Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 25 (3) : 392-396 (September - 2023)
https://doi.org/10.54386/jam.v25i3.2260
https://journal.agrimetassociation.org/index.php/jam

Research paper

Comparative study of water requirements and water footprints of fibre crops hemp (*Cannabis sativa*) and cotton (*Gossypium hirsutum* L.)

KIMBER WISE[1,2], ESTELLA BAZIOTOPOULOS[3], CATHERINE ZHANG[3], MYLES LEAMING[3], LI-HENG SHEN[3], and JAMIE SELBY-PHAM[2*]

[1]School of Science, RMIT University, Bundoora, VIC 3083, Australia
[2]Cannabis and Biostimulants Research Group, Sunshine West, Victoria, 3020, Australia
[3]School of BioSciences, University of Melbourne, Melbourne, VIC, 3010, Australia
**Corresponding Author E-mail: jamie@cbrg.com.au*

ABSTRACT

Water is a valuable and limited resource, which is becoming increasingly under pressure due to the impacts of climate change and over utilization by the agricultural industry. Cotton is the predominant natural fibre utilized within textiles and is a highly water-intensive crop, thereby contributing to the negative environmental impacts of water use in agriculture, such as depletion of water from ecosystems and other uses, land degradation, and dissemination of pollutants. Accordingly, there is significant interest in establishing alternative natural fibre sources, which have lower water requirements. *Cannabis sativa* (hemp) fibre is becoming an increasingly popular fibre alternative and is purported to require less water during its cultivation. Accordingly, herein data was compared across 28 prior published sources, which identified that hemp has a 38% lower crop water requirement (CWR), 60% lower water footprint (WF), 84% lower crop irrigation requirement (CIR), and 91% lower irrigated water footprint (IRF) as compared to cotton. Therefore, these results support hemp as a water-efficient environmentally sustainable alternative to cotton for fibre cultivation.

Keywords: *Cannabis sativa (*hemp*)*, *Gossypium hirsutum (*cotton*)*, fibre crops, CWR, CIR, WF

Due to limited availability of freshwater resources, any inefficiencies of water use is considered to exacerbate water shortages and place further pressure on other water uses in society (Kumar *et al.*, 2021). The World Bank's statistics indicate that agriculture is currently the most water intensive sector, accounting for approximately 70% of all freshwater withdrawals globally (International Bank for Reconstruction and Development, 2022; World Wildlife Fund). Of note, cotton (*Gossypium hirsutum* L.) production is highly water-intensive, the largest water use among agricultural commodities (Barrett *et al.*, 2005; Kooistra *et al.*, 2006; World Wildlife Fund), and accounts for 2.6% of the full global water footprint (Chapagain *et al.*, 2006). However, cotton is critically important to the textile industry, representing the dominant raw material for textile production, and accounting for almost one third of total global fibre production (Chapagain *et al.,* 2006; International Cotton Advisory Committee, 2022; Manalil *et al.*, 2017; Okafor *et al.*, 2021; Voora *et al.*, 2020). Accordingly, there is interest in exploring strategies to reduce the water burden associated with cotton cultivation.

Water utilisation during crop cultivation is often distinguished between 'blue water' (irrigated water consumed) and 'green water' (rain-water consumed) (Mekonnen and Hoekstra, 2011). Greater emphasis tends to be placed on 'blue water' crop requirements, as irrigation systems require diversion of limited water resources (Feike *et al.*, 2017; Jayakumar *et al.*, 2015), are often inefficient due to leaks (Aquatech, 2020; World Wildlife Fund) and are commonly associated with negative impacts to the surrounding environment (Gómez-Armayones *et al.*, 2018; Oosterbaan, 1988; Verma, 1986). Approximately 73% of global cotton production is grown on irrigated lands (Barrett *et al.,* 2005;Kooistra *et al.,* 2006; Kouser and Qaim, 2014). Therefore, assessing the irrigated water requirements for cotton cultivation is considered a crucial

Article info - DOI: *https://doi.org/10.54386/jam.v25i3.2260*
Suplimentary Tables : https://journal.agrimetassociation.org/index.php/jam/article/view/2260/1497
Received: 21 June 2023; Accepted: 03 August 2023; Published online : 31 August 2023
"This work is licensed under Creative Common Attribution-Non Commercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0) © Author (s)"

issue when exploring the environmental sustainability of cotton cultivation (Feike *et al.,* 2017; Ibragimov *et al.*, 2007).

Hemp (*Cannabis sativa*) is a fibre, or a dual-purpose (fibre and grain) crop, which has been suggested as an environmentally-friendly alternative to cotton for use in the textile industry (Campbell *et al.*, 2019; Schumacher *et al.*, 2020). Multiple studies have also stipulated that hemp requires little water, no pesticides or herbicides during cultivation, and is a highly productive plant, thereby suggesting the potential to reduce water needs and environmental impacts during the cultivation of textile crops (Fortenbery and Bennett, 2004; Schumacher *et al.,* 2020). However, despite both cotton and hemp being well established crops, minimal studies are available that have explored comparison of these crops in terms of industrial-scale cultivation water requirements and associated environmental impacts. Therefore, the work presented here involved the collation of available data on the respective water requirements and use efficiencies of cotton and hemp, followed by statistical analyses to explore the potential of hemp as an environmentally-friendly alternative textile crop to cotton.

MATERIALS AND METHODS

Data collection and analysis

Measures of water requirements and water use efficiency indicators for cotton (Table S1) and hemp (Table S2) were collected from 27 prior publications. Measures explored included: crop irrigation requirement (CIR), which is the volume of irrigated water consumed by the crop (m^3 per ha) as indicated by provided irrigated water measured using a water meter (Allanov *et al.*, 2020), crop water requirement (CWR), which accounting for crop evapotranspiration is the total water usage (m^3 per ha) including irrigation, rainfall, and available soil water (Casa *et al.*, 2009), and irrigation water footprint (IWF) and water footprint (WF), which are calculated (as m^3 per ton) by dividing CIR or CWR (m^3 per ha) by the quantity of production (ton per ha), respectively (Mekonnen and Hoekstra, 2011).

Statistical analysis

Where multiple data points (multiple studies) were available for a measure for both hemp and cotton, two-sample T-tests were performed in the Minitab 19 statistical software package (Minitab Inc., State College, PA). Where multiple data points (multiple studies) were available for a measure for one crop but only one data point was available for the other crop (a single study or no variation across studies), one-tailed one-sample T-tests were performed in Minitab 19, utilising the value from the single measure crop for the associated hypothesis test.

RESULTS AND DISCUSSION

Water shortages and associated threats to water security impact almost 80% of the world's population (Mehari, 2019). Noting the high global usage of water during crop cultivation (International Bank for Reconstruction and Development, 2022; World Wildlife Fund), a primary measure during comparative crop assessment is the 'crop water requirement' (CWR, m^3 per ha), which represents the total litres of water required per area of crop growth, i.e. the volume of water required to compensate for evapotranspiration and plant water needs during growth (Surendran *et al.*, 2015). Accordingly, during comparison of crops, a higher CWR value indicates a less efficient conversion of water input into area of produce output, which should be a key sustainability consideration as an indicator of water management efficiency (Quezada *et al.*, 2011). Cotton ($n = 13$) was identified as having a CWR of 8,050, whilst hemp ($n = 6$) was identified as having a significantly lower ($p = 0.003$) CWR of 5,024, indicating that hemp is significantly more efficient in the conversion of water input into area of produce output (Fig. 1A).

Cotton ($n = 11$) was identified as having a WF of 5,569 which was significantly higher ($p = 0.030$) than the hemp ($n = 3$) WF, identified as 2,002 (Fig. 1B). Hatfield *et al.,* (2001) identified that for major crops, varying cropping practices or nutrient management practices was associated with substantial variation of WF across the range of approximately 300–7,000 m^3 per ton, and approximately 300–4,500 m^3 per ton, respectively. Accordingly, the mean differences observed between hemp and cotton WF of approximately 1,600 m^3 per ton (Fig. 1B) is not only statistically significantly, but also meaningful in terms of effect size. These results demonstrate that hemp is more efficient in the conversion of water input into yield output than cotton and highlights that this crop substitution is a potentially valuable strategy to substantially improve water use efficiency during crop growth for textile production.

Goods water use efficiency (m^3 water per ton of goods) was explored as an indicator of efficiency of conversion of water input into produce output. Hemp fibre ($n = 2$) was identified as requiring 2,723 m^3 per ton which was significantly lower ($p = 0.028$) than the 9,113 m^3 per ton identified as required for cotton lint ($n = 1$). Similarly, processed hemp products ($n = 2$) were identified as requiring 2,769 m^3 per ton, which was significantly lower ($p = 0.004$) than the 9,982 m^3 per ton required for cotton fabric ($n = 1$). These results highlight that in addition to hemp being more efficient at converting water into plant yield, the conversion of hemp into usable yield and end-point fabric is also significantly more water-efficient than its cotton counterparts.

Agricultural irrigation impacts over 80% of water resources (Beshir, 2017), with this irrigated land accounting for 18% of total cultivated land. Water required for agricultural irrigation is a particularly vulnerable water requirement that is projected to rapidly increase as a result of climate change due to associated impacts to temperature and precipitation (Mehari, 2019). The associated crop measure, 'crop irrigation requirement' (CIR, m^3 per ha) represents the volume of irrigated water (i.e., 'blue water') required per area of crop growth, wherein higher values are indicative of less efficient conversion of irrigated water input to area of produce output. As CWR is anticipated to increase with climate change, to fulfil the increased water need, crops are anticipated to become more dependent on supply of supplemental irrigated water (Ali, 2010; Mehta and Pandey, 2016). Of note, the provision of water below threshold imposes water stress to plants and results in reductions in crop yield (Falkenmark, 1997; Stone, 2003). Accordingly, comparison of CIR between crops should be a key consideration during assessment of relative crop sustainability (Richards *et al.*, 2002). Cotton ($n = 9$) was identified as having a CIR of 4,840, which

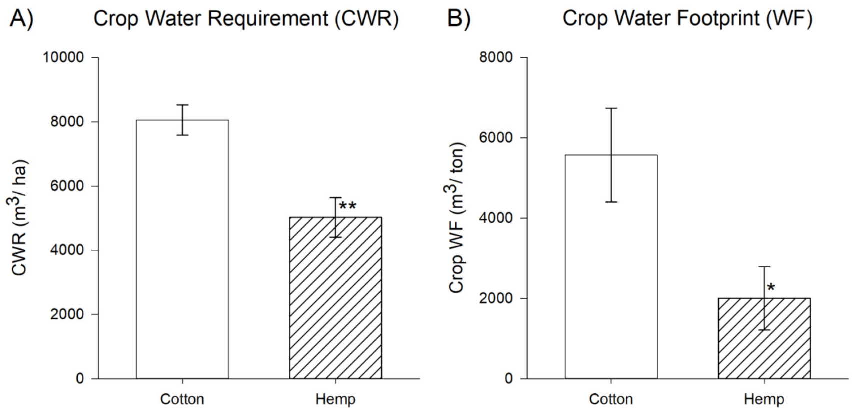

Fig. 1: Crop water requirements. A) Crop water requirement (n = 13 for cotton, n = 6 for hemp), and B) Crop water footprint (n = 11 for cotton, n = 3 for hemp). Data presented as mean ± standard error, * indicates p < 0.05, ** indicates p < 0.01.

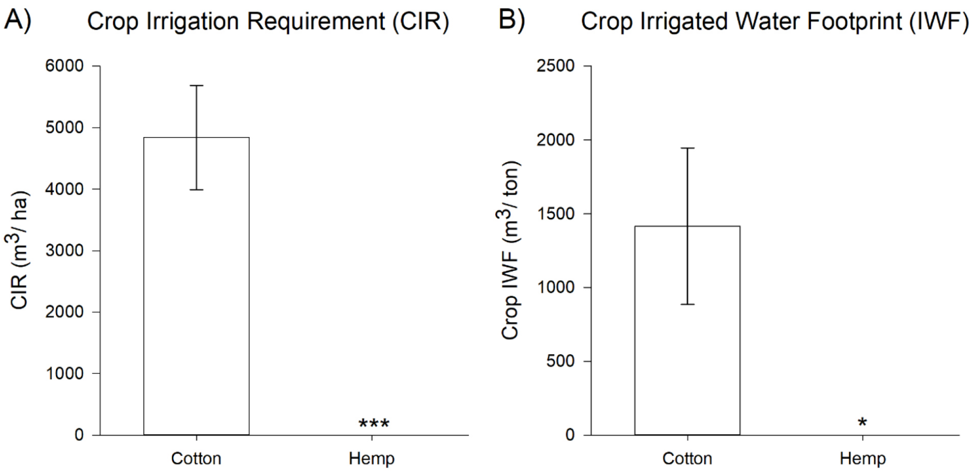

Fig. 2: Crop irrigation requirements. A) Crop irrigation requirement (n = 9 for cotton, n = 3 for hemp), and B) Crop irrigated water footprint (n = 3 for cotton, n = 2 for hemp). Data presented as mean ± standard error, * indicates p < 0.05, ** indicates p < 0.01.

was significantly higher (p = 0.006) than hemp (n = 4) which was identified as having a CIR of 761. This result indicates that hemp is significantly less reliant on irrigated water for growth than cotton (Fig. 2A). Similarly, the 'irrigated water footprint' (IWF, m^3 per ton) is representative of volume of irrigated water required per kg yield wherein a higher value is indicative of less efficient conversion of irrigated water input to yield output. Cotton (n = 4) was identified as having an IWF of 1,416 whilst hemp (n = 2) was identified as having a significantly lower (p = 0.038) IWF of 0. Accordingly, whilst irrigation has been shown to improve hemp yield (Campbell *et al.,* 2019), these results indicate that hemp is significantly less reliant on irrigated water than cotton in terms of input per yield output (Fig. 2B).

Additionally, Mekonnen and Hoekstra (2011) identified that the 'blue water' footprint of cotton lint and cotton fabric are 2,955 m^3 per ton and 3,253 m^3 per ton, respectively, and that by contrast, hemp fibre and its derived fabrics have a 'blue water' footprint of 0 m^3 per ton. These results highlight that a follow-on consequence of the hemp crop being less reliant on irrigated water than cotton is that associated crop-derived material and fabrics have smaller 'blue water' footprints, and are by extension less dependent on irrigated water for production. Noting that cotton accounts for approximately 7.5% of the global 'relevant for environmental deficiency' water needs (Pfister *et al.*, 2011) and that the primary goal of water-resources management is the maximisation of the beneficial utilisation of water (Seckler *et al.*, 2003), potential solutions should include exploration of crop alternatives with reduced water requirements (Grant and Elemental Solutions, 2008). This is needed now more than ever to mitigate the rapidly worsening water security pressures associated with climate change (Fader *et al.*, 2016).

CONCLUSION

With climate change exacerbating environmental pressures associated with limited availability of water resources, it is critical to explore opportunities to reduce water requirements and improve efficiencies associated with water use. One sector that is notorious for having a large dependence on irrigated water is the agricultural sphere, with cotton requiring particular focus due to its pervasive cultivation and high requirement for irrigated water.

Herein, water use requirements, and water use efficiency from multiple previous studies on cotton and a proposed environmentally sustainable alternative fibre, hemp, were collated and contrasted to explore their relative needs and efficiencies. The results indicated that across multiple measures hemp has lower water requirements and thereby superior water use efficiency, suggesting that transition of cotton to hemp (as the crop input for textile manufacture) may be a valuable strategy for reducing the environmental impacts of the textile industry.

ACKNOWLEDGEMENT

The authors would like to thank Jay Black, Alex Mullaney, David Rogers, and Robyn Schofield from The University of Melbourne for their support throughout this project.

***Funding*:** The authors declare no specific funding for this project.

Conflict of interest: The authors declare no conflicts of interest.

Author contributions: **EB, CZ, ML,** and **L-HS** sourced and collated data. **KW** and **JSP** carried out data analysis, constructed figures, and drafted the manuscript. **KW**, **EB**, **CZ**, **ML**, **L-HS**, and **JSP** contributed to editing and revision of the manuscript.

***Disclaimer*:** The opinions, contents, and views expressed in the research article published in the Journal of Agrometeorology are the authors' own and do not necessarily reflect the position of the organizations they are affiliated with.

***Publisher's Note*:** The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Ali, M. (2010). Crop water requirement and irrigation scheduling. Fundamentals of irrigation and on-farm water management: volume 1. Springer, New York, NY, pp. 399-452.

Allanov, K., Shamsiev, A., Durdiev, N., Avliyakulov, M., Karimov, A., and Khaitov, B. (2020). Improving nutrition and water use efficiencies of pima cotton (*Gossypium barbadense* L.) varieties under arid conditions of Uzbekistan. *J. Plant Nutri.,* 43: 2590-2600. https://doi.org/10.1080/01904167.2020.1793186

Aquatech, (2020). "Water Scarcity: Our Essential Guide to Humanity's Mega Challenge." Date Accessed: 17/03/2023 https://www.aquatechtrade.com/news/water-treatment/essential-guide-water-scarcity/

Barrett, J., Chadwick, M., and Chadwick, M. (2005). Ecological footprint and water analysis of cotton, hemp and polyester. Report prepared for and reviewed by BioRegional Development Group and World Wide Fund for Nature, Cymru. Stockholm Environment Institute.

Beshir, S. (2017). Review on estimation of crop water requirement, irrigation frequency and water use efficiency of cabbage production. *J. Geosci. Environ. Prot.,* 5: 59. https://doi.org/10.4236/gep.2017.57007

Campbell, B.J., Berrada, A.F., Hudalla, C., Amaducci, S., and McKay, J.K. (2019). Genotype × environment interactions of industrial hemp cultivars highlight diverse responses to environmental factors. *Agrosyst. Geosci. Environ.,* 2: 1-11. https://doi.org/10.2134/age2018.11.0057

Casa, R., Rossi, M., Sappa, G., and Trotta, A. (2009). Assessing crop water demand by remote sensing and GIS for the Pontina Plain, Central Italy. *Water Resour. Manag.,* 23: 1685-1712.

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H., and Gautam, R. (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. *Ecol. Econ.,* 60: 186-203. https://doi.org/10.1016/j.ecolecon.2005.11.027

Fader, M., Shi, S., von Bloh, W., Bondeau, A., and Cramer, W. (2016). Mediterranean irrigation under climate change: more efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrol. Earth Syst. Sci.,* 20: 953-973. https://doi.org/10.5194/hess-20-953-2016

Falkenmark, M. (1997). Meeting water requirements of an expanding world population. *Phil. Trans. R. Soc. Lond., B* 352: 929-936. https://doi.org/10.1098/rstb.1997.0072

Feike, T., Khor, L.Y., Mamitimin, Y., Ha, N., Li, L., Abdusalih, N., Xiao, H., and Doluschitz, R. (2017). Determinants of cotton farmers' irrigation water management in arid Northwestern China. *Agric. Water Manag.,* 187: 1-10. https://doi.org/10.1016/j.agwat.2017.03.012

Fortenbery, T.R., and Bennett, M. (2004). Opportunities for commercial hemp production. *Appl. Econ. Perspect. Policy,* 26:97-117. https://doi.org/10.1111/j.1467-9353.2003.00164.x

Gómez-Armayones, C., Kvalbein, A., Aamlid, T.S., and Knox, J.W. (2018). Assessing evidence on the agronomic and environmental impