Is Cotton a Water-Guzzling Crop? Some Principles of Cotton Water Relations

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Water availability is potentially one of the most limiting abiotic factors for profitable cotton production. Cotton appears to be well adapted to the production of lint under a range of water regimes and is therefore able to be grown in areas throughout the world with variable rainfall and limited water for irrigation. However, adequate soil moisture through the correct timing of irrigation or precipitation events is essential for the successful commercial production of cotton. This article refers to the information presented in the cotton webinar of the WCRC-7 Monthly Plenary Lecture Series and will discuss four aspects related to water relations in cotton:

1. Water and cotton: myths or facts or misinformation?
2. How cotton deals with water availability for its growth and development
3. The main limitations for cotton production and physiological processes involved
4. Agronomical practices to circumvent water stress.

Water and cotton: myths, facts or misinformation?

There are several different sources and estimates on water consumption in cotton production worldwide. However, different stakeholders take different positions related to water use and impacts. Having reliable data makes our analysis and position stronger whether the information represents a myth, fact or misinformation. Websites and media usually take different positions related to water use in cotton:

- Negative impact on environment
- Competition for water with other cash crops
- Sustainability issues related to water wastage and energy usage
- Compromise of irrigation water with potable drinking water needs

The cotton community will have to decipher which actions it needs to develop to inform, adopt and include within the community regarding water in cotton production. It is necessary to keep working together to improve national public policies. Concerns are not limited to cotton production; they encompass water usage in all sectors including agriculture, industry, transport, infrastructure and household activities. Water is definitely essential for life and must always be part of the agenda for sustainability.

The reduction of the waterwater footprint of cotton was discussed in the Third Open Session at the 75th ICAC Plenary Meeting held in Islamabad, Pakistan, in 2016. Cotton has been criticised for the intensive use of water in its production and processing, even though 52.4% of the global cotton area is grown under rainfed conditions and the volume of water used in cotton production is only half that of rice and sugarcane.

Irrigated wheat, rice and maize consume 15%, 13% and 10% of the global irrigation water respectively, while cotton consumes about 3% (Hoekstra et al, 2011). Other sources indicate that cotton uses 1.5% of global irrigation water used in agriculture. Irrigation use differs from season to season over the years; therefore accuracy of available information from one season to the next one is essential. The environmental variability between seasons holds the key to the dynamics of crops under irrigation or rainfed and to quantify water usage.

The distribution of cotton worldwide varies across climatic regions (arid, semiarid and humid regions). The xerophytic adaptation of cotton confers a unique characteristic on water relations of the crop that is unusual if not unique among field crops. In addition, in many countries, cotton farms are located in the most extreme and water-limited environments compared to other commercial crops.

Irrigated cotton extends through America, the Mediterranean, North Africa, Asia and Australia. On the other hand, rainfed cotton is mostly located in South America, the United States, sub-Saharan Africa and India. Between these extremes, cotton is produced with supplementary irrigation (semi-arid and humid regions) in India, Australia and regions of North America (Hearn, 1994).

Cotton productivity is generally linked to irrigation facilities and availability of water when the crop needs it the most. However, higher yields are not only attributed to water, but also to the technology applied in terms of seed, management programs, irrigation systems and others.

How many litres of irrigation water do we need to produce 1 kg of lint? The ICAC data (ICAC Cotton Databook 2020) shows that an average of 1,931 litres of water were used to produce 1 kg of lint. However, information on various websites available refers to 7,000 to 29,000 litres of water to produce 1 kg of lint. These values often include green (rain) water and grey (decontamination) water. However, the estimates differ significantly, highlighting the importance of having a consistent dataset of statistics around the world.

The percentage of rainfed cotton area around the world is about 52% and 41.3% of global cotton is produced without irrigation water (ICAC). This situation is likely to change year to year depending on environmental conditions, water availability and rainfall occurrence. In some cases, supplementary irrigation might be needed. This also shows how challenging it is to produce cotton exclusively under rainfed conditions due to uncertain monsoon patterns and erratic rainfall distribution.

How cotton deals with water availability, How cotton grows and develops?

There are fundamental principles about water and cotton:

1. The xerophytic background shared with wild ancestors of cotton confers intrinsic adaptation to water deficit compared to other commercial crops.
2. Crop development stages influenced by water availability. This refers to the influence of water on cotton development with reference to the patterns of regular production of main stems, lateral fruiting branches, fruiting sites, abortions, fruit development and fibre development.Modern cotton varieties are indeterminate, with vegetative and reproductive development following an orderly and regular pattern. Vegetative growth is characterised by the successive development of the main stem (primary axis) nodes. A new node is produced every two to four days, depending on the temperature during growth (Hearn and Constable, 1984) and soil moisture availability. Axillary branches differentiate from the main stem. At the lower nodes, monopodial branches (similar to the primary axis) can develop, but from approximately the fifth main stem node and upward, only sympodial branches develop (Heitholt, 1999). Fruiting sites are produced at regular intervals, about every five to six days, along the fruiting branch (Hearn, 1994).
3. Growth physiological processes in response to water stress. This aspect is fundamental to understand when cotton is planted and how varying stages and amount of water availability can affect physiological aspects of the crop.

