water footprint network

A guide to reducing the water footprint of cotton cultivation in India

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April 2017

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The current study was funded by C&A Foundation and results will be used by C&A business.

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1 Introduction

Separating the lint from the boll, Vellitiruppur, Erode, Tamilnadu.
Source: Indiawaterportal.org (July, 2012)

Few industries have the impact that the textile sector has had on the world. Globally, an average of almost 10,000 litres of water is necessary to produce 1 kilogram of cotton fabric, with approximately 2,500 litres needed for a standard 250-gram cotton t-shirt [1]. Water is a key natural resource for the textile sector as its supply chain is both dependent upon the availability and quality of water, and its use creates an impact on those water resources through consuming and polluting water. The textile sector increasingly faces water availability and quality issues in its global supply chain.

Reductions in the consumption and pollution of water resources in cotton cultivation will lead to greater water security for farmers and are necessary for water use to be sustainable, efficient and equitable.

The Water Footprint Network has been supporting C&A in developing a deeper understanding of water consumption and pollution arising from raw materials production and garment processing. This has been done through quantifying the water footprint of raw materials and processing, assessing the sustainability of these water footprints and recommending strategic response options which will reduce the water footprint and make it more sustainable. Three studies have been completed: “C&A’s Water Footprint Strategy: Cotton Clothing Supply Chain’[2], ‘Grey Water Footprint Indicator of Water Pollution in the Production of Organic vs. Conventional Cotton in India’[3] and “Toward sustainable water use in the cotton supply chain: A comparative assessment of the water footprint of agricultural practices in India”[4].

1.1 Water and cotton in India

India has 18% of the world's population with only 4% of the total usable water resources. The annual water availability per capita of India has already been decreased by 15% from 1,816 m^3/capita in 2001 to 1,545 m^3/capita[5] in 2011. Most water sources in India are contaminated by sewage and agricultural runoff. The National Water Policy[6] has identified the following water challenges of the country, amongst others:

- Large parts of India have already become water stressed.
- Issues related to water governance have not been addressed adequately. Mismanagement of water resources has led to a critical situation in many parts of the country.
- Water resources projects, though multi-disciplinary with multiple stakeholders, are being planned and implemented in a fragmented manner without giving due consideration to optimum utilization, environment sustainability and holistic benefit to the people.
- Growing pollution of water sources is affecting the availability of safe water besides causing environmental and health hazards.
- Low consciousness about the overall scarcity and economic value of water results in its wastage and inefficient use.

India has been producing cotton for textiles for thousands of years and the textile industry and cotton play an important role as well in the Indian economy. India is the second largest producer of cotton in the world (after China), producing around 26% of the world’s cotton. It also has the largest area under cotton cultivation in the world, representing about 36% of the world area under cotton cultivation[7]. The export value of cotton of India in 2015 was 3231.57 million USD, about 0.16% of the country’s GDP in 2015[8]. Cotton in India provides direct livelihood to 6 million farmers and about 40-50 million people are employed in cotton processing and trade[9].

Whilst cotton agriculture is an important sector in India, due to variety of cotton grown in India (Hybrids with long duration), much of its production uses water inefficiently, relies on the use of pesticides which harm human health and ecosystems, contributes to eutrophication through mismanagement of nutrients, depletes soil health and even though it provides work for many farmers, in many cases, those livelihoods are marginal at best. Due to the limitation on the legal size of landholdings and succession laws, theallcotton farmers in India are smallholders. Farmers’ knowledge of and skills in proper management of materials inputs (water, crop nutrients, pesticides, herbicides), farming technologies and techniques, and farming practices are key factors to increasing yields while reducing negative environmental and social impacts.

Smallholder farmers have limited knowledge and skills on good agricultural practices with limited access to basic information and training largely due to failure of extension services and complicated external regulatory environment. Therefore, there is an urgent need for capacity building for cotton farmers in India.

Companies selling products using cotton fibres, e.g., apparel retailers, are recognising that they face physical, regulatory and reputational risks associated with the environmental (including water), economic and social issues of cotton production. Water is increasingly seen as a limiting factor for cotton production, therefore, sustainably using water – improving water productivity and reducing water pollution – is vital to securing the sustainability of the cotton sector given the already highly strained condition of water resources in India.

Currently, water and land productivity of cotton production in India (measured as the volume of cotton production per unit of water or land used) is low due to sub-optimal utilization of agronomic measures that can reduce inputs (e.g., water, fertilisers, pesticides, etc.) and/or increase outputs (crop yield). At the same time, due to a high volume and inefficient use of pesticides and fertilisers in cotton fields in India, surface and groundwater sources are being contaminated heavily due to leaching of these pollutants from the fields. Both factors contribute to a higher water footprint of cotton production.

Rockström *et* al[10] point out that the large observed differences between farmers' yields and attainable yields globally cannot be explained by differences in rainfall. Rather, they are a result of differences in water, soil, and crop management. Several studies (Rockström *et* al.[10] and Kijne *et* al.[11]) reveal that there are large opportunities to improve yields through better water management practices on the ground, and consequently reduce the green, blue and grey water footprint of cotton production. Crop yield can also be significantly increased by applying better agronomic practices[12] such as soil preparation, mulching, fertiliser application, selection of better cultivars, short duration cultivars etc.

India has diverse agro-ecological zones. The zones differ in climate, soil type and financial means to implement a certain measure. Therefore, it must be noted that region-specific measures and strategies are essential to achieve the best results.

1.2 Water footprint

The water footprint is an indicator of how much fresh water is being used to produce goods, such as cotton, in volumes of water consumed and/or polluted. The water footprint includes three components.

- The blue water footprint is the amount of fresh surface or groundwater used to grow a crop or produce goods or services. It is the amount of water evaporated, incorporated into the product or returned to a different location or in a different time from where and when it was withdrawn.
- The green water footprint is the total rainfall or soil moisture used to grow plants. It is relevant for products that include agricultural crops and wood and other forestry inputs; where it refers to the quantity of water either evapotranspired by plants or incorporated into the harvested crop, or both.
- The grey water footprint is a measure of pollution. It is expressed as the volume of water required to assimilate the pollutant load to meet ambient water quality standards. The pollutant that requires the largest assimilation volume is referred to as the critical pollutant and is used to calculate the grey water footprint; if there are both surface and groundwater discharges, the grey water footprint for each discharge is calculated separately.

The water footprint can be measured for a single process such as growing cotton, for a product such as a pair of jeans, for a producer such as a textile wet processing factory, or for an entire multi-national company and in this case, the water footprint is measured in volumes of water per unit of production, e.g., cubic metres per tonne and measures the productivity of water use.

Both arable land and water are limited. Reducing the green, blue and grey water footprint per tonne of cotton uses these scarce resources wisely. Maximizing efficiency of both land and water is a requisite part of sustainable cotton cultivation.

The water footprint can also measure the total amount of water consumed and polluted by industry, domestic water supply and agriculture in a geographic area such as a river basin or a whole country. This is measured in cubic metres per year and can be used to understand the sustainability of water use.

The geographic water footprint provides insight into the potential for specific agricultural practices to contribute to an increase or decrease of water scarcity and declining water quality.

The focus of this guidance document is to support farmers in taking appropriate feasible actions to reduce the environmental impacts of cotton production (water footprint reduction measured in cubic metres of water per hectare of land used) and to improve the economic efficiency of crop production by improving yields (water footprint reduction measured in cubic metres of water per tonne of crop produced. This can be achieved by either: 1) reducing the inputs required for plant growth over the growing season, e.g., water, fertilisers and pesticides; or 2) increasing the outputs from the farm field by increasing yields, or both.

Whilst not directly addressed in this guidance document, it is important to consider also the cumulative impact that cotton production has on freshwater resources. Improving water and land productivity can only contribute to more sustainable use of local water resources if there is also a reduction in the volumes of water consumed or polluted by all water users.

This guidance document has been developed for use by those involved in training and capacity building of farmers, e.g. experts at agriculture extension services and other organisations helping farmers improve their agricultural practices. The guidance presented here can help farmers understand why, how and when they can minimise the water footprint of cotton farming in their fields. Every farm is different; the agricultural practices presented here should be taken individually or in combination to maximise yields while minimising the environmental impacts. i.e., the water footprint, of cotton cultivation.

2 Key stages in cotton farming

Organic cotton boll, Vellitiruppur, Erode, Tamilnadu.
Source: Indiawaterportal.org (July, 2012)

Before planting, decisions must be made on the type of farming system that will be used by the farmer. These decisions set the course of farming and are defined by the various options available to a farmer. Some options are influenced by issues under the direct control of a farmer such as finances, capacity and skills of the farmer and technologies used in irrigation, some may depend on the availability of enabling institutions (farmers' association, extension services, etc.) and irrigation facilities and coverage, while the rest depend on the availability of water supplies to the farms e.g., the amount of reliable rainfall during farming period, other water using activities in the river basin where the farm is located, etc.

The guidance document is presented in the sequential order from a farmer's perspective (Figure 1). The stages of cotton farming addressed in the guidance document include land-preparation, planting, growing and harvesting. The specific farming practices within each stage are grouped together as shown below.

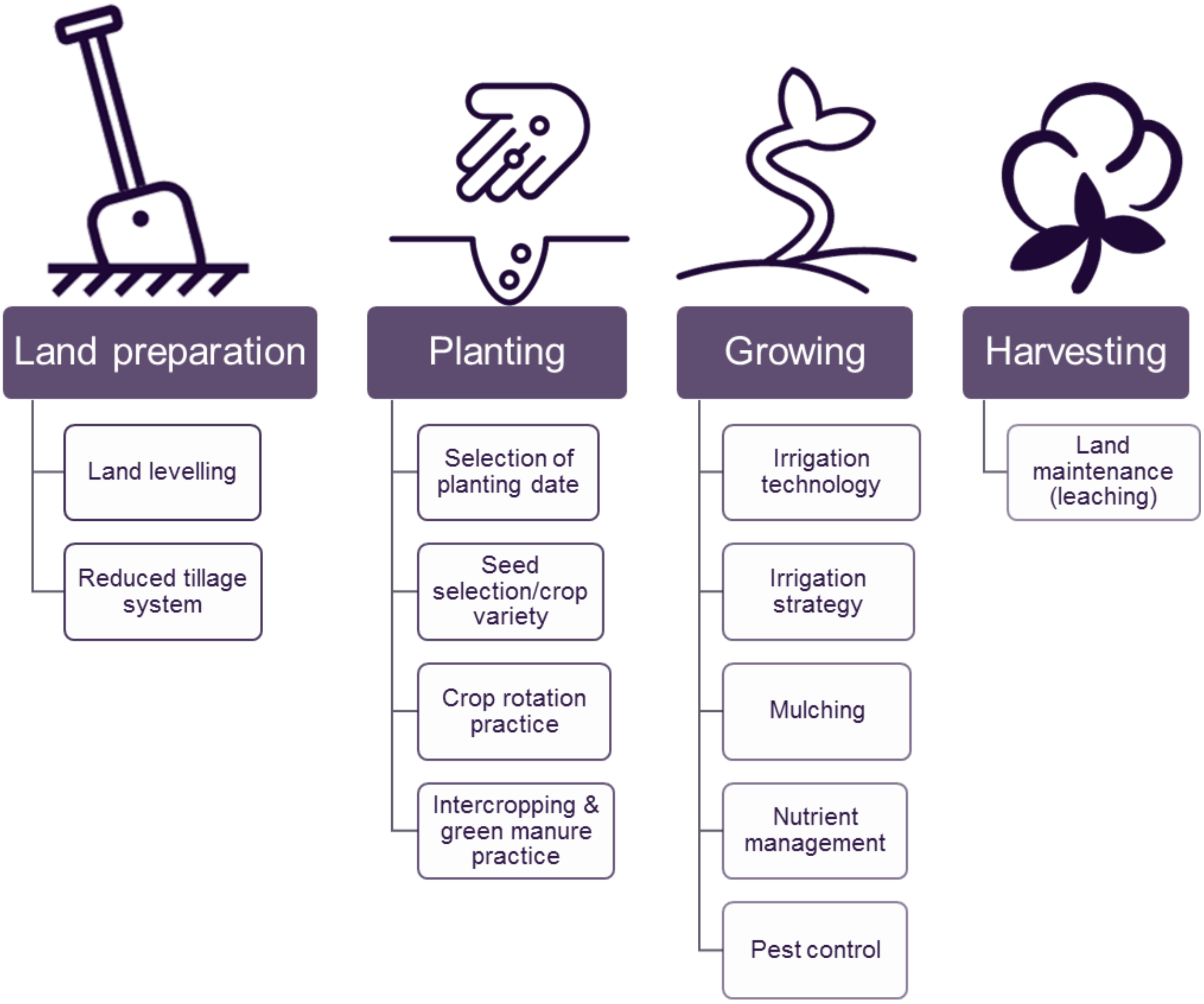

Figure 1. Key stages and potential farming practices available to a cotton farmer.

Each section begins with a brief description of various agricultural practices and options available followed by the impact of each action on the green, blue or grey water footprint and crop yield. Each action's contribution to reducing the water footprint or increasing yield is highlighted with icons (Figure 2). In the final section of the document, an overview of relevant actions specific to each of the components of water footprint (in cubic metres of water per hectare) and yield improvements (in tonnes per hectare) is presented separately in a set of four tables.

Figure 2. Icons used to indicate the impact on the green, blue and grey water footprint and crop yield.

3 Farming type

A farmer sprays pesticide in a cotton field at Pandharkawada in Maharashtra.
Source: Raj K Raj / HT Photo

The three farming types to consider are:

- Conventional farming
- Organic farming
- Hybrid farming

Conventional farming: Conventional farming is the standard practice that is used extensively, employing a combination of mostly synthetic agrochemicals for pest control and fertilisers and has the least restrictions in terms of the chemicals used. While quantities of sustainably produced cotton are increasing, approximately 90% of all cotton is grown conventionally[13]. Conventional cotton uses about 16% of the world's insecticides and 7% of pesticides, while grown on 2.5% of arable land[14]. In 2000, a49% of the global cotton field is irrigated[15] . Conventional farming can look different from farm to farm and in different geographies as there are no guiding principles compared to the other practices. Spraying of chemicals is often done on an extensive scale on all plants, timed according to a prescriptive schedule. Conventional farming can be rainfed or irrigated.

