosynthesis efficiency [30]. It also affects the plant's ability to produce carbohydrates due to its role in chlorophyll production. N promotes vegetative growth and can be effective in increasing the number of bolls by increasing nodes and fruiting positions. The presence of nitrogen affects root morphology (root length, thickness, volume, and mass) and is associated with dry matter formation [31]. To maximize the effectiveness of N applied in cotton production, both pre-plant and side applications are recommended [32]. Inadequate N in early vegetative growth can be unfavorable to yield and quality [33]. Proper management of nitrogen is required in productive and high-quality cotton cultivation. To increase the efficiency of use (NUE), nitrogen should be given

Macronutrients (kg ha^{-1})					
N	**P_2O_5**	**K_2O**	**MgO**	**CaO**	**S**
220–230	50–60	270–280	70–75	280–300	70–75
Micronutrients (g ha^{-1})					
Fe	**Cu**	**Zn**	**Mn**	**B**	
400–420	75–80	270–280	800–850	600–650	

Table 2.
Nutrient requirement of cotton [28].

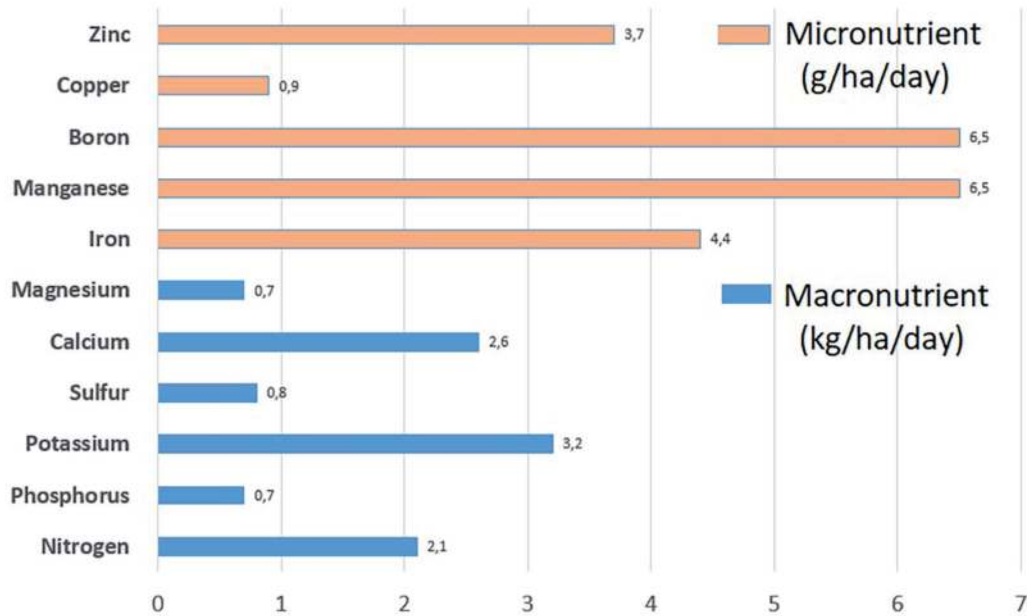

Figure 2.
Daily maximum nutrient uptake rates in cotton [29].

in the required amount, time, and form (such as NO_3^-, NH_4^+ or NH_2), to reduce leaching and evaporation losses with excessive irrigation, and to be given with partial and fertigation applications for effective management [34]. To reduce nitrogen losses, soil and tissue tests can be performed, and NDVI (Normalized Difference Vegetation Index) measurements can be applied using satellite or drone techniques [35].

4.2.1 Managing N fertility

Nitrogen is given in two periods, before planting (or with sowing) and before flowering. Pre-planting fertilization can be done according to the amount of nitrate-nitrogen to be determined in the soil test, considering the amounts given in **Table 3**.

The nitrogen fertilization system consists of two parts: (1) about 10–20% of the total nitrogen requirement before flowering (before or with planting), (2) the remaining nitrogen during the irrigation period of 60–75 days from the beginning of the flowering period. Additional nitrogen application may be required when needed against a sudden nitrogen deficiency to mature the crop later. However, it may be

NO_3^- N (ppm)	N/ha
0–5	30–50
5–10.	20–30
10–15.	0–20
> 15	0
**Source: [29]*	

Table 3.
Nitrogen fertilization according to nitrate nitrogen level in the soil.*

advisable to give the last nitrogen fertilizer application in the flowering period with one of the nitrogen fertilizers produced as urea or slow-release nitrogen fertilizer. Because urea needs time to turn into ammonium and nitrate [36], it may be possible for the plant to benefit from nitrogen for a longer period with slow release. Measures such as reducing the losses of nitrogen under the root zone with surface irrigation methods (border or furrow) or preventing leaching with more controlled irrigation with pressure irrigation methods can be applied. It may be beneficial to increase the efficiency of nitrogen use by dividing the needs of the plant throughout the season into the growth period in climatic regions such as the Mediterranean where irrigation is used. In addition to these, utilizing the residual nitrogen from the plants entering the crop rotation may prevent the use of excess nitrogen. Considering that unnecessary or excessive nitrogen may delay maturation by encouraging leaf development by keeping the plant constantly green [9], it is necessary to be prepared for harvest with an optimum termination.

The base fertilization to be made before sowing is spread on the soil with fertilizer dispersing equipment, and then it is mixed into the soil at a depth of 10–12 cm with one of the appropriate tillage tools (such as a cultivator, rotavator), and the seedbed is prepared for planting. It is recommended to apply the fertilizers 5–6 cm below [37] and on the band so that they do not contact with the seeds, in the fertilization to be made on the seedbed with sowing.

Petiole sampling (**Figure 3**) is necessary for the health monitoring of nitrogen management in the plant [39]. The petiole test is done by plucking the first fully expanded leaf from the top of the plant 1 week before flowering. Repeat weekly for the following 8–9 weeks by breaking off the petiole of the first fully expanded leaf from the top of the plant [38].

For the first petiole analysis of the season, the petiole from the third node at the top of the plant should be taken and sampled from about 40 different locations in the field. As the results will show the nitrogen levels in the plant, it will be understood whether the fertilizer has been used adequately or insufficiently. The timely application of nitrogen prevents the reduction of leaf nitrate. If the level of nitrate-nitrogen drops to 4000 ppm or less before the first bolls open (**Figure 4**), it is recommended to apply nitrogen in the form of nitrate or urea.

Nitrogen in the form of nitrate in the soil solution is easily transported into the plant body. For this reason, the time required to eliminate the deficiency is shortened. In such a case, the source of nitrogen is not so important. Because the nitrification of

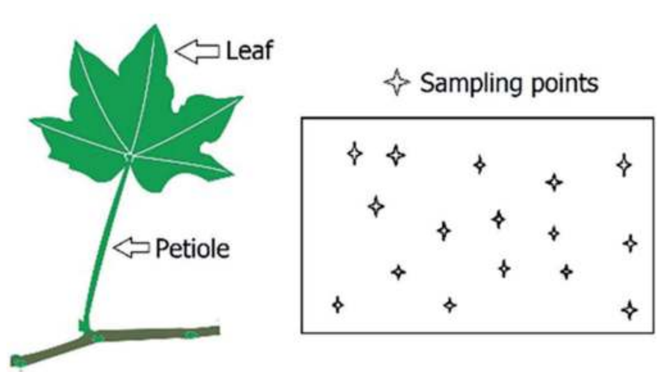

Figure 3.
Petiole sampling for analysis and location [38].

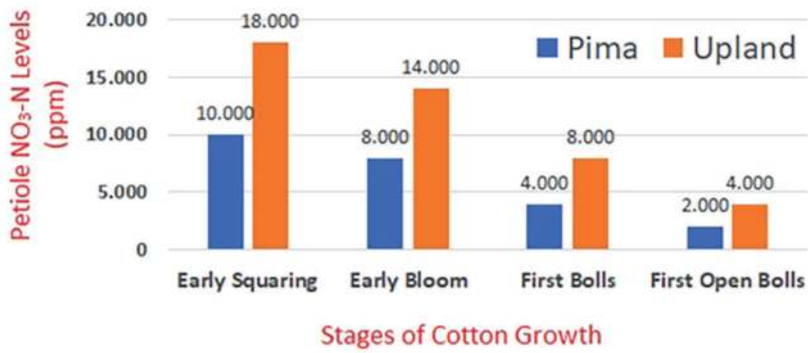

Figure 4.
Desired levels of petiole nitrate-nitrogen in cotton varieties [29].

ammonium sources can occur quickly enough to allow the resulting nitrate nitrogen to be transported to the root zone to meet the plant's needs [40].

4.3 Phosphorus

Phosphorus is effective in the energy transfer (ATP), transport, and storage of substances such as sugar and starch in plants [41]. It is necessary for flower and fruit formation, root development, and vital for the formation of new cells. In its deficiency, it causes lifeless, weak, and soft flower formation, weakening of the roots, lack of life and absorbent hairs, shortening of shoots, thinning and filamentous development, narrowing between the nodes, formation of small and amorphous fruits, decrease in the number of seeds, seed development disorders, and shortening in shelf life [42].

Phosphorus deficiency is commonly caused by conditions such as the presence of fully bound phosphorus in soils with a pH lower than 5.5 or higher than 7.5, with high clay content and low organic matter content, and soils with high aluminum or iron hydroxide content. In addition, plants need a large amount of phosphorus in their young stages, before the flowering period and during the seed formation periods. Phosphorus is also effective in metabolic activities such as energy production and gene transfer. In the excess of phosphorus in the soil, especially the intake of iron (Fe), zinc (Zn), and copper (Cu) is limited [43].

Cotton yield responds positively to the presence of phosphorus and affects dry matter accumulation in the soil [44]. Phosphorus (P) plays a crucial role in cotton by increasing reproductive growth and yield. Phosphorus contributes to root development by increasing root length, width, and diameter in plants [45]. Therefore, P deficiency inhibits cotton growth by reducing biomass accumulation and especially reduces seed cotton yield, stunted growth, and low yields have been detected [46].

4.4 Potassium

Potassium (K) affects vital metabolic, physiological, and biochemical functions in plants and increases product quantity and product quality. Studies show that potassium increases starch synthesis, helps to transport and store water and plant nutrients and photosynthesis products, prevents water loss in plants by regulating turgor, accelerating root development, promotes branching and lateral root formation. If there is enough potassium, the plants will form more branched roots. Root diameter expands, and root length and root growth rate increase [47]. Plants that do not get enough potassium are mostly high in nitrogen and low in carbohydrates. Potassium affects the development of the cell wall in plants and accelerates maturation, increases the effectiveness of nitrogen, and positively affects the resistance against diseases and pests. In a study conducted, the effectiveness of potassium against diseases and pests in plants was determined to be 65% effective [48].

Heavy-textured soils in the clay-type illite group, which have insufficient K reserve and are rich in magnesium, have acid (low pH) character, light-textured sandy, are leached by excessive irrigation or precipitation, may show potassium deficiency [49]. Potassium concentrations in both the blade and petiole of fully expanded upper leaves on the main stem are good indicators of K deficiency. Potassium deficiency causes many disorders including a decrease in leaf area index, photosynthesis, and plant biomass in cotton, while the decrease in leaf photosynthesis and stomatal conductivity, low chlorophyll content, weak chloroplast structure, restricted saccharide translocation are attributed to K deficiency [50]. Potassium deficiency affects the seedling development of cotton and shows this with shortening of plant height, decrease in leaves and roots, and biomass. It also inhibits enzyme activities in cotton seedlings by affecting photosynthesis and respiration [51].

Potassium demand increases in cotton during boll formation, flowering, and fiber elongation periods [52]. Potassium deficiency manifests itself with interveinal chlorosis on old leaves 3–4 weeks after the first flowering; in addition to symptoms, leaves may begin to curl downward and thicken. If the deficiency is severe enough, the cotton plant may begin to shed leaves on its own. The high demand for potassium generated during boll formation in cotton can be greater than 3.4 kg per hectare per day [53]. Severe potassium deficiency caused by extremely hot and dry conditions can cause other undesirable effects, including fruit drop [54]. Drought, due to soil moisture deficiency, is a limiting factor for potassium uptake.

Potassium is an important nutrient that affects fiber length and quality in cotton. In a study conducted in an area with potassium deficiency in the soil, fiber strength and weight decreased up to 7.8% and 2.1%, respectively [50]. The most effective way to meet the potassium requirement is to regularly test the soil.

4.5 Secondary nutrients

4.5.1 Sulfur

The source of sulfur that can be taken up by plants is elemental sulfur and sulfur in organic matter. Plants take up sulfur in the form of the SO_4^{-2} ion. In addition, they can also take SO_3 and a little elemental sulfur with their sulfur leaves. In addition, plants can absorb this element in the form of SO_2 gas. Sulfur is an element that enters the structure of organic matter. Sulfur takes place in the structure of sulfurous amino acids such as cystine, cysteine, and methionine in plants and combines with them to form proteins. During this cycle, the sulfur takes part in many enzymatic activities [55]. Sulfur is easily transported (mobile) within the plant. However, it is less mobile than N, P, K, as it forms various compounds immediately after entering the plant body [56]. Sulfur deficiency shows symptoms very similar to nitrogen deficiency. Nitrogen deficiency is seen in old leaves, while sulfur deficiency is seen in young leaves [57]. It is found in the structure of some amino acids necessary for protein synthesis. It takes part in the synthesis of energy, hormones, and some enzymes, and accelerates nitrate and carbohydrate metabolism [58].

4.5.2 Calcium

Calcium is taken up by plants as Ca^{+2} ions through root tips. Calcium ions are transported to all plant tissues by xylem pipes due to transpiration [59]. Calcium is effective in the development of the endpoints of newly developing cell tissues, and the normal formation of roots and flowers. Calcium is located between the cell walls and is the building block of the cell wall [60]. Strengthening the cell wall, it helps cell growth and elongation. It is effective in the permeability of the cell membrane. It is necessary for normal flowering and root development. It helps in the uptake of nitrates. It increases the plant's resistance to diseases, drought, and stress [61].

Calcium is immovable within the plant. In other words, calcium, previously taken to the plant or in the leaf, does not pass to the fruit and newly formed leaves and shows the first signs of deficiency with the drying or upward curling of the leaf tips [62]. Dying at the shoot tips and stopping the growth of dead tissue, discoloration at the fruit tip, and brown-black rot (blossom end rot) in the following period are seen. To eliminate the calcium deficiency, Calcium Nitrate fertilizer should be applied regularly, if necessary, in each irrigation, or spraying calcium on the fruit 3–4 times is effective. The first calcium deficiency is seen on young leaves and shoots tips [57]. Young leaf margins dry up and die. Shoot tip growth stops, shoot tips dry out. Plant tissue and fruits are soft, shelf and storage life are short. Root development weakens, the durability of the root's decreases. The plant's resistance to diseases and pests is reduced [63].

Conditions reducing calcium uptake: Feeding with high ammonium (NH_4) nitrogen, insufficient water, or high salt concentration in the soil, conditions that prevent new root formation, such as low temperature and insufficient aeration, low pH soils, organic soils, or high organic matter added soils and giving too much potassium or magnesium with fertilizer [64].

4.5.3 Magnesium

Plants take magnesium in the form of Mg^{+2} ions. Magnesium is the central atom of chlorophyll and is vital in photosynthesis [65]. Therefore, in magnesium deficiency, the number of chlorophylls decreases and photosynthesis regresses. Due to mobility in plants, it accumulates most in the growing tips of plants and especially in young leaves. It is transported from these regions to the seed during seed formation [66]. Magnesium deficiency first manifests itself in older leaves. In magnesium deficiencies, older leaves become discolored, the main and secondary veins on the leaf are green, the thinner veins turn yellow, and local wavy round yellowing is seen between the veins [67]. Magnesium plays a very important role in the transport and placement of phosphorus and the conversion of amino acids into polypeptides. It is an enzyme activator and helps the function of many enzymes [68].

Conditions that cause decreased magnesium intake: Excessive potassium and calcium fertilization or high lime content, sandy soils with heavy rainfall, soil compaction, insufficient drainage, drought, and cold soils, and pH drop below 5. Toward the end of the development period, the deficiency increases due to the increase in the need for magnesium [69].

4.6 Micronutrients

Micronutrients are not needed in large quantities as macronutrients but are vital because of their role in plant development. Zinc (Zn) for plant hormone balance, auxin activity, growth, cell division; iron (Fe) for photosynthesis with chlorophyll synthesis; boron (B) for flowering, maturation, sugar transport, cell division, and amino acid production; manganese (Mn) for chloroplast production and enzyme activation; copper (Cu) for stimulating enzymes necessary for photosynthesis; legumes need Molybdenum (Mo) elements for nitrogen fixation [70].

The deficiencies of these nutrients manifest themselves in the form of different symptoms. For example, in zinc deficiency, growth in plants stops, the internodes become shorter, and young leaves become smaller than normal, while chlorosis or yellowing occurs between the new leaf veins in iron deficiency. In boron deficiency, mild general chlorosis, death of the growing point, the color of the leaves fades and becomes deformed. Similarly, in Manganese (Mn) deficiency, chlorotic mosaic patterns occur on the leaves; in copper deficiency, mild general chlorosis, leaf tips are bent, and turgor loss is seen in young leaves; In molybdenum deficiency, like ordinary nitrogen deficiency, general chlorosis is seen in young plants [71].

EDTA (Ethylene Diamine Tetra-Acetic Acid) is a chelating agent that allows the molecular structure to bind to heavy metals, and chelation is a form of attachment of ions and molecules to metal ions. Chelates, on the other hand, are complex compounds called ligands in their structure and play a role in the uptake of micronutrients such as EDTA. Micronutrients are transported to the plant body mainly by applications such as soil, leaves, and irrigation water [72].

4.7 Foliar fertilization

In arid and some subtropical climatic regions where precipitation is insufficient, soils rich in lime are a problem in the uptake of microelements such as zinc, iron, and boron due to high soil pH [73]. Studies show a reduction in seed cotton yield in calcareous soils due to an imbalance of nutrients, especially micronutrients [74]. In general, high pH is a limiting factor for nutrient uptake in such lands with low organic matter and nitrogen content, and this type of soil is insufficient in terms of zinc, boron, and iron [75]. In addition, the imbalance between some elements and calcium can lead to nutritional problems, especially in terms of potassium and magnesium [76]. In such cases, foliar applications of micronutrients, whose uptake is limited by soil applications, are an inevitable need [77].