The concept of sensitivity to water stress (drought or waterlogging) related to crop stages is essential and includes intensity and duration of water stress. The definition of water stress includes weather vagaries, plant water content and soil moisture availability.

In terms of management, the cotton is different from most others that are normally grown as rotation crops within the farm. The water requirements and nutrient needs of cotton get accentuated during the peak boll formation stage, especially when boll-retention is high. Retention of fruits and squares greatly influences plant growth. Increased fruit retention on the plant is the best plant growth regulator for controlling plant growth. As the plant accumulates fruit load, vegetative growth slows down and finally ceases when bolls mature completely. As boll load increases, terminal growth and the production of new nodes slow and then cease. An appropriate balance between vegetative and fruiting development is essential for high yields.

Cotton is mainly cultivated to produce fibre. It is a smart plant that uses 2.25 times more energy to produce oil (seed) than cellulose (fibre). It is important to understand the target growth and development curve. This curve shows the accumulation of vegetative dry matter and the partitioning to reproductive fruiting parts. About 70% of the boll weight is accumulated after the termination of vegetative period. Any limiting situation that happens during this period with reference to heat, water and nutrient availability will be negative to cotton yield and quality. It is necessary to focus on water and nitrogen needs of the crop in this critical period in terms of agronomical management.

What does it take to obtain high yields? The population of plants per meter; the number of bolls retained per plant; and the fibre weight per seed should enhance yield and yield stability.

It is important to understand the critical stages of the crop to appreciate the effects of limiting environmental conditions on yields. The cotton plant undergoes a series of growth stages during the development from dormant seed to mature fibre. These stages are distinct but also overlap. When water supply is optimum, phenological development continues for a longer time, resulting in healthier plants and higher yields; when the supply is limiting, the opposite occurs. The key adaptation of the cotton plant is that when water supply starts to become limiting, the plant responds to stop further morphological development and focuses on the maturation of fruit already set. During the vegetative stage, the consumption of water is less at 2-3 mm per day compared to the medium and later stages when the crop needs 6-8 mm per day. Cotton needs 600-700 mm of water per plant, which translates to 6-7 million litres per hectare. Depending on the type of irrigation systems used, water use efficiency (WUE) varies from 0.4 to 0.8 (kg/m3) for drip irrigation; 0.5 to 0.6 for sprinkler and 0.6 to 0.9 for furrow irrigation. The evapotranspiration rate, plant available water and soil water content are key measurement parameters to monitor and predict cotton performance (Paytas, 2013).

Figure-1 Regulating soil moisture through plastic mulches

Figure-2 Regulating soil moisture through plastic mulches

Figure-3 Aerial view of the experimental fields at INTA

Figure-4 Experiments at INTA to understand the effects of water stress on cotton under field conditions

The main limitations for cotton production and physiological processes involved

Cotton productivity can be negatively impacted by water scarcity caused by drought or flooding conditions caused by excessive rains or flood irrigation.

Drought stress

Experiments were carried out at INTA Reconquista (Argentina) to understand the effects of water stress on cotton under field conditions, using plastic mulches between rows and rainout shelters to ensure that a water-limiting factor was created. A soil-moisture meter and other equipment were used to characterise physiological processes such as photosynthesis, stomatal conductance and water potential on plants.

While cotton has a xerophytic background, the crop generally requires enough water to allow about 700 mm of evapotranspiration (transpiration plus soil evaporation) to prevent yield reductions. Scarcity of water in certain stages such as peak boll development phase can be critical for yields. Drought is defined by low soil water availability, and high evapotranspiration demand. Water stress occurs when the soil has less than 50% of field capacity. Cotton's response to stress varies on the stage of growth, the degree of stress and the length of time imposed.

When water stress was imposed during the vegetative stage, the following effects were observed:

- A reduction of plant population
- A reduction in vegetative dry matter
- Physiological processes involved in cell expansion and division were affected
- Reduction of yield due to an imbalance source to sink partitioning (about 6 kg fibre reduction per day of stress).

When the water stress was imposed during the flowering stage, the following effects were observed:

- Reduction of fruiting sites
- Abortion of flower buds
- Yield reduction and weak compensation (about 15 kg fibre reduction per day of stress);
- Poor-quality fibre.

When water stress was imposed during maturity stress, the following effects were observed:

- Boll size reduction
- Yield reduction (4-8 kg fibre reduction per day of stress)
- Early maturity
- Poor-quality fibre.