Organic farming: Organic farming is a form of agriculture that uses techniques such as crop rotation, compost, and biological pest control, leading to improved ecosystem and soil health[16]. Organic farming also makes use of fertilisers and pesticides, including herbicides, insecticides and fungicides, so long as they are derived naturally and within the guidelines of the organic certification. Organic production forbids the use of any synthetic inputs and the organic inputs tend to be more readily assimilated by the natural ecosystem. Farms must ensure these standards for two to three years before being eligible for organic status and must maintain these standards to comply with the certificate.

Hybrid farming: Hybrid approaches to cotton farming have been developed with the aim to improve environmental, social and economic sustainability in cotton cultivation. These programmes often provide farmer capacity building and cover a range of issues including soil, water and pest management, as well as decent work practices. Environmental sustainability is improved through reduction of toxic chemical inputs, increased water efficiency, improved soil health and biodiversity, intercropping and using natural/ organic fertilisers and pesticides. Socio-economic sustainability of cotton cultivation is improved by Increasing the productivity of farmers by reducing input costs and increasing yields, thereby improving their profitability and their livelihoods. These programmes may also offer farmer finance and business management training, gender empowerment, supply chain mapping, supply chain conventions and procurement support to brands and retailers.

The grey water footprint decreases in general from conventional to hybrid to organic production practices. The average grey water footprint for conventional farm can be more than five times than in organic farming[17]. A detailed study by Water Footprint Network for C&A [17] shows that for the growing season 2013-2014 the grey water footprint decreased from conventional to REEL (a type of hybrid farming practice) and organic production. the average grey water footprint of conventional systems was 18 times, and the average grey water footprint of the REEL system 4.2 times larger than that of the organic system. It was also found that the pesticides Endosulphan and Cypermetrine led to large grey water footprint values in conventional farming due to their high toxicity[17]. Currently by the order of Supreme Court Bench, the production licences granted to the manufacturers of endosulfan till further order is to be frozen[18].

There are significant differences in the water footprint and yields depending on the agricultural practices used as is shown in Figure 3; the largest differences were in the grey water footprint.

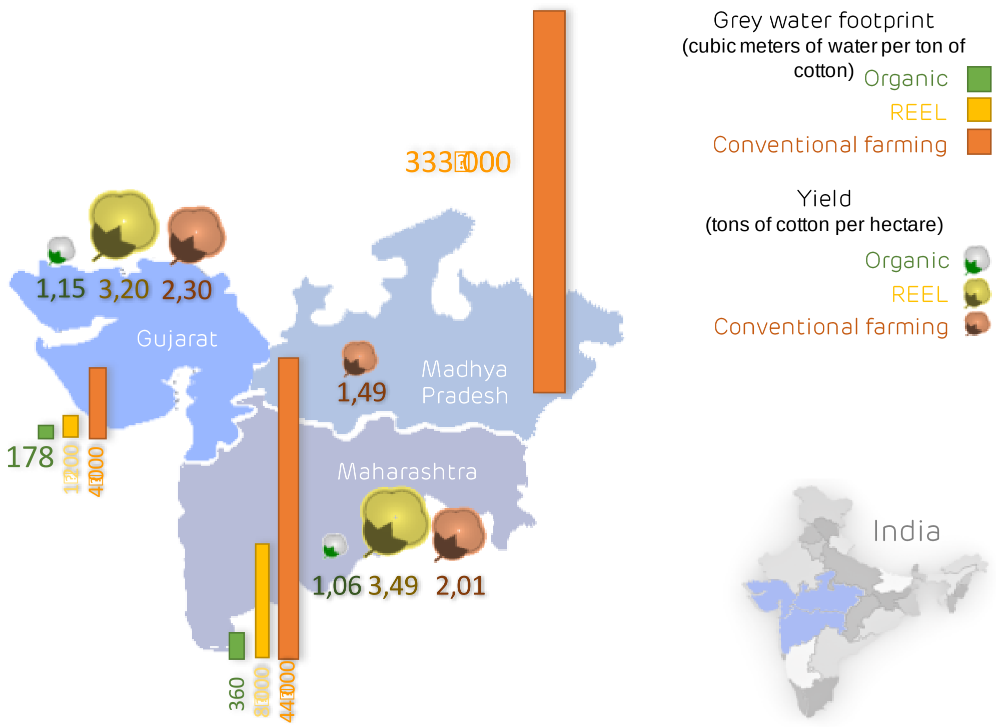

Figure 3. Comparison between the grey water footprint and crop yield for conventional, organic and hybrid farms in three states in India.

In general, it is best to strive for a transition towards organic farming for a substantial reduction in the grey water footprint in cotton fields. However, there may be reductions in crop yield, particularly in the early years. This transition period and its impacts on economic viability of the farm system must be addressed. The hybrid farming type is a good compromise for reducing the environmental impact of cotton farming while maintaining farmer livelihoods.

4 Land preparation

Source: http://www.eoi.es/blogs/mavisasare/;
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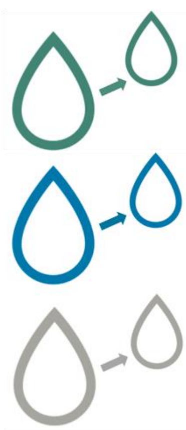
The two agricultural practices to consider in the land preparation stage are:

- Land levelling, contour and ridge farming
- Reduced tillage

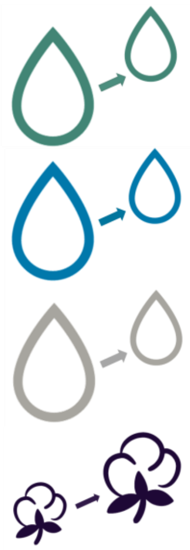
4.1 Land levelling, contour and ridge farming



Undulating topography is the second most important factor in reducing the crop yield of rainfed cotton[19]. Better land levelling can achieve good results both in terms of savings in the water and time required to irrigate fields. It improves the efficiency of the application of irrigation water and makes it easier to apply fertilisers efficiently. Contour, furrow and ridge farming helps capture rainfall for longer, increasing soil moisture and reduces the loss of fertilisers from the fields.

Land levelling maintains soil moisture (either from rainfall, irrigation or both) and reduces unproductive evaporation and runoff from the field reducing the green and blue water footprint components.

4.2 Reduced tillage system



Reduced tillage or no tillage minimises soil disturbance and, thus, reduces soil erosion and the runoff of particulate nutrients. It improves water infiltration and increases organic matter that helps to keep a suitable soil moisture content, which can result in better yields and less leaching of nutrients. It also controls weed growth, reducing the need for herbicides. Deep ploughing once in two to three years is beneficial in controlling deep-rooted weeds and to destroy pest larvae or cocoons. Deep ploughing/sub-soiling once in two years before cotton sowing was found effective in increasing the yield of irrigated cotton Similarly, pre-plant herbicide application and one pass of harrow and two inter-row cultivation for early and late season weed control, respectively, was found to be a viable technology for cotton growers of Central India[20].

Increased soil moisture retention will reduce the green and blue water footprint and reduced soil erosion and runoff of nutrients will reduce the grey water footprint. The downside of reduced tillage is that due to the build-up of Phosphorus (P) content in top soil and crop residues at the soil surface, the losses of dissolved Phosphorus may increase the grey water footprint.

5 Planting stage

Hand dibbling of cotton seeds
Source: krishijagran.com

The four agricultural practices to consider in the planting stage are:

- Selection of planting date
- Seed selection
- Crop rotation
- Intercropping and green manure

5.1 Selection of planting date

Selection of planting date has a profound impact on crop yield. For the best results, before sowing, the field must have a minimum soil moisture content. Detailed knowledge of the rainfall regime at a given location is an important prerequisite for agricultural planning and management. This is more so for rainfed agriculture, as rainfall is the single most important agro-meteorological variable influencing crop production. However, the planting dates are often dictated by rainfall patterns and their reliability leading to sowing later than recommended periods.

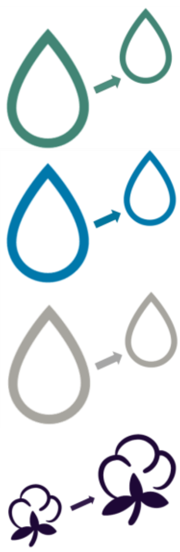
For fully rainfed farms, the best period for sowing cotton in India is from 15 June to 5 July. With supplementary irrigation, the planting dates could be one month earlier. Full irrigation gives flexibility to plant the cotton seeds from mid-May in northern India, to late-May in southern India. Recommended planting dates and impacts are presented in Table 1.

Table 1. Recommended planting dates, impacts and remedial measures for yield gain for cotton in India.

Type of production	Best planting date*	Impact
Rainfed	15 June – 5 July	Beyond 15 July, in general in India, the yield can drop substantially up to 40-50% resulting in a substantial increase in the overall water footprint of the crop production.
Supplementary irrigation	15 June – 15 May	Increase in crop yield resulting in: lower blue water footprint compared to full irrigation; and, overall reduction in the water footprint due to increased yield.
Full irrigation	Mid-May (northern India) & Late-May (southern India)	Increase in crop yield resulting in reduced water footprints, but relatively higher blue water footprint compared to the above two practices.

*Note: The best planning dates are largely decided by the advent of the monsoon, however it also depends on the number of sunshine hours available in different geographic regions in India.

5.2 Seed selection

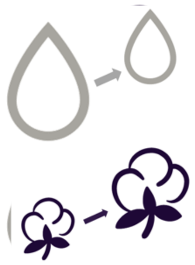


Crop variety plays a role in stabilising the yield at the same time impacting crop water requirements. A suitable crop variety can impact the overall water footprint in multiple ways such as reducing transpiration without lowering the yield and stabilising the yield despite adverse conditions that can lead to reduction in crop yield, e.g., drought tolerance, resistant to water logging, salinity resistant varieties, etc. Though more than 1500 hybrids of genetically modified cultivars were released in India by the Ministry of Environment & Forest (Genetic Engineering Approval Committee), due to a lack of through testing some of the cultivars are susceptible to producing a downward spiral of impacts such as susceptibility to pests leading to increased pesticide use.

Intensive research is on-going regarding breeding and genetically modifying seeds to develop varieties that are best suited for a given environment, coping with pests and are both high yielding and optimized in terms of water and nutrient use. Central Institute for Cotton Research[21] (CICR) provides the most recent information on the newest developments regarding crop improvement and provides recommendations regarding the choice of cotton crop varieties for a given region in India, In the absence of any specific study on the comparison of impacts of one particular variety over other varieties with respect to the crop yield and water use, it is suggested to use the recommended crop variety for regions of India from CICR[22].

The green and blue water footprint can be reduced by using improved crop varieties that reduce transpiration. The grey water footprint is reduced with varieties that are pest resistant due to less demand for pesticide use. Some crop varieties will increase yield and climate resilient variety could stabilise crop yields.

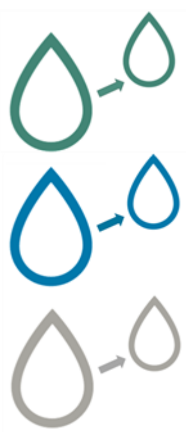
5.3 Crop rotation



Crop rotation is a practice of growing different crops in succession. Crop rotation has a positive effect on soil fertility and helps control pests. It is a good agronomy practice that can either reduce, or at least maintain the current level of the grey water footprint of crop production due to reduction in the application of pesticides. It also increases crop yields. However, in India, the practice of crop rotation is not getting due attention, which is leading to soil loss, reduced soil fertility and increased pests and pest types.

A CICR[23] study shows that the long-term effect of nutrient management with cotton-sorghum rotation out-yielded cotton monocrop by 38%. One study found that cotton-sorghum, cotton-sunflower and cotton-red gram rotations to be effective in keeping pests below the Economic Tolerance Level (ETL)[24]. The frequency of crop rotation or the substitute crop types and their contribution to water footprint reduction will need to be tested at the farm level, however, as a general guidance an annual rotation of crops with different root systems is recommended[25].

5.4 Intercropping and green manure



Monoculture, i.e., planting only one crop at a time, is the most common practice used by farmers. It has strong negative impacts on soil fertility in the long run. In a monoculture system, there is a lack of diversity that reduces key biological functions available in a diverse cropping regime. Over time, monoculture imbalances the insect population, deteriorates soil structure due to a single root penetration in the field, reduces fertility due to absence of naturally Nitrogen fixing plants such as legumes, improves soil structure, etc. Increased insect infestations may require the use of more herbicides, insecticides, bactericides and reduced soil fertility may require more fertilizers to be applied, both increasing the grey water footprint.

As there is less ground cover in monoculture fields, the retention of soil moisture is poor, and there is increased risk of topsoil washing off thereby reducing land fertility and increasing soil particles loading to the rivers. This increases the grey water footprint of monoculture farming compared to that for intercropping farming. As an alternative to monoculture, intercropping can improve soil moisture retention and reduction in unproductive evaporation due to increased soil cover resulting water footprint reduction. It provides crop residue (green manure) that can be incorporated into the soil to improve soil nutrients and build a favourable soil structure.

6 Growing stage

Photo credits: Jane Kahler, CSIRO

The five agricultural practices to consider in the growing stage are:

- irrigation technologies
- Irrigation strategies
- Mulching
- Nutrient management
- Pest control

6.1 Irrigation technologies

The five irrigation technologies to consider are:

- Surface flooding
- Sprinkler irrigation
- Furrow irrigation
- Drip irrigation
- Subsurface drip irrigation

About 65-70% of the cotton production area in India is rainfed[19]. Whilst the farms in India may be receiving plenty of rain in the form of monsoons, there can still be dry spells between rain events. Rainfed cotton yields are generally low due to erratic and uneven rainfall. In India, cotton suffers from water stress at the crucial phase of boll development on 70% of rainfed areas. At the same time, even in rainfed farming there may be a substantial gap between the existing crop yield and the attainable yield. With better management practices, e.g., high density planting, Bt-varieties, conservation tillage, plastic mulching, canopy management, square and boll retention, precision input management, etc., yields can be increased by 700-1100 kg per hectare[26]. As there is no irrigation water used in rainfed systems, there is no blue water footprint of the cotton produced on these farms.

Unproductive evaporation in irrigation systems can first occur due to evaporation from reservoirs/dams and canals that are conveying irrigation water to the farm field. This can be reduced with measures at the system level and may extend beyond the reach of a farmer's direct actions. With better practice of conveyance and application, water losses should be not higher than 15% of the fresh water diverted by the reservoir. If there is not sufficient irrigation water available, a farmer can either opt for partial irrigation to all his crop lands, or to fully irrigate a portion of his land and rely on rainfall on the other portion.

Extensive simulation using a crop water productivity model for different irrigation technologies indicate that the blue water footprint reduces from sprinkler to furrow, to surface drip, to subsurface drip. The reduction potential is in the order of 35-65% in blue water demand. With sophisticated drip irrigation the freshwater demand of cotton could be reduced to 7,000 litres per kilogram of lint cotton[27].

Whilst drip irrigation may not increase yield relative to well-managed furrow, sprinkler or even surface flooding systems, the practice of sprinkler and surface irrigation may result in water wastage, i.e. non-beneficial use as the irrigation water evaporates rather than contributing to crop growth through transpiration. Irrigation technology in the order of degree of investment needed and level water footprint reduction are presented in Figure 4.

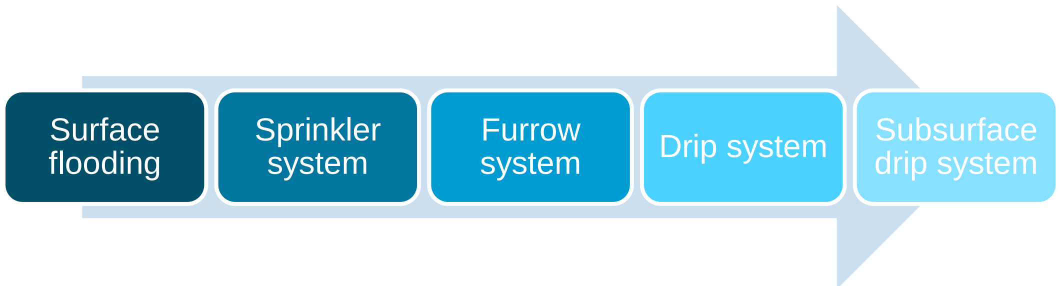


Figure 4. Irrigation technology in the order of increasing investment and decreasing blue water footprint.

6.1.1 Surface flooding

Most irrigation systems in cotton production rely on the traditional technique of surface flooding – fresh water is taken out of a river, lake or reservoir and transported through an open canal system to the place of its consumption and applied as a sheet of water with the help of gravity to spread over the land. Losses of fresh water occur through evaporation, seepage and inefficient water management. Due to open and standing water on the top of the soil, unproductive evaporation is highest in this irrigation system when compared to other technologies. Hence, the blue water footprint is high relative to other irrigation techniques. With proper technology and water management strategies, these unproductive losses could be minimised to some extent. The water demand is also high due to percolation from the inefficient application of water.

6.1.2 Sprinkler irrigation

Sprinkler irrigation is a method of applying irrigation water that mimics natural rainfall. Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small water drops that fall to the ground. Unproductive evaporation can be reduced by using technologies such as LESA (low elevation spray application) and MESA (mid-elevation spray application). As a farmer would have more control over managing the application of water, sprinkler irrigation is better than surface flooding with respect to water demand.

6.1.3 Furrow irrigation

Furrow irrigation is a type of surface irrigation in which water is released into the furrows, often using gravity, and it seeps vertically and horizontally to enrich the soil moisture. Best management practice in furrow irrigation (short furrows, ideal slope, fast application) may lead to reduced evaporation and hence reduced blue water footprint when compared to surface flooding and sprinkler irrigation systems.

The blue water footprint can be further reduced through the practice of alternate furrow irrigation, which consists of irrigating every other furrow of a field, whereby the off furrow is left dry. Alternate furrow irrigation results in a reduction of water application, hence, reduction of blue water footprint, without significantly affecting yield and thereby leading to more efficient water use.

6.1.4 Drip irrigation

Drip irrigation systems commonly use tubes that are placed on the soil surface next to the crop to apply irrigation water with high precision. Due to the application of water nearer to the root zone of the crop, the unproductive evaporation from the surrounding land is avoided. The water use efficiency of irrigated cotton with drip irrigation was found to be 60% higher than that with furrow irrigation[28] in Uzbekistan.

By means of simulations with a crop water productivity model, a WFN study[17] of 702 cotton farms in India found that drip irrigation would lead to a reduction of the blue water footprint by 37-63% for individual farms when compared to furrow irrigation.

6.1.5 Subsurface drip irrigation

Subsurface drip irrigation is where a low-pressure, high efficiency irrigation system uses buried drip tubes or drip tape to meet crop water needs at the soil-root interface itself. Due to water being applied directly to the plant's roots at subsurface level, the unproductive blue water footprint is significantly reduced. Though the crop yields are similar to that in other irrigation technologies, due to the lowest unproductive evaporation, it has the lowest blue water footprint as well.

6.2 Irrigation strategies

The three irrigation strategies to consider are:

- Flood irrigation
- Supplemental irrigation
- Deficit irrigation

Farmers can take meaningful water management actions to reduce the unproductive blue and green water footprint by selecting appropriate irrigation strategies. Under abundant blue water availability, but unreliable and insufficient rainfall situations, for the maximum total production per individual farmer, full irrigation is recommended. However, from a basin perspective, trade-offs between individual farmer's yields being maximised through irrigation and limiting the total basin consumption of blue water to sustainable levels need to be considered. The adequate application of deficit irrigation practice can generate significant savings in irrigation water allocation. If there is not sufficient irrigation water available, a farmer can either opt for a deficit irrigation to all his crop lands, or to fully irrigate a portion of his land and rely on rainfall for the rest. Optimizing irrigation both in time and in space will result in the most resource efficient irrigation management.

6.2.1 Full irrigation

The simplest strategy is full irrigation, i.e., irrigate to meet the full evapotranspiration needs of the plant throughout the growing season. As the irrigation water demands are met in full, the blue water footprint is highest in this case mainly due to a higher unproductive evaporation from the fields surrounding the crop.

6.2.2 Supplemental irrigation

Supplemental irrigation is the application of water at critical growth points where rainfall is not adequate to support the full plant growth.

Compared to full irrigation, it has lower unproductive evaporation thereby reducing the blue water footprint; however, crop yield may be lower with supplemental irrigation than with full irrigation.

Provision of supplemental irrigation at sowing if the monsoon is delayed and at critical crop growth stages, in particular flowering and boll formation, can result in higher yields than the rainfed system when rainfall is insufficient for optimal plant growth [29].

6.2.3 Deficit irrigation

The application of water below the evapotranspiration requirements of a crop – irrigation at ~60-80% of actual crop water demand – is called deficit irrigation (DI).

The relationship between crop water demand (cubic metres per hectare) being met and crop yield (tonnes per hectare) achieved is not linear. The crop yield per unit of extra water rises steeply at the beginning, however it slows down as it approaches meeting the total crop water demand. Hence, a decrease in the volume of irrigation water applied doesn’t decrease crop yield in the same proportion.

According to recent scientific studies, cotton can be grown under controlled water stress (deficit irrigation) without severe negative impacts on its yield and sometimes with an improvement in the quality of cotton fibre[30]. An optimisation could be reached by adjusting the use of limited land and water resources for the best outcome for the farmer.

In irrigated agriculture, deficit, can result in a lower blue water footprint compared to full irrigation. Adequate application of deficit irrigation practice can generate significant savings in irrigation water allocation without impacting crop yields significantly.

6.3 Mulching

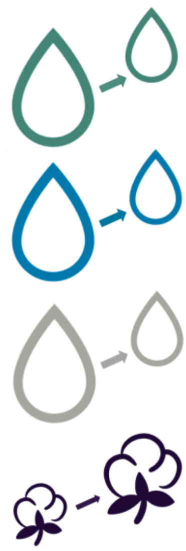
The three mulching practices to consider are:

- Mulching applied at early crop growth stage
- Mulching applied at late crop growth stage
- Mulching materials

Mulching is the application of natural and/or synthetic material to cover the soil surface. Mulching reduces the unproductive evaporation from open land surrounding the crop resulting in a direct reduction in the green and blue (where irrigation is used) water footprint. The other benefits are reduced weed growth, stabilised soil temperatures, less soil erosion and reduced runoff of water and fertilisers from the field.

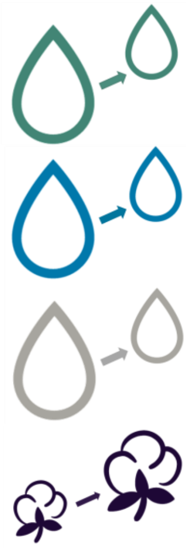
The amount of mulch applied should be controlled keeping in mind the soil temperature required for the crop growth. It is effective in maintaining soil moisture during dry periods between rainfall and in places where there is a shortage of irrigation water supply. It is also effective in places where the water retention capacity of the soil is poor. The effectiveness and appropriateness of mulching is determined by the time of application and the type of mulching material used.

6.3.1 Mulching applied at early crop growth stage



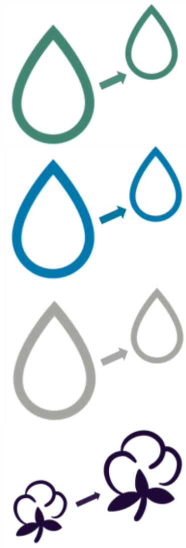
If mulching is done during the early stage of crop growth when the crop canopy is minimal, it is effective in reducing the unproductive evaporation from the open land surrounding the crop, hence the water footprint is reduced. Due to the retention of rainfall in the root zones, it reduces irrigation water demand. It also reduces weed growth, thus less herbicide application is required. Mulching reduces surface runoff and percolation losses, leading to less fertilisers being leached to fresh water and there is less soil erosion reducing sedimentation of surface water, all leading to a lower grey water footprint. In general, mulching leads to an increase in crop yield.

6.3.2 Mulching applied at late crop growth stage



Though mulching can be applied at any stage of crop growth, it is easier for a farmer in terms of actual application when the plants are grown to full size. However, application at the late growth stage is less effective in terms of the water footprint compared to early stage application.

6.3.3 Mulching materials



A variety of materials can be used as mulch, e.g. hay, leaves, manure, compost, vermi-compost, wood, bark, cocoa hulls, rice straw, wheat straw, peanut hulls, plastics, synthetic black polyethylene, gravel, and geo-textiles.

The choice of mulching material is mainly based on investment needed and desired reduction of water footprint. Organic mulch is relatively low cost compared to synthetic mulch. However, with respect to water saving, synthetic black polyethylene mulch (BPM) is more effective than organic bark materials, straw mulch (e.g. rice, wheat) or other plant residues.

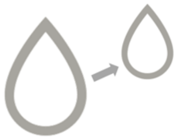
Using non-natural materials such as plastic mulch increases certain beneficial effects such as weed control, reduction of soil evaporation, increase of soil temperature, increase of soil water stored, however it does not help with rainfall infiltration, Nitrogen regulation or salinity control. Compared to black polyethylene mulch, white polyethylene mulch is not as effective in weed suppression. Permeable geotextiles may pose a viable alternative to plastic mulch in general, and for black polyethylene mulch, in particular.

6.4 Nutrient management

The three nutrient management practices to consider are:

- Selection of nutrient type and quantity
- Synchronised application
- Fertigation

6.4.1 Selection of nutrient type and quantity



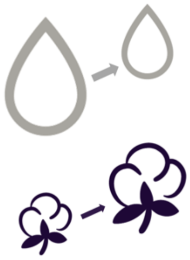
Nutrient availability, particularly Nitrogen and Phosphorus, are critical to high yield and water use efficiency. Nutrient deficiency in most states of India has become a limiting factor in increasing crop productivity. Chemical fertilizers are a major source of nutrients to crops; however, extended use of chemical fertilizers has unfavourable effects on the physical, chemical and biological properties of soil. Inorganic fertilizers do not improve soil fertility and structure. With their use, yield increases initially, but declines over time. Addition of Nitrogen in amounts exceeding plant requirements can lead to outbreaks of insects, e.g., sap sucking pests.

Nutrients may be provided by organic and locally available replacements such as farmyard manure without sacrificing yield. However, farmyard manure may not be available to all cotton farmers. Organic manures, though low in nutrients, leave a favourable effect on soil properties. A good approach is to integrate organic manures with chemical fertilizers to avoid ill effects on the soil. The integration of nutrients results in improved efficiency of chemical fertilizers and a better cost benefit relationship. Intercropping with legumes can significantly enrich soil nutrition at the same time enhancing soil structure. Hence, in the short term it is recommended to aim for a hybrid approach where a portion of the required nutrients are provided from organic sources. Deficiency of micronutrients needs to be corrected through the application of micronutrient carrying fertilizers.

Application of nutrients can be optimized and potentially reduced after determination of actual soil fertility and the amount of fertilizer applied can be adjusted sequentially. Over application of fertilizer is inefficient both from a water and fertiliser use efficiency point of view. Nutrients can leach to groundwater or runoff to surface water, leading to eutrophication of freshwater bodies. The type of fertiliser required should be determined after testing the soil Nitrogen level. The fertiliser deficiency could be measured based on: 1) analysis of the soil (laboratory or with portable kit); or 2) plant symptom analysis[31].

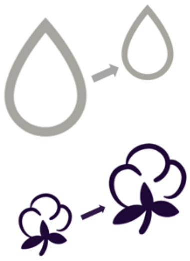
Another useful strategy could be the application of bio-inoculants (living organisms containing strains of specific bacteria, fungi, or algae). They take Nitrogen from the air and make it available to plants reducing the need for Nitrogen fertilizer, make inorganic phosphate and micronutrients soluble and available to plants, collect and store available nutrients, enhance plant uptake of Phosphorus and zinc, provide physical barriers against pathogens, stimulate plant growth and decompose organic residues.

6.4.2 Synchronised application



Precision agriculture technology, e.g. variable-rate Nitrogen application can reduce the application amounts of nutrients without yield losses. Synchronizing Nitrogen and potassium supply with crop demand has the potential to result in higher crop yield and at the same time may lead to reduction of the total required nutrient application. Switching from single to variable rate application based on soil sampling could reduce 17% in Phosphorus and 43% in Potassium demands[32].

6.4.3 Fertigation



Fertiliser application is efficient when applied together with irrigation, in a method called fertigation. Fertigation (controlled irrigation and simultaneous fertiliser application) significantly reduces Nitrogen application amounts by 30-50% without any reduction in crop yield. Fertigation is mostly done in combination with drip irrigation technology.

Fertigation with subsurface drip irrigation at the level of 75% of total crop water demand offered the best option with less off-site run-off, erosion and pesticide movement. In this system, the crop yield is slightly reduced, however the grey water footprint decreases significantly due to a reduction in Nitrogen application compared to the conventional system of fertiliser application.

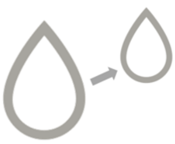
Application of Nitrogen together with application of irrigation in a furrow system at the level of 120% of total crop water demand (over irrigation by 20%) is 5 times more prone to losses compared to fertigation using subsurface drip irrigation. The Nitrogen losses are smaller in fertigation with deficit irrigation practices. There are no Phosphorus losses recorded from deficit subsurface drip irrigation rates.

6.5 Pest control

The two pest control practices to consider are:

- Pesticide selection
- Integrated Pest Management practices

6.5.1 Pesticide selection



There is a trade-off to be made with respect to efficiency gain (increased crop yield) and arising negative environmental impacts (higher grey water footprint) due to the use of pesticides. In general reduction of pests, increases crop yields. However, as plants don't normally uptake the applied pesticides, a significant part of it gets into the soil system and ends up in surface and groundwater resources resulting in a grey water footprint. Hence, the aims of increased crop yields (higher economic efficiency gains), and decreased grey water footprint (smaller environmental impacts) need to be balanced.

Large gains in reducing the grey water footprint can be achieved through substituting chemicals that have a lower toxicity, thereby generating a smaller grey water footprint, whilst targeting the same pests.

Pesticides that have a low water footprint should be used and highly toxic synthetic substances could be avoided altogether. Certainly, if the same pesticide is effective against a number of different pests, this is the most preferred chemical to apply or, if there is an organic alternative, this should be used.

The application of natural pesticides, such as Neem oil, result in much lower grey water footprint than artificial pesticides. Organic pesticides can sometimes be more expensive and farmers may need to be trained on how to make natural pesticides. In cases where natural organic alternatives are not available, replacing those pollutants that result in exceptionally high grey water footprint with less harmful, but equally or even more efficient substances is of critical importance to significantly reduce the grey water footprint.

Application rates should be managed to maximise effectiveness whilst reducing the amounts that may runoff or leach to fresh water. There should be no calendar or random spraying.

Other practices resulting in a lower grey water footprint are:

- Intercropping of cotton with red gram, cowpea, soybean, moong, sorghum/maize and random planting of marigold and Hibiscus subdariffa (lal ambari) are potential means to limit the pest population to the ETL (economic threshold limit);
- Mulching of the field reduces weed growth, and hence less herbicide needed; and
- Hand picking of infested buds and bolls and removal of cotton stocks help in control of bollworms, thus reduces the use of pesticides.

6.5.2 Integrated Pest Management (IPM) practice

Integrated Pest Management poses an opportunity for less adverse effects on the environment. IPM is simply using the right tools at the right time to attack common pests. It requires detailed knowledge of the crop and information about a pest or potential pests and includes an analysis of the pest population, a survey of the economic severity of the pest, the surrounding environment, and the various tools that are available to control pests. It is recommended to apply pesticides only when needed based on careful monitoring of the crop and pest populations and use the most cost effective and efficacious treatments for the targeted pests. Monitoring and training is required to successfully implement such management.

IPM doesn't have a specific set of rules and is rather an approach on how farmers can protect their cotton crop from pests.

The key principles underpinning IPM include:

- Preserving and enhancing populations of beneficial organisms;
- Prevention of pest population build-up (target and reduce the population of pests);
- Ensuring a healthy crop that can withstand some degree of damage;
- Regular monitoring of the crop for pests, beneficial insects and crop damage;
- Management of resistance or stop building up of pesticide resistance; and
- Managing the crop to early maturity to reduce the length of time the crop is exposed to pests.

Both preventative and curative measures are to be used. For example, IRM (Insecticide Resistance and Management) is based on the principle that the most effective strategy to combat insecticide resistance is to do everything possible to prevent it occurring in the first place.IRM has three basic principles: monitoring pest complexes in the field for changes in population density, focusing on economic injury levels and integrating multiple control strategies.

A range of pest control strategies needs to be considered and those effective to a given environment chosen. The specific approaches that can be taken depend upon a range of agro-climatic and socio-economic factors, to be accessed by local experts or agriculture extension service institutes. No single strategy should be followed and relied upon. The presence of pests should not automatically lead to pesticides application. If there is an absolute need, the first choice should be non-chemical pest control options.

The recommended stage-wise IPM practice as given by the Ministry of Agriculture of India[25] is summarised in the accompanying technical report prepared by University of Twente[33]. The summary table in the report from the University of Twente presents key farming stages, pest types, methods to be used and the stepwise IPM approach.

7 Harvesting

Cotton harvest, Vellitiruppur, Erode, Tamilnadu.
Source: Indiawaterportal.org (July, 2012)

The agricultural practice to consider after harvesting is:

- Leaching of fields

7.1 Land maintenance - leaching

All irrigation waters contain salts and, as water evaporates, salts concentrate in the soil profile and must be displaced below the root zone before they reach a concentration that limits crop production. Salt leaching is achieved by the movement of water applied in excess of evapotranspiration. Drainage results in leaching of salts, but improper practice may potentially also lead to increased leaching of nutrients and pesticides. The leaching increases the grey water footprint due to leaching of salt, and potentially nutrients and pesticides, to surface and groundwater. Field leaching may reduce the build-up of resistance in pests to pesticides by reducing the length of their exposure to the pesticides. This may reduce the use of pesticides in subsequent growing seasons.

Applying leaching water at the end of harvest to flush the accumulated salt in the soil is more efficient compared to applying water in excess to the required irrigation during the crop growth. However, if there is enough rainfall before the next land preparation, there is no need to apply irrigation water to leach the salts and pesticides from the field immediately after the harvest.

8 Overview of agricultural practices and their impacts on the water footprint and crop yield

Image source: Global Footprint Network

8.1 Agricultural practices that reduce the green water footprint

Crop stages	Actions	Effects contributing to a smaller green water footprint
 **Land preparation**	Land levelling	Reduction in unproductive evaporation and runoff and better retention of soil moisture.
	Reduced tillage system	Reduction in unproductive evaporation due to increased organic matter that maintains suitable soil moisture content.
 **Planting**	Seed selection	Reduction in transpiration and greater drought tolerance.
	Intercropping and green manure	Reduction in unproductive evaporation due to increased soil cover.
 **Growing**	Mulching applied at early crop growing stages	Reduction in unproductive evaporation due to less open land surrounding the crop.
	Mulching applied later crop growing stage	Similar but lesser effect compared to early stage application.
	Polyethylene mulch or permeable geotextiles	Most effective mulching materials for soil moisture retention.

8.2 Agricultural practices that reduce the blue water footprint

Crop stages	Actions		Effects contributing to a smaller blue water footprint
Land preparation		Land levelling	Reduction in unproductive evaporation and runoff and better retention of soil moisture.
		Reduced tillage system	Reduction in unproductive evaporation due to increased organic matter that maintains suitable soil moisture content.
Planting		Seed selection	Reduction in transpiration and greater drought tolerance.
		Intercropping and green manure	Reduction in unproductive evaporation due to increased soil cover.
Growing	Irrigation technology	Surface flooding	High levels of unproductive evaporation due to standing water on the field during irrigation. Largest water demand due to high percolation rates from the field during irrigation.
		Sprinkler system	Unproductive evaporation similar to surface flooding system in general. However, LESA and MESA sprinkler systems can result in lower unproductive evaporation – at levels similar to furrow system.
		Furrow system	Reduction in unproductive evaporation compared to surface flooding. Further reduction potential with alternate furrow irrigation.
		Drip system	Greater reduction in unproductive evaporation due to the application of water nearer to the root zone of the crop.
		Sub-surface drip system	Further reduction of unproductive evaporation due to application of water directly to the root zone at subsurface level.
	Irrigation strategy	Full Irrigation	High levels of unproductive evaporation.
		Supplemental Irrigation	Reduced unproductive evaporation compared to full irrigation strategy.
		Deficit Irrigation	Deficit irrigation practice can generate significant savings in irrigation water demand without impacting crop yields significantly.
	Mulching	Mulching applied at early crop growing stages	Reduction in unproductive evaporation from open land surrounding the crop. Reduction in irrigation water demand due to the retention of rainfall in the root zones.
		Mulching applied later crop growing stage	Less effective compared to early stage application.
		Polyethylene mulch or permeable geotextiles	Most effective mulching material for reduction of soil evaporation and increased soil moisture retention.

8.3 Agricultural practices that reduce the grey water footprint

Crop stages	Actions		Effects contributing to a smaller grey water footprint
Land preparation	Land levelling		Reduction in runoff and washing off of fertilisers.
	Reduced tillage system		Reduction in herbicide application. Increase in losses of dissolved Phosphorus with time increasing the grey water footprint.
Planting	Seed selection		Reduction in pesticide application due to improved pest resistance.
	Crop rotation practice		Reduction in pesticide, herbicide and fertiliser application.
Growing	Intercropping and green manure		Reduction in pesticide, herbicide and fertiliser application.
	Selection of irrigation technology		Leaching of fertilisers highest with surface and furrow irrigation.
	Mulching	Mulching applied at early crop growing stages	Reduction in herbicide application due to reduced weed growth. Reduction in leaching and washout of fertilisers due to reduced surface runoff and percolation losses. Reduction in sediment reaching rivers and lakes due to les soil erosion.
		Mulching applied later crop growing stage	Less effective compared to early stage application.
		Polyethylene mulch or permeable geotextiles	Most effective mulching material for weed control.
	Nutrient management	Synchronised application	Reduction in the fertiliser demand without yield losses due to the variable-rate N application.
		Fertigation: subsurface drip irrigation at 75% crop water demand	Reduction of Nitrogen application compared to conventional system of fertiliser application.
		Fertigation: subsurface drip irrigation at 120% of crop water demand	Slight increase in grey water footprint compared to 75% case due to requirements for additional Phosphorus application and leaching of nutrients due to over-irrigation

Crop stages	Actions		Effects contributing to a smaller grey water footprint
Growing	Intercropping and green manure		Reduction in grey water footprint due to reduced pesticides, herbicides and fertiliser application.
	Selection of irrigation technology		Increase in grey water footprint due to increased wash out (surface and furrow) and potential of leaching of fertilisers in all irrigation technologies.
	Mulching	Mulching applied at early crop growing stages	Reduction in herbicide application due to reduces weed growth. Reduction in leaching and washout of fertilisers due to reduced surface runoff and percolation losses. Reduction in concentration of suspended solid particles reaching out to rivers and lakes due to lower erosion.
		Mulching applied later crop growing stage	Less effective compared to the early stage of application.
		Polyethylene mulch or permeable geotextiles	Most effective other types of mulching materials used.
	Nutrient management	Selection of nutrient type and quantity	Reduction in the amount of chemical fertiliser leached. The use of bio-inoculants helps fixing the naturally occurring Nitrogen from air reducing the need for chemical fertilisers.
		Synchronised application	Reduction in the fertiliser demand without yield losses due to the variable-rate Nitrogen application.
		Fertigation: Subsurface drip irrigation at 75% crop water demand	Reduction of Nitrogen application compared to conventional system of fertiliser application.
		Fertigation: Subsurface drip irrigation at 120% of crop water demand	Slight increase in grey water footprint compared to 75%-case due to a higher need for Phosphorus application and over irrigation leading to higher leaching of nutrients.
	Pest control	Conventional farming	Increase in grey water footprint due to leaching of chemical fertilisers to surface and ground water. There is approximately 18 times higher grey water footprint in this system compared to organic farming.
		Hybrid farming	Significant reduction in grey water footprint due to the hybrid approach. It is in general 4-5 times higher than in the organic farming.
		Organic farming	Lowest grey water footprint possible due to no chemical fertilisers being applied.
		IPM	Significant reduction in grey water footprint due to reduction in pesticide use and better management practices regarding pesticide control.
Harvesting	Land maintenance - leaching		Increase in grey water footprint

8.4 Agricultural practices that increase crop yield

Crop stages	Actions		Effects contributing to increased crop yield
Land preparation	Reduced tillage system		Crop yield increases as a result of increased soil moisture and less leaching of nutrients.
Planting	Planting date selection		Planting at an optimal period determined by climate and soil condition of the location improves crop yields.
	Seed selection		Yield stabilisation or improvement with the selection of resilient varieties for local conditions.
	Crop rotation		Crop rotation stabilises or improves crop yield.
	Intercropping and green manure		Yield increases due to green manure and mulching effect of intercropping. Monoculture reduces yield over time.
Growing	**Irrigation strategy**	Full Irrigation	Highest crop yield per unit of land.
		Supplemental Irrigation	Crop yield higher than rainfed system, but can be lower than yields under deficit and full irrigation strategies.
		Deficit Irrigation	Higher crop yields compared to rainfed and supplemental irrigation.
	Mulching		Increase in crop yield due to better soil moisture retention and weed control.
	Nutrient management	Synchronised application	Increased crop yield due nutrition needs of plant being met
		Fertigation: Subsurface drip irrigation at 75% crop water demand	Optimum yield with minimum fertiliser use.
		Fertigation: Subsurface drip irrigation at 120% of crop water demand	Highest crop yield achieved due to nutrient and water needs being met.
Harvesting	Land maintenance - leaching		Increased yield in subsequent seasons due to increased soil fertility.

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