Foliar fertilization provides advantages such as low cost and rapid plant response in situations where soil problems arise, and root development is insufficient. Further, foliar feeding has disadvantages due to problems such as possible leaf toxicity and solubility [78], and therefore, it is not possible to fully meet the needs of the plant. Success in foliar fertilization can be achieved when the effects of many factors such as the development period of the plant to be applied, its need, the toxicity level, the number of applications, the number of repetitions, the method of application, the time of application, the compatibility with other pesticides and fertilizers are known. The quality of the nutrient to be applied to the plant is important. Because the dose and application stage to be used in the application of macro and micronutrients to be applied in foliar feeding can be different. The efficiency of foliar fertilization can be affected by the type of fertilizer, its solubility, the concentration and pH of the solution, and its incompatibility with some pesticides and chemicals used in foliar feeding [79].

Foliar fertilization of cotton is a convenient way of applying certain fertilizers that can complement conventional soil methods. Foliar fertilization can increase yield and fiber quality. The transport rate of plant nutrients used in foliar fertilization is given

Fast	Moderate speed	Slow	Very Slow
NH_2—Nitrogen	Phosphorus, P	Zinc, Zn	Boron, B
NH_4—Nitrogen	Sulfur, S	Copper, Cu	Magnesium, Mg
NO_3—itrogen		Ferrous, Fe	Calcium, Ca
Potassium		Manganese, Mn	
Sodium		Molybdenum, Mo	

Table 4.
Transition rates of nutrients to leaves [80].

Nutrient	The time required for 50% of the nutrient intake
NH_2—Nitrogen	0.5–2 hours
Phosphorus, P	5–10 days
Potassium, K	10–25 hours
Calcium, Ca	1–2 days
Magnesium, Mg	2–5 hours
Zinc, Zn	1–2 days
Manganese, Mn	1–2 days

Table 5.
The time required for the uptake of some nutrients into the plant [80].

in **Table 4**, and the times required for 50% of the applied plant nutrients to be taken are given in **Table 5**.

5. Water management

5.1 Critical stages for irrigation management

Although cotton varies according to the climatic regions where it is grown and the day length of the varieties, daily plant water consumption of cotton is different at plant growth stages. It increases from 2.5 mm at the seedling stage to the maximum value (6–10 mm) in the most intense flowering from the soil and gradually decreases in the boll development (5–8 mm), reaching the minimum value (2–4 mm) in the opening stage of the bolls. Even though susceptibility to water stress varies according to phenological periods, squaring, flowering, and boll development are critical stages in cotton [81]. Water stresses that will occur during these periods reduce the number of squares and cause yield and quality losses by shedding squares, flowers, and bolls [82].

The first square in cotton is seen approximately 50–60 days after sowing and the flowering period continues for 7 weeks. **Table 6** shows the effect of flowers formed during flowering on yield. As seen in the table, the bolls formed by the flowers formed in the first 3 weeks constitute 88% of the product. Considering the yield of flowers formed in the first 3 weeks, the importance of preserving the first bolls emerges spontaneously.

	Weeks of flowering						
	1	2	3	4	5	6	7
Total flowers (%)	8.1	23.5	29.4	25.6	9.8	2.3	1.3
Boll retention rate (%)	94.1	77.7	43.1	20.7	13.3	10.8	5.0
Total product (%)	21.0	43.0	24.0	8.5	2.5	0.9	0.5
Average boll weight (g)	5.3	4.6	3.7	2.8	3.1	3.2	—

Table 6.
The effect of flowering weeks on yield in cotton [83].

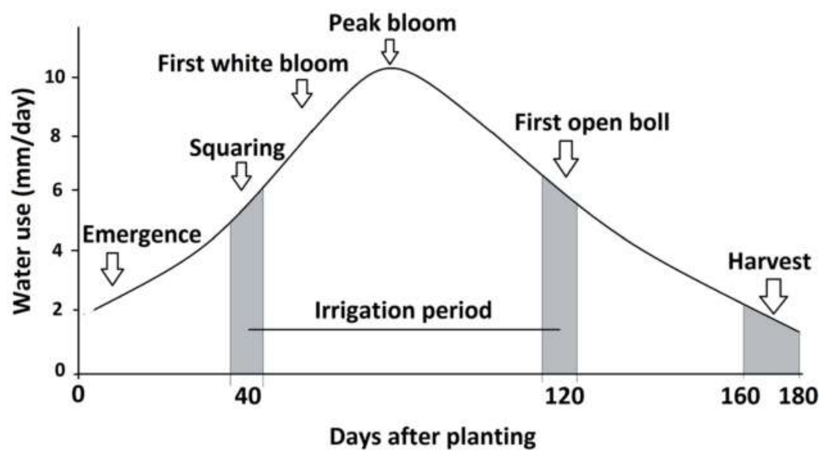

Figure 5.
Irrigation period of cotton throughout the growth stage (adapted from [84]).

The time between squaring and the opening of the bolls (between 40 and 120 days after planting) is considered the critical process for managing water in the root zone of cotton. The common practice in determining the irrigation period (**Figure 5**) is the 70–80 days period between the appearance of the first squares and the period when the rate of the first bolls to open reaches 10% [85].

Productive and high-quality cotton growth is important for the initiation and termination of irrigation [86]. Considering the sensitivity to water stress, it is necessary to start irrigation during the squaring period of the plant (35–45 days after planting) to prevent yield losses [87]. Because the water stress that may occur during this period can lead to boll shedding, resulting in significant losses in yield. Early termination of the irrigation period may result in yield losses, while delay may result in continued vegetative growth, delayed maturation of the bolls, increased pest management and harvesting costs, and reduced irrigation efficiency [88]. For climatic regions where the average daily plant water consumption is around 8–10 mm, the irrigation interval of 10–12 days is recommended in lands with medium and heavy-textured soil where surface irrigation methods such as furrows are applied [89]. Irrigation intervals can be selected as 6–8 days for lands where drip and sprinkler methods are used in lands with similar climates and as 4–5 days for sandy soils. While it is recommended to terminate the irrigation when the first opened bolls are seen in areas where surface irrigation methods are used, it can be delayed for 1–2 weeks in medium and heavy-textured fields where sprinkler and drip methods are used.

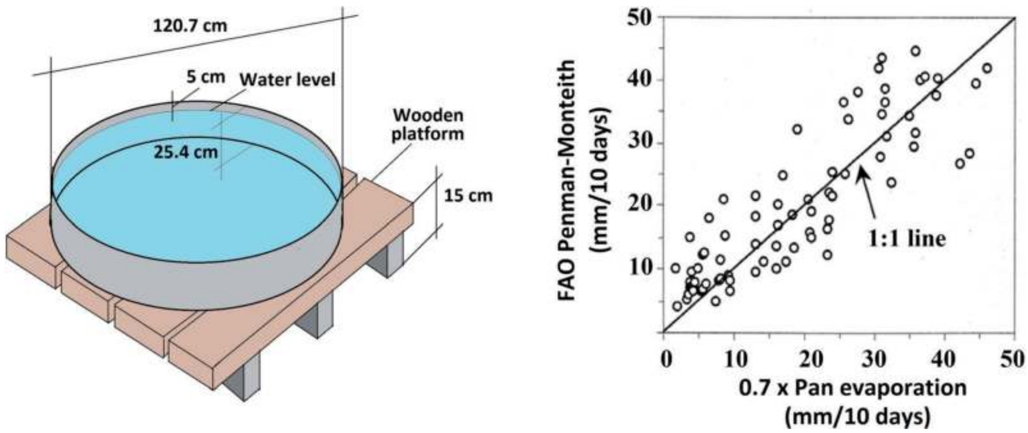

Figure 6.
Measuring of evaporation from Class A pan (left) and the relationship between FAO Penman-Monteith and pan evaporation (right) [90].

5.2 Crop water requirement

Plant water consumption is the sum of the water lost by evaporation and transpiration. Numerous methods have been developed for estimating plant water consumption. These are such direct measurements, estimating from climate data, plant and soil-based methods. The FAO Penman-Monteith method [90] is one of the most reliable methods in estimating using climate data. The results obtained by multiplying the evaporation volumes determined from Class A pan with a coefficient of 0.7 were analyzed together with the plant water depletion values estimated at 10-day intervals by the FAO Penman-Monteith method. In the results obtained, it was determined that the agreement was very high (**Figure 6**).

5.3 Effective root depth of cotton

Soil water potential is related to the soil texture and is important to determine the available water holding capacity (AWHC) at the effective root depth considered. The results of some studies on plant root morphology in recent years have revealed that a significant part of the cotton roots is concentrated at 0–30 cm and an average of 90% is at a depth of 60 cm [91]. For this reason, when determining the irrigation interval in cotton cultivation on lands with medium and heavy-textured soil, an effective root depth of 60 cm and allowing a maximum of 60% of the available water to be consumed is a suitable approach to ensure yield and quality without creating water stress on the plant.

The irrigation schedule is determined by considering the plant water consumption, the AWHC of the soil, and the part of the soil moisture that is allowed to be consumed. In terms of AWHC, soil texture is generally decisive and sandy soils have less capacity than clay soils. Sandy soils have an AWHC of 20–35 mm, medium-textured loamy soils 45–65 mm, and heavy-textured clayey soils 40–50 mm for each 30 cm soil profile.

5.4 Irrigation methods in cotton cultivation

The irrigation method is the way of applying water to the plant root zone. Today, two main methods are used, namely surface and pressurized.

5.4.1 Surface irrigation

Surface irrigation methods generally take place in the form of vertical and forward movement of water by gravity on land with no slope or very low slope (generally below 3%). These methods generally take place in the form of vertical and forward movement of water by gravity on land with no slope or very low slope (generally below 3%). In practice, furrow and border methods and their derivatives are widely used in cotton cultivation. Reducing in-field losses in the irrigation network is related to the irrigation method applied. The success of these methods depends on the reduction of water transmission in the channels and infiltration into the field and surface flow losses. Surface flow and infiltration losses are the most important problems in surface irrigation methods. These methods cause drainage problems by rising the groundwater in the field, the root zone remains wet for a long time, negatively affecting plant growth, and increasing fungal diseases, tillage, salinity, and sodium problems. Along with the deep infiltration, a significant part of the plant nutrients as fertilizer to the root zone is washed and pollutes the groundwater. The mixing of nitrogen losses, especially in the form of nitrates, into drinking and utility water is the biggest threat to human and environmental health.

5.4.2 Pressured irrigation methods

Pressurized irrigation systems use energy (such as electricity, diesel oil) to take water from a canal, stream, or well and transmit it to the land to be irrigated through lateral lines under a certain pressure. Irrigation water is directed to the lateral lines from the main canal at the head of the field and given to the root zone by various methods (such as drip or sprinkler methods).

5.4.2.1 Drip irrigation

Drip irrigation is the process of taking the water from a well, canal, or stream and giving the filtered water to the plant root zone in the field with a certain pressure (1–1.5 atm.) using plastic pipes called lateral and having drippers placed on it at certain intervals. With this method, it is possible to transmit irrigation water to the root zone in a controlled manner by the drip method and high WUE (85–95%). With successful planning, it is ensured that water, plant nutrients, and agricultural pesticides are supplied, and significant savings are achieved in labor, energy, and time. Thanks to the vertical and horizontal control of water, high efficiency and quality products can be obtained with an appropriate irrigation schedule.

Today, in the drip method, two types can be used by placing the lateral lines above ground and underground (30–35 cm from the surface). In the drip method, two types can be used by placing the lateral lines above ground and underground (30–35 cm from the surface).

The arrangement of the lateral lines in drip irrigation affects the irrigation water requirement and therefore the energy cost. In the application of one lateral line in two rows (**Figure 7a**), the required lateral line requirement per hectare is 7140 m. It may be necessary to irrigate for 24–36 hours, especially in the first irrigation, to bring soil moisture to the field capacity throughout the 60 cm effective root depth in medium and heavy-textured lands in hot and arid regions where cotton is grown in the Mediterranean climate. During the following 75–80 days irrigation period, half of the initially calculated water can meet the need if it is every 6–8 days. The condition

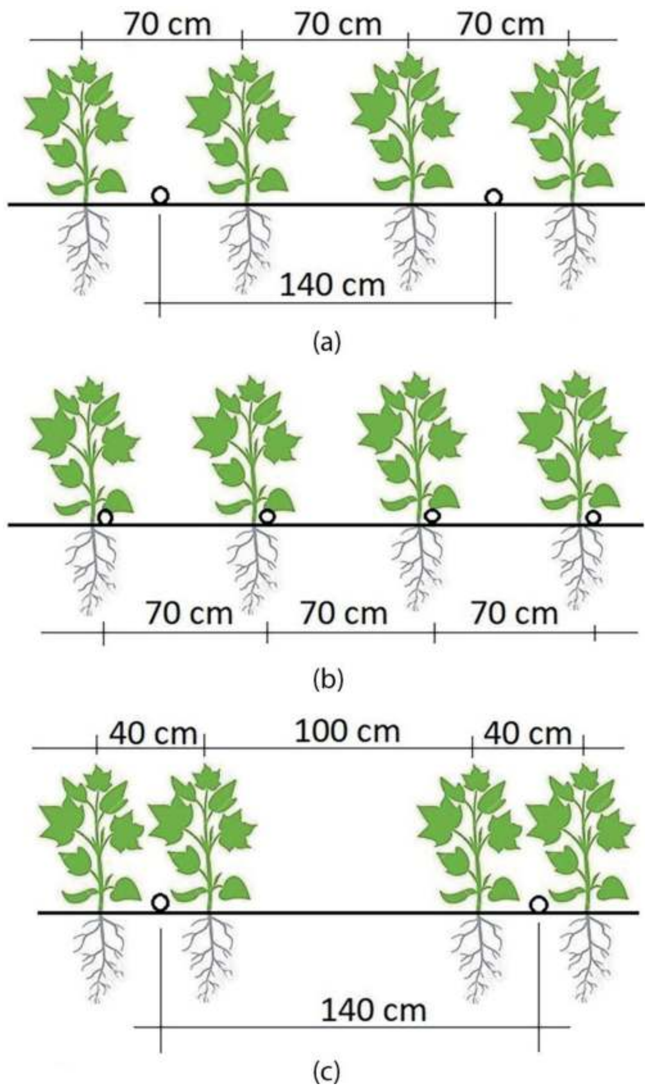

Figure 7.
Representation drawing of drip irrigation lateral positions in field systems. Systems are defined as follows: (a) surface one lateral line in two rows, (b) surface every row, and (c) surface twin rows (adapted from [92]).

of high yield and quality cotton cultivation in the calculated irrigation intervals depends on the application of the program that will not cause water stress in the root zone. This application, which will be repeated 12–14 times during the irrigation period, requires an average of 600–750 mm of plant water consumption. Generally, in dry climatic regions, the calculated amount of irrigation water may be needed to meet plant water consumption. With a motor pump with an average water application rate of 50 m^3/h, it is necessary to irrigate for an average of 120–150 hours per hectare throughout the year. During the irrigation period in the specified land, the diesel requirement per hectare is 204–255 liters and the average is around 265 US dollars for 2022 in Turkey.

Applying a lateral line to each row (**Figure 7b**), the lateral line requirement is 14280 m per hectare. In this application, lateral lines are placed in each row and adjacent to the plant. At the beginning of the irrigation period, it is sufficient to irrigate for a maximum of 10–12 hours in order to bring the soil moisture at 60 cm depth to the field capacity in medium and heavy-textured lands. During the following 75–80-day irrigation period, it will be sufficient to irrigate for a maximum of 5–6 hours at intervals of 6–8 days on average. During this process, which will be repeated 12–14 times during the irrigation period, the annual irrigation water volume is an average of 3000–3500 m^3/year per hectare. With a motor pump with a water application flow rate of 50 m^3/hour, the annual irrigation period is 60–70 hours, and the energy consumption is approximately 102–119 liters of diesel fuel. The cost of irrigation energy per hectare of the land in question is an average of 122 US dollars in Turkey.

The cost of lateral line planting in twin rows (**Figure 7c**) in cotton cultivation is the same as when planting a line in two rows (**Figure 7a**). In contrast, the cost of irrigation water and energy will be close to or slightly higher than the line-up (**Figure 7b**) per row. Although this method is not a common practice yet, it will provide significant savings, especially in irrigation water. It is a method that can provide significant water savings without causing a decrease in yield and quality in sowing in narrow and wide intervals by adjusting the planter's feet with a telescopic planter in sowing. Especially with wide row spacing, it will be possible to use pesticides, foliar fertilization, and defoliants effectively with agricultural machinery until the end of the harvest period.

5.4.2.2 Sprinkler irrigation

This system is the process of applying the water supplied by pumping from a water source to the land by spraying it with sprinkler heads at a certain operating pressure. The water source can be a well, canal, or stream. In general, after the irrigation water is taken from the source, it is conveyed to the main lines under pressure varying between 1.5 and 5 atmospheres and then to the sprinkler heads on the lateral lines. The sprinkler method has a very high-water application efficiency (Ea, 60–95%) and uniform water distribution with proper planning. It is a method that can be used for

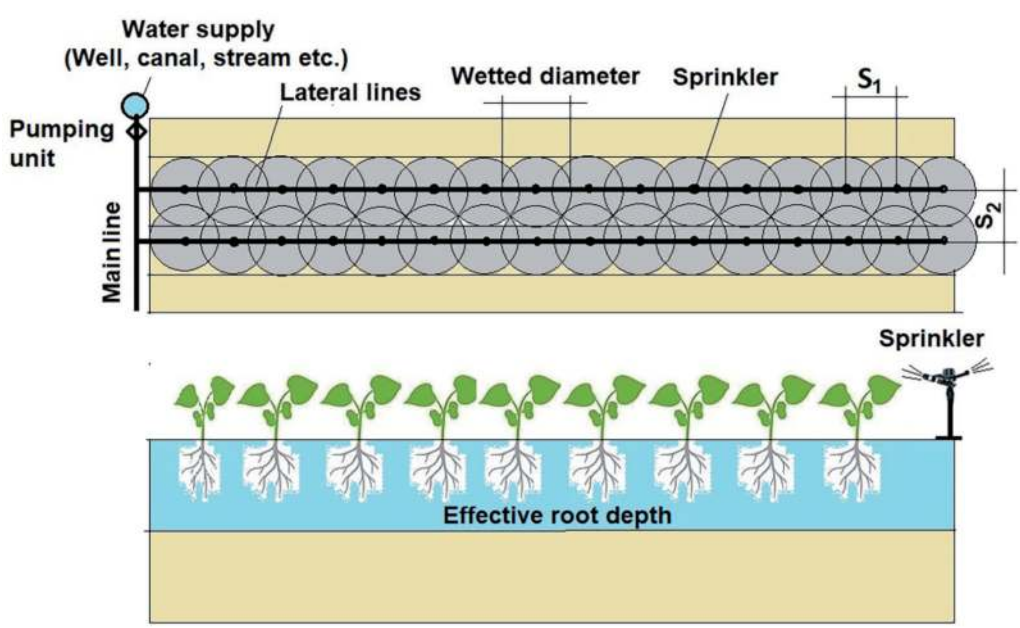

Figure 8.
Sprinkler irrigation system elements [93].

irrigation of all plants whose leaves are not sensitive to wetting in all kinds of field conditions. The factor limiting the application of this method is the wind. When placing the lateral lines on the land, it is essential to pay awareness to the fact that the effective winds in the region are perpendicular to the direction of movement.

The sprinkler system (**Figure 8**) can be immobile, mobile (linear or circular), and portable in the field.

In the design and operation of the sprinkler system, a higher precipitation rate than the infiltration rate of the soil is not desired. For this, the system's placement arrangement (S_1xS_2), nozzle (sprinkler) discharge, and operating pressure must be evaluated together. In practice, the fact that the precipitation rate is higher than the water intake rate of the soil causes the accumulation of water by ponding and drainage problems in flat topography, while surface runoff may occur in areas with slightly sloped topography. Therefore, it is crucial to pay attention to the selection of sprinkler heads with a high-water application efficiency in sprinkler irrigation.

6. Pesticide management

6.1 Weed control

Weed control in cotton is generally done in three periods: pre-sowing, pre-emergence, and post-emergence [94]. After the herbicides used before planting are applied to the field with a sprayer, they are mixed into the soil at a depth of 8–12 cm using a rotavator or cultivator. In this period, herbicides containing Pendimethalin, Metalochlor, and Benoxacor active ingredients can be used [95].

Pendimethalin, Alachlor, Fluometuron, Prometryne, and Linuron active ingredient herbicides can be used for weed control in the post-sowing and pre-emergence period. If there is no rain within 24 hours after the application, the effectiveness of the herbicides decreases due to evaporation. For this reason, it is useful to ensure that the herbicides infiltrate to a depth of 15–20 cm by making sprinkler irrigation after the pre-emergence applications [96].

Clethodim (116.2 g/L), Fluazifop-P-Butyl (125 g/L), Haloxyfop ethoxyethelester (125 g/L), Quizalofop + P/Ethyl (50 g/L), and Quizalofop/P/Tefuryl (40 g/L) active ingredients can be widely used in post-emergence herbicide applications. However, it is the best way to choose according to the weeds we want to control during this period [97].

6.2 Insect control and management

There are seven main issues that must be followed in order to be successful in the fight against pests. These are respectively, 1-diagnosis, 2- fighting method, 3-application time, 4-pesticide selection, 5-tool selection, 6-application, and 7-control [97]. In a plant protection process to be applied, it is easily possible to achieve success when these are applied in the order of the management. If someone makes a mistake, such as a wrong or incomplete application, not following the order, it brings failure or causes success to be caught by chance.

The periods in which the insects, which are commonly encountered in cotton and have the highest damage potential, are effective according to the development periods of the plant are given in **Table 7**.

Growth stages	Emergence	Seedling	The First Squares	The First Flowers	Green Boll	Opening Boll
Insects/Weeks	3	6	9	12	15	18
Agrotis spp	X					
Aphis gossypii		X	X	X		
Bemisia tabaci	X			X	X	
Empoasca decipiens		X	X			
Earias insulana					X	
Frankliniella intonsa				X		
Helicoverpa armigera			X	X	X	
Pectinophora gossypiella				X	X	
Spodoptera exigua			X			
Spodoptera littoralis		X			X	
Tetranychus cinnabarinus				X	X	
Thrips tabaci		X				

**Adapted from [98].*

Table 7.
Common pests and emergence periods in cotton during the growing season.*

6.3 Disease control and management

Disease management in agriculture is the practice of minimizing disease in crops to improve the quantity or quality of harvest yields [99]. Organisms such as fungi, bacteria, and viruses that cause infectious diseases can be found in plants. Effective disease management should be integrated into farm management, focusing on the host, potential pathogen, and environment. The way to reduce the risks of epidemics is through the adoption and implementation of disease management strategies. It is useful to have knowledge of the types and origins of diseases to implement solution-oriented management strategies [100]. Disease management in plants is based on several important principles. While disease control is often impractical or even possible, it may be possible to reduce disease progression and keep it at an acceptable level. Disease management has basic principles such as exclusion, eradication, protection, resistance, therapy, and avoidance [101]. Each of these principles helps in deciding the method and method of the application according to the course of the disease, its prevalence, severity, degree of effect, the area affected, the recurrence status, and risks. For example, exclusion includes applications to remove disease-causing pathogens from the disease-free area, so that the disease can be prevented from entering the area where the plants grow. Eradication is such as the destruction of infected plants, disinfection of storage areas, fumigation, and solarization. Cultural practices such as removing diseased plants from the environment, destroying crops, and crop rotation can also be evaluated within this scope. Conservation practices include the protection of the elements that cause the spread of the disease with physical and chemical barriers. Cultural practices such as tillage, irrigation, and drainage are within this scope. In addition, applications such as determining the planting date or depth, distances between plants, pruning, and thinning due to disease risks, for example, are applications that help plants get away from infection and reduce the severity of diseases. Practices such as soil drainage and ridge planting, especially the cultural management of root diseases, are also conservation practices. Selecting and developing resistance, disease-resistant plants is a viable way to reduce losses. It has been determined that this application is especially successful in rust diseases, powdery mildew, and root rot. With some hybridization techniques in plant breeding, the effect of pressures on yield can be controlled by increasing the rust resistance of plants [102].

The main diseases in cotton cultivation are seedling root rot, verticillium, and fusarium wilt, leaf angular spot disease. Those diseases, which can lead to significant yield and quality losses if no precautions are taken, can be resolved with an integrated management approach. Integrated disease management is a concept that enables the application of one or more of the abovementioned applications in combination and should be applied in a coordinated, integrated, and harmonious manner to maximize the benefits of each component.

7. Plant growth regulators

Plant growth regulators (PGRs) affect many physiological events such as flowering, maturation, root development, bending and death of leaves, stems, and other organs, inhibition or advancement of stem elongation, the coloration of fruits, and prevention of foliation or defoliation, prevention of overgrowth, earliness, and plants themselves. Chemicals produced by the effects of PGR boll seed cotton weight, 100 seed weight, ginning yield, plant height, the number of fruit branches, 100 seed weight, the number of bolls, fiber fineness, and fiber rupture strength were determined by research [103].

It has been observed that the prevention of excessive grading in cotton, the lengthening of the distance between the nodes due to the sowing frequency, the increase in boll, boll holding, and yield [104]. Positive effects of Mepiquat Chloride (Pix) have been observed in terms of its effects on the abovementioned properties. Between the beginning of flowering and the peak of the flower or from the beginning of the boll, it is recommended to apply 3–4 applications at 25–50 ml/da with 10–15 days intervals. Mepiquat Chloride is 45–60 days from October when the first white flowers appear on a small number of plants. The first application should be made before the first watering in days. The second application is 20 days after the first application in 65–80 days. It is done on days to encourage the plant to produce mostly fruit, together with the green parts. The third application is 85–100 days after emergence for the plant to complete its development at an average of 14–16 nodes. Although it varies according to the regions and the variety, the estimated post-emergence is 100–120. The fourth and last application, which is recommended to be done on days, is aimed to complete the growth of green parts, maturing the bolls, and harvesting earliness. With this application, it is encouraged to increase the cotton core and fiber quality [105].

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Active ingredient	Dosage (L/ha)	Effect
DE-4-Thidiazuron, 119 g/L+ Diuron, 60 g/L	0.6	Defoliant
Pyraflufen, 26.5 g/L	0.16	Defoliant
Carfentrazone-ethyl, 240 g/L	0.15	Defoliant
Ethephon, 480 g/L	3	Boll Opener and Defoliant
Ethephon 480 g/L+ Cyclanilide, 60 g/L	2	Boll Opener and Defoliant
Ethephon 720 g/L +Cyclanilide, 45 g/L	1.75	Boll Opener and Defoliant

Compiled from [106, 110].

Table 8.
Some chemicals used as boll opener and defoliant in cotton.*

8. Boll openers and defoliants in cotton

Manufacturers who will use chemical pesticides before cotton harvest must determine issues such as “chemical selection,” “management time,” and “management dose.” There are three different methods to determine the most appropriate application time for defoliating and boll-opening chemicals. These are: (a) the boll opening rate should be at least 65–70%, (b) 85% of the bolls to be harvested should be mature, and (c) the number of knuckles on the cracked boll should be 4 or less [106].

The boll opening rate is determined by counting the bloomed and unopened bolls from 20 randomly selected plants representing the field [107]. Early and clean harvest with the use of defoliant or boll-opening chemicals, prevention of rotting of the lower bolls, especially in places where the humidity is high and high humidity, prevention of fiber contamination. It has benefits such as reduction. To get rid of the harmful effects of chemicals, the bolls must be at least 35–40 days old [108]. Depending on the nature of the plant, environmental conditions such as temperature and humidity, and the chemicals used, the leaves begin to fall 3–7 days after the application of the defoliant, and the defoliation process takes place after 10–14 days [109]. Early varieties can be harvested approximately 10 days after application. During the application of chemicals, the sprayer must be calibrated, 200–250 liters of water should be used per hectare; If there is an expectation of rain within 24 hours after the application, if the daily average temperature is below 17 ^{0}C, the application should not be made, and suitable conditions should be expected; care should be taken not to spread the chemical to the surrounding plants, it should not be used on other plants other than cotton. A suitable chemical should be selected according to the purpose. If only defoliation is aimed, a defoliant chemical should be used, if both defoliation and boll opening are aimed, defoliant + boll-opening chemicals should be used (**Table 8**).

9. Conclusion

In high-yield and quality cotton cultivation, the plant should not be exposed to any stress during the growing period. Problems such as extremely hot and cold climatic conditions, lack of water and nutrients in the soil, excessive nitrogen fertilizer applications, pesticide residues applied to the plant grown before, overdose in foliar fertilization, extreme and redundant use of pesticides, excessive and improper irrigation due to the need for drainage owing to the root zone remaining wet for a long time can affect cotton yield, quality, and sustainable management. Considering these problems, applications to be made in a timely manner, with appropriate mechanization, in sufficient quantities and as needed are the key to controlling the stress conditions relatively. Success in sustainable cotton production depends on increasing controllable conditions. Effective management in cotton production is possible with the control of water, nutrient, and pesticide management. In this respect, maximum water and nutrient management in the root zone is ensured thanks to the high application efficiency, especially with drip and sprinkler methods. In this way, it is conceivable not only to control productivity and quality but also to protect environmental resources caused by deep infiltration due to excessive applications. Therefore, success in controlling the events in the rhizosphere will be the determining factor of sustainable production in the future.

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References

[1] Hinze L, Kohel R. Cotton. In: Gupta S, editor. Technological Innovations in Major World Oil Crops. Vol. 1. New York, NY: Springer; 2012

[2] Khan MA, Wahid A, Ahmad M, Tahir MT, Ahmed M, Ahmad S, et al. World cotton production and consumption: An overview. In: Ahmad S, Hasanuzzaman M, editors. Cotton Production and Uses. Singapore: Springer; 2020. DOI: 10.1007/978-981-15-1472-2_1

[3] Park JH, Kyung WO, Hyung-Min C. Preparation and characterization of cotton fabrics with antibacterial properties treated by cross-linkable benzophenone derivative in choline chloride-based deep eutectic solvents. Cellulose. 2013;**20**(4):2101-2114. DOI: 10.1007/s10570-013-9957-8

[4] Soth J, Grasser C, Salerno R. The Impact of Cotton on Fresh Water Resources and Ecosystems: A Preliminary Analysis. Gland, Switzerland: Worldwide Fund for Nature; 1999

[5] OECD/FAO. Agricultural Outlook 2021-2030. Paris, France: OECD Publishing; 2021. p. 337. DOI: 10.1787/19428846-en

[6] Martini X, Kincy N, Vaughn K, Dever J, Nansen C. Positive association between thrips and spider mites in seedling cotton. Agricultural and Forest Entomology. 2013;**15**(2):197-203. DOI: 10.1111/afe.12004

[7] EJF. The Deadly Chemicals in Cotton, Environmental Justice Foundation in collaboration with Pesticide Action Network UK. London, UK: Emmerson Press; 2007

[8] Gill HK, Garg H. Pesticides: Environmental impacts and management strategies. In: Larramendy ML, Soloneski S, editors. Pesticides—Toxic Aspects. London: IntechOpen; 2014. DOI: 10.5772/57399

[9] Sainju UM, Ghimire R, Pradhan GP. Nitrogen Fertilization I: Impact on crop, soil, and environment. In: Rigobelo EC, Serra AP, editors. Nitrogen Fixation. London: IntechOpen; 2019. DOI: 10.5772/intechopen.86028

[10] Oosterhuis DM. Development of a cotton plant. In: Seagull R, Alspaugh P, editors. Cotton Fiber Development and Processing, an illustrated overview. Lubbock, TX: International Textile Center, Texas Tech University; 2001

[11] Freeland T, Pettigrew W, Thaxton P, Andrews G. Agrometeorology and cotton production. World Meteorological Organization. 2011;**10**(1):1-128

[12] Oosterhuis DM. In: Nitrogen Nutrition of Cotton. Miley WN, Oosterhuis DM, editors. Growth and Development of a Cotton Plant. Practical Issues, Chapter 1. 2015. p. 1-24. DOI:10.2134/1990.nitrogennutritionofcotton

[13] Gorman C. Mixing It Up—Crop Rotation In The Mid-South. 2020. Available from: https://www.cottonfarming.com/feature-story/mixing-it-up-crop-rotation-in-the-mid-south/

[14] Bowers CG, Collins CA, Harris EP. Low Soil Moisture Planting of Cotton for Optimum Emergence. Applied Engineering in Agriculture. 2006;**22**(6):801-808. DOI: 10.13031/2013.22248

[15] Aydemir M. Cotton Breeding, Cultivation Technique, and Fiber Properties (in Turkish). Ministry of Agriculture and Rural Affairs, General Directorate of Cotton Affairs. Nazilli, Aydın: Nazilli Cotton Research Institute, Publication No: 33; 1982

[16] Unger PW, Baumhardt RJ. Factors related to dryland grain sorghum yield increases 1939 through 1997. Agronomy Journal. 1999;**91**:870-875. DOI: 10.2134/agronj1999.915870x

[17] Traore O, Traore K, Bado VB, Lompo DJ. Crop rotation and soil amendments: impacts on cotton and maize production in a cotton-based system in western Burkina Faso. International Journal of Biological and Chemical Sciences. 2007;**1**(2). DOI: 10.4314/ijbcs.v1i2.39684

[18] Ahmad M, Khan MD, Sultan W, Hassan M, Austin N. Long-term cotton based crop rotation experimentation. In: Proceedings of the World Cotton Research Conference-2. Athens, Greece; 1998. pp. 377-378

[19] Kato M, Kobayashi K, Ogiso E, Yokoo M. Photosynthesis and dry-matter production during ripening stage in a female-sterile line of rice. Plant Production Science. 2004;**7**(2):184-188. DOI: 10.1626/pps.7.184

[20] Gadana DB, Sharma PD, Selfeko DT. Effect of soil management practices and slope on soil fertility of cultivated lands in Mawula Watershed, Loma District, Southern Ethiopia. Advances in Agriculture. 2020;**2020**(8866230):13. DOI: 10.1155/2020/8866230

[21] Ahmed N, Ali MA, Danish S, Chaudhry U, Hussain S, Hassan W, et al. Role of macronutrients in cotton production. Cotton Production and Uses. 2020;**2020**:81-104. DOI: 10.1007/978-981-15-1472-2_6

[22] Kopittke PM. Interactions between Ca, Mg, Na and K: Alleviation of toxicity in saline solutions. Plant and Soil. 2012;**352**:353-362. DOI: 10.1007/s11104-011-1001-x

[23] Santos E, Pongrac P, Reis A, White P, Lavres JJ. Phosphorus-zinc interactions in cotton: consequences for biomass production and nutrient-use efficiency in photosynthesis. Physiologia Plantarum. 2019;**164**(4):996-1007. DOI: 10.1111/ppl.12867

[24] Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y, et al. Temperature increase reduces global yields of major crops in four independent estimates. Proceedings of the National Academy of Sciences of the USA. 2017, 2017;**114**(35):9326-9331. DOI: 10.1073/pnas.1701762114

[25] Seddaiu G, Porcu G, Ledda L, Roggero PP, Agnelli A, Corti G. Soil organic matter content and composition as influenced by soil management in a semi-arid Mediterranean agro-silvopastoral system. Agriculture, Ecosystems and Environment. 2013;**167**:1-11

[26] Havlin HL, Beaton JD, Tisdale SL. Fertility and Fertilizers—An introduction to nutrient management. 7th ed. New Delhi: PHI Learning Private Limited; 2010

[27] Chaudhry MR, Guitchounts A. Cotton Facts, International Cotton Advisory Committee, Technical Paper No. 25 of the Common Fund for Commodities. New York: The United Nations; 2003

[28] Rochester IJ. Phosphorus and potassium nutrition of cotton: Interaction with sodium. Crop and Pasture Science. 2010;**61**:825-834. DOI: 10.1071/CP10043

[29] Silvertooth JC, Norton ER. Management of Fertilizer Nitrogen in Arizona Cotton Production. The University of Arizona Cooperative Extension; 2016. Available from: https://www.researchgate.net/publication/279500445

[30] Khan A, Wang L, Ali S, Tung SA, Hafeez A, Yang G. Optimal planting density and sowing date can improve cotton yield by maintaining reproductive organ biomass and enhancing potassium uptake. Field Crops Research. 2017;**214**:164-174

[31] Meng Q, Yue S, Chen X, Cui Z, Ye Y, Ma W. Understanding dry matter and nitrogen accumulation with time-course for high-yielding wheat production in China. PLoS One. 2013;**8**(7):e68783. DOI: 10.1371/journal.pone.0068783

[32] Xinhua Y. In-season side-dressing of urea and ammonium nitrate to cotton on no-till soils with high residual nitrogen and pre-plant nitrogen application. Open Journal of Soil Science. 2015, 2015;**5**: 276-286. DOI: 10.4236/ojss.2015.511026

[33] Leghari SJ, Wahocho NA, Laghari GM, Talpur KH, Wahocho SA, Lashari AA. Role of nitrogen for plant growth and development: A review. Advances in Environmental Biology (Jordon). 2016;**10**(9):209-218

[34] Groenveld T, Kohn YY, Gross A, Lazarovitch N. Optimization of nitrogen use efficiency by means of fertigation management in an integrated aquaculture-agriculture system. Journal of Cleaner Production. 2019;**212**:401-408. DOI: 10.1016/j.jclepro.2018.12.031

[35] Mahajan U. Drones for normalized difference vegetation index (NDVI), to estimate crop health for precision agriculture: A Cheaper Alternative for Spatial Satellite Sensors, Conference: International Conference on Innovative Research in Agriculture, Food Science, Forestry, Horticulture, Aquaculture, Animal Sciences, Biodiversity. Ecological Sciences and Climate Change (AFHABEC-2016). 2016

[36] Guan W. Effects of Nitrogen Fertilizers on Soil pH. Purdue: Purdue University Extension Service; 2016. Available from: https://vegcropshotline.org/article/effects-of-nitrogen-fertilizers-on-soil-ph/

[37] Wilfret GJ. Gladilolus. In: Larson RA, editor. Introduction to Floculture. Elsevier Inc., Academic Press; 1992. DOI: 10.1016/B978-0-12-437651-9.50001-4. ISBN: 978-0-12-437651-9

[38] Hickey MG, Stichler CR, Livingston SD. Using Petiole Analysis for Nitrogen Management in Cotton. Texas: Texas A&M University Extension Service; 1996. p. L-5156

[39] Havlin JL, Austin R, Hardy D, Howard A, Heitman JL. Nutrient management effects on wine grape tissue nutrient content. Plants. 2022;**11**:158. DOI: 10.3390/plants11020158

[40] Westcott M. Petiole Sap Analysis—A Ouick Tissue Test for Nitrogen in Potatoes. Montana State University Extension Service, Fertilizer Facts: June 1993, Number 5; 1992

[41] Kohlmeier M. Chapter 11—Minerals and trace elements. In: Second E, editor. Kohlmeier MBT-NM. San Diego: Academic Press; 2015. pp. 673-807

[42] Razaq M, Zhang P. Shen Hl (2017) Influence of nitrogen and phosphorous on the growth and root morphology of Acer mono. PloS one. 2017;**12**:e0171321

[43] Johan PD, Ahmed OH, Omar L, Hasbullah NA. Phosphorus transformation

in soils following co-application of charcoal and wood ash. Agronomy. 2021;**2021**:11. DOI: 10.3390/agronomy11102010

[44] Roy RN. Integrated plant nutrition systems—Conceptual overview. In: Proceedings of symposium on "Integrated plant nutrition management". Islamabad, Pakistan: National Fertilizer Development Center; 2000. pp. 45-48

[45] Lynch JP. Root phenes for enhanced soil exploration and phosphorus acquisition: Tools for future crops. Plant Physiology. 2011;**156**:1041-1049

[46] Singh V, Pallaghy CK, Singh D. Phosphorus nutrition and tolerance of cotton to water stress: I. Seed cotton yield and leaf morphology. Field Crops Research. 2006;**96**:191-198

[47] Rosolem CA, Helena R, Esteves SAF. Potassium supply to cotton roots as affected by potassium fertilization and liming. Pesquisa Agropecuária Brasileira. 2003;**38**:635-641. DOI: 10.1590/S0100-204X2003000500012

[48] Amtmann A, Troufflard S, Armengaud P. The effect of potassium nutrition on pest and disease resistance in plants. Physiologia Plantarum. 2008;**133**(4):682-691. DOI: 10.1111/j.1399-3054.2008.01075.x

[49] Krishnan K, Ngerong AA, Ahim K, Ahmed OH, Ali M, Omar L, et al. Mitigating potassium leaching from muriate of potash in a tropical peat soil using clinoptilolite zeolite, forest litter compost, and chicken litter biochar. Agronomy. 2021;**2021**:11. DOI: 10.3390/agronomy11101900

[50] Yang JS, Hu W, Zhao W. Soil potassium deficiency reduces cotton fiber strength by accelerating and shortening fiber development. Scientific Reports. 2016;**6**:28856. DOI: 10.1038/srep28856

[51] Fontana JE, Wang G, Sun R, Xue H, Pan X. Impact of potassium deficiency on cotton growth, development and potential microRNA-mediated mechanism. Plant Physiology Biochemistry. 2020;**153**:72-80. DOI: 10.1016/j.plaphy.2020.05.006

[52] Gormus O, Yucel C. Different planting date and potassium fertility effects on cotton yield and fiber properties in Cukurova region, Turkey. Field Crops Research. 2002;**78**:141-149. DOI: 10.1016/S0378-4290(02)00121-1

[53] Oosterhuis DM. Potassium management of cotton. In: Pasricha NS, Bansal SK, editors. Potassium for sustainable crop production. International Potash Institute Basel, Switzerland and Potash Research Institute of India; 2002. pp. 331-346

[54] Tiwari KN. Diagnosing potassium deficiency and maximizing fruit crop production. Better Crops. 2005, 2005;**4**:29-31

[55] Brosnan JT, Brosnan ME. The sulfur-containing amino acids: an overview. Journal of Nutrition. 2006;**136**(6 Suppl):1636S-1640S. DOI: 10.1093/jn/136.6.1636S

[56] Edwards PJ (1998) Sulfur cycling, retention, and mobility in soils: A review. Gen. Tech. Rep. NE-250. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 18

[57] Hawkesford MJ. Plant responses to sulphur deficiency and the genetic manipulation of sulphate transporters to improve S-utilization efficiency. Journal of Experimental Botany. 2000;**51**(342): 131-138. DOI: 10.1093/jexbot/51.342.131

[58] Singh R, Parul P, Prasad SM. Sulfur and calcium simultaneously regulate photosynthetic performance

and nitrogen metabolism status in as-challenged brassica juncea L. Seedlings, Frontiers in Plant Science. 2018;**9**:772. DOI: 10.3389/fpls.2018.00772

[59] Clarkson DT. Calcium transport between tissues and its distribution in the plant. Plant Cell Environment. 2006;**7**:449-456

[60] Thor K. Calcium—Nutrient and messenger. Frontiers in Plant Science. 2019;**10**:440. DOI: 10.3389/fpls.2019.00440

[61] Capaldi FR, Gratão PL, Reis AR. Sulfur metabolism and stress defense responses in plants. Tropical Plant Biology. 2015;**8**:60-73. DOI: 10.1007/s12042-015-9152-1

[62] Gao H, Wu X, Zorrilla C, Vega S, Palta E, Jiwan P. Fractionating of calcium in tuber and leaf tissues explains the calcium deficiency symptoms in potato plant overexpressing CAX1. Frontiers in Plant Science. 2020;**10**:1793. DOI: 10.3389/fpls.2019.01793

[63] Rahman M, Punja ZK. Calcium and plant disease. In: En Datnoff LE, Elmer WH, Huber DM, editors. Mineral Nutrition and Plant Disease. Saint Paul, MN: APS Press; 2007. pp. 79-93

[64] White PJ, Broadley MR. Calcium in plants. Annals of Botany. 2003;**92**(4): 487-511. DOI: 10.1093/aob/mcg164

[65] Shaul O. Magnesium transport and function in plants: the tip of the iceberg. Biometals. 2002;**15**(3):309-323. DOI: 10.1023/a:1016091118585

[66] Zhang B, Cakmak I, Feng J. Magnesium deficiency reduced the yield and seed germination in wax gourd by affecting the carbohydrate translocation. Frontiers in Plant Science. 2020;**11**:797. DOI: 10.3389/fpls.2020.00797

[67] Jákli M, Tränkner M. Critical leaf magnesium thresholds and the impact of magnesium on plant growth and photo-oxidative defense: A systematic review and meta-analysis from 70 years of research. Frontiers in Plant Science. 2019;**110**:776. DOI: 10.3389/fpls.2019.00766

[68] Ryan MF. The role of magnesium in clinical biochemistry: an overview. Annals of Clinical Biochemistry. 1991;**28**:19-26

[69] Cazzola R, Della Porta M, Manoni M, Iotti S, Pinotti L, Maier JA. Going to the roots of reduced magnesium dietary intake: A tradeoff between climate changes and sources. Heliyon. 2020;**6**(11):e05390. DOI: 10.1016/j.heliyon.2020.e05390

[70] Tripathi D, Singh S, Singh S, Mishra S, Chauhan D, Dubey N. Micronutrients and their diverse role in agricultural crops: advances and future prospective. Acta Physiologiae Plantarum. 2015;**37**:1-14. DOI: 10.1007/s11738-015-1870-3

[71] Hajiboland R. Effect of micronutrient deficiencies on plants stress responses. In: Ahmad P, Prasad M, editors. Abiotic Stress Responses in Plants. New York, NY: Springer; 2012. DOI: 10.1007/978-1-4614-0634-1_16

[72] Saleem MH, Ali S, Kamran M, Iqbal N, Azeem M, Tariq Javed M, et al. Ethylenediaminetetraacetic acid (EDTA) mitigates the toxic effect of excessive copper concentrations on growth, gaseous exchange and chloroplast ultrastructure of Corchorus capsularis L. and improves copper accumulation capabilities. Plants. 2020;**9**(6):756. DOI: 10.3390/plants9060756

[73] Pal D, Dasog G, Bhattacharyya T. Secondary calcium carbonate in soils

of arid and semi-arid regions of India. In: Lal R, Kimble JM, Eswaran H, Stewart BA, editors. Global climate change and Pedogenic Carbonates. London: Lewis Publishers; 2000. pp. 149-185

[74] Rafique E, Rashid A, Bhatti A, Rasool G, Bughio N. Boron deficiency in cotton grown on calcareous soils of Pakistan. Boron in Plant and Animal Nutrition. 2002:357-362. DOI: 10.1007/978-1-4615-0607-2_35

[75] Morgan JB, Connolly EL. Plant-soil interactions: Nutrient uptake. Nature Education Knowledge. 2013;**4**(8):2

[76] Kodama N, Nishimuta M, Suzuki K. Negative balance of calcium and magnesium under relatively low sodium intake in humans. Journal of Nutritional Science Vitaminology (Tokyo). 2003;**49**(3):201-209. DOI: 10.3177/jnsv.49.201

[77] Brown P, Fernández V, Sotiropuolus T. Foliar Fertilization: The Facts and the Fiction. Paris, France: International Fertilizer Industry Association (IFA); 2013. ISBN 979-10-92366-00-6

[78] Xie R, Zhao J, Lu L, et al. Penetration of foliar-applied Zn and its impact on apple plant nutrition status: in vivo evaluation by synchrotron-based X-ray fluorescence microscopy. Hortic Research. 2020;**7**:147. DOI: 10.1038/s41438-020-00369-y

[79] Aziz MZ, Yaseen M, Abbas T, Naveed M, Mustafa A, Hamid Y, et al. Foliar application of micronutrients enhances crop stand, yield and the biofortification essential for human health of different wheat cultivars. Journal of Integrative Agriculture. 2019;**18**(6):1369-1378. DOI: 10.1016/S2095-3119(18)62095-7

[80] Çolakoğlu H, Çiçekli M. Foliar Fertilization Guide (in Turkish). Istanbul: Toros Tarım; 2016. p. 115

[81] Zonta JH, Brandão ZN, Rodrigues JIS, Sofiatti V. Cotton response to water deficits at different growth stages. Engenharia Agrícola, Rev. Caatinga, Mossoró. 2017;**30**(4):980-990. DOI: 10.1590/1983-21252017v30n419rc

[82] Tariq M, Yasmeen A, Ahmad S, Hussain N, Afzal MN, Hasanuzzaman M. Shedding of fruiting structures in cotton: Factors, compensation and prevention. Tropical and Subtropical Agroecosystems. 2017;**20**:251-262

[83] Mart C. Integrated production in cotton (in Turkish). Journal of Turkish Seed Growers Association; 2017;(21):42-44

[84] Enciso J, Hillyer C, Porter D, Fipps G. Irrigation Timing During Drought. Texas AM Agri Life Extension; 2019. Available from: https://cdn-ext.agnet.tamu.edu/wp-content/uploads/2019/07/EBN-015_-Irrigation-Timing-During-Drought_-Corn-Cotton-and-Sorghum-Furrow-Systems.pdf. [Accessed: 2022-02-10]

[85] Hall D, Cloud C, Porter W. Cotton Irrigation Termination. University of Georgia Extensive Service; 2020

[86] Ale S, Omani N, Himanshu SK, Bordovsky JP, Thorp KR, Barnes EM. Determining optimum irrigation termination periods for cotton production in the Texas high plains. Transactions of ASABE. 2020;**63**:105-115

[87] Ahmad F, Din S, Perveen A, Afzal MN. Investigating critical growth stage of cotton subject to water deficit stress. Iranian Journal of Plant Physiology. 2013;**4**(1):873-880

[88] Tronstad R, Silvertooth JC, Husman S. Irrigation termination of cotton: an economic analysis of yield, quality, and market factors. Journal of Cotton Science. 2003;7:86-94

[89] Sankaranarayanan K, Praharaj CS, Bandyopadhyay KK. Water management practices to improve cotton production. Model Training Course on "Cultivation of Long Staple Cotton (ELS)" December 15-22, 2007. Central Institute for Cotton Research, Regional Station, Coimbarote. 2007;**2007**:171-182

[90] Allen RG, Pereira L, Raes D, Smith M. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56. Rome, Italy: FAO; 1998

[91] Min W, Guo H, Zhang W, Ma L, Ye J, Hou Z. Root distribution and growth of cotton as affected by drip irrigation with saline water. Field Crops Research. 2014;**169**:1-10. DOI: 10.1016/j.fcr.2014.09.002

[92] Camp CR, Bauer BJ, Busscher WJ. A comparison of uniformity measures for drip irrigation. Transactions of the ASAE. 1997;**40**(4):1013-1020

[93] FAO. Irrigation Manual: Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation—Volume II Module 7. Harare: The Food and Agriculture Organization of the United Nations; 2002

[94] McGinty J, Kimura E, Dotray P, Morgan G, Byrd S. Weed Management in Texas Cotton. 2017. Available from: http://cotton.tamu.edu/Weed%20Management/2017%20Cotton%20Weed%20Control%203-15-2017.pdf

[95] Tariq M, Abdullah K, Ahmad S, Abbas G, Rahman MH, Khan MA. Weed management in cotton. In: Ahmad S, HasanuzzamanM,editors.CottonProduction and Uses. Singapore: Springer; 2020. DOI: 10.1007/978-981-15-1472-2_9

[96] Pala F, Mennan H. Determination of activity preemergence herbicides for weed control in cotton. International Plant Protection Congress (September 5-8, 2008 Konya), In: Cotton Production Under Abiotic Stress. 2016. pp. 257-288

[97] Singh K, Singh H, Singh K. Weed management in cotton with pre-and post-emergence herbicides. Indian Journal of Weed Science. 2016;**48**:348. DOI: 10.5958/0974-8164.2016.00090.3

[98] TAGEM. Pamuk Entegre Mücadele Teknik Talimatı (in Turkish). Ankara, Turkey: General Directorate of Agricultural Research and Policies; 2017. p. 106

[99] Davara D, Rajani V. Integrated disease management of cotton. Journal of Cotton Research Development. 2020;**34**(2):261-266

[100] Haq İ, Ijaz S. Plant Disease Management Strategies for Sustainable Agriculture through Traditional and Modern Approaches. Berlin: Springer International Publishing; 2020. DOI: 10.1007/978-3-030-35955-3

[101] Pscheidt JW, Ocamb CM. PNW Plant Disease Management Handbook. Oregon State University; 2021. 998 p. ISBN-13: 978-1931979214

[102] Ogle H, Dale M. Disease management: Cultural practice. In: Brown J, Ogle H, editors. Plant Pathogens and Plant Diseases. Armidale: Rockvale Publishers; 1997. pp. 390-404

[103] Soliman AS. Plant Growth Hormones. In: Vikas B, Fasullo M, editors. Cell Growth. London: IntechOpen; 2019. DOI: 10.5772/intechopen.84350

[104] Biles S, Cothren JT. Flowering and Yield Response of Cotton to Application of Mepiquat Chloride and PGR-IV. Crop Science—CROP SCI. 2001;**41**:1834-1837. DOI: 10.2135/cropsci2001.1834

[105] Çopur O, Demirel U, Karakuş M. Effects of several plant growth regulators on the yield and fiber quality of cotton (Gossypium hirsutum L.). Not. Bot. Hort. Agrobot. Cluj. 2010;**38**(3):104-110

[106] Stewart A, Edmisten K, Wells R. Boll openers in cotton: Effectiveness and environmental influences. Field Crops Research. 2000;**67**:83-90. DOI: 10.1016/S0378-4290(00)00093-9

[107] Ren Y, Meng Y, Huang W, Ye H, Han Y, Kong W, et al. Novel vegetation indices for cotton boll opening status estimation using sentinel-2 data. Remote Sensing. 2020;**12**:1712. DOI: 10.3390/rs12111712

[108] Leon RG, Wright DL, Brecke J. 2020 Cotton Defoliation and Harvest Aid Guide. 2021. Available from: https://edis.ifas.ufl.edu/publication/AG188

[109] Gormus O, Kurt F, EL Sabagh A. Impact of defoliation timings and leaf pubescence on yield and fiber quality of cotton. Journal of Agricultural Science and Technology. 2017;**19**:903-915

[110] Beyyavaş V. The effect of different harvest aiding chemicals on yield and yield components of cotton (Gossypium Hirsutum L.). Applied Ecology and Environmental Research. 2019;**17**(2):2733-2743. DOI: 10.15666/aeer/1702_27332743