INTA conducts programmes on genetic improvement, genetic selection by molecular markers, mutagenesis for abiotic stress and higher ginning rate (ginning percentage). It is well documented that modern genotypes may show better water use efficiency (shorter period to maturity) than older genotypes (from the 80s for example).

Waterlogging

Excessive soil water availability during certain stages of the crop is considered waterlogging. Experiments were conducted at INTA Reconquista under simulated waterlogged field conditions using a non-drainage facility to study the effects of water logging on yields and fibre quality .

Cotton's response to stress varies on the stage of growth, the degree of stress and the length of time imposed. Yields were reduced by 16%-19% due to waterlogging during flowering in narrow row and conventional systems (Scarpin, 2017). Argentina produces mainly narrow row and high plant density systems.

If we consider a gradient of water available, we may understand that:

1. From excess moisture in soil, rank growth would happen.
2. From optimum irrigation towards increasing water stress, the first process affected is leaf expansion, followed by limiting fruiting sites and fibre length, with a decrease in carbohydrate production affected by weak photosynthesis and boll retention.

This situation will vary depending on the cotton stage. The sequence of the processes involved are related to crop sensitivity, starting at a cellular level, following a growth rate, leaf area index and light interception, finally affecting cotton yield. This explains the results of the experiments (shared previously) from the physiological point of view as to how varying water stress at different stages of development affects cotton yields.

As soon as available soil moisture starts to decrease, leaf expansion is the first affected and then photosynthesis. Leaf expansion will limit the sink and source assimilate relations and negatively affect fruit retention. When plants suffer a period of water deficit, leaf water potential will be affected, with reductions in photosynthesis and later on (if the stress continues) the translocation assimilates.

Long-term results of a few seasons are important to understand variability in terms of evapotranspiration rates and rainfall. A significant decrease in yield occurs in some years when the soil water deficit increases with higher evaporative demands. Thus, water management strategies vary year to year.

Agronomical practices to circumvent water stress in cotton

Appropriate agronomical practices are necessary to circumvent limiting situations for a better water use efficiency. A few such practices are listed below:

1. Crop rotation and cover crops
2. Zero tillage
3. Fertilization at sowing and pre flowering
4. Planting geometry / crop configuration
5. Sowing dates
6. Crop regulations
7. Integrated pest management
8. Integrated fibre management

The following strategies can help to achieve sustainability of cotton production systems:

- Incorporation of concepts like soil health and management, drainage systems and water-saving irrigation systems.
- Conducting further research to integrate different management aspects for cotton and other crops within the rotation for each region of production.
- Strengthening regional genetic improvement programs to obtain high yielding varieties well adapted to sub-optimal conditions and with improved water-use efficiency.
- Conducting research on cotton physiology with specific emphasis on stress physiology in each production region and the diverse environmental conditions.
- Developing training for farmers and other cotton supply chain stakeholders on aspects related to cotton production under abiotic stress.

- Invest in meteorological stations to get online historical and daily basis data related to weather in a regional scale.
- Usage indicators to estimate water footprints of the whole cotton chain for sustainable production. The Delta Project will help with indicators of sustainability.

Finally, some key important messages:

Modern varieties may have higher water use efficiency

Other commercial crops use, in some cases, more amount of water than cotton

Outstanding advances in research around the world allow us to understand water relations and efficiencies

Advanced technologies are available to enhance water use efficiency within and outside the farm

Sustainable cotton programs and existing indicators to be used for auditing and to develop actionable plans

Key statistic information must be made freely available and training of cotton stakeholders on sustainability is essential.

References

Hearn, A. B. Constable, G.A., 1984. Irrigation for crops in a sub-humid environment: Evaluation of irrigation strategies for cotton. Irrigation Science 5:75-94.

Hearn, A. B., 1994. The principles of cotton water relations and their application in management. En: World Cotton Research Conference. pp. 66-92.

Heitholt J. J. 1999. Cotton: Factors associated with assimilation capacity, flower production, boll set, and yield, in: D. L. a. H. C. Smith (Ed.), Crop Yield, Physiology and Processes, Springer.

Hoekstra, A. Y., Chapagain, A, Mekonnen, M, Aldaya, M. 2011. The Water Footprint Assessment Manual: Setting the Global Standard. Routledge, 2011 - 203 p.

Paytas, M. J., Ploschuk, E. L., 2013. Cultivos Industriales. Algodón. In: Aires., U.d.B. (Ed.), Cultivos Industriales, pp. p. 413-445.

Scarpin, G. J., Paytas, M., 2017. Respuesta de rendimiento y calidad de fibra del algodón al estrés por anegamiento. Revista Voces y Ecos N° 38. Diciembre 2017. ISSN 0328-1582.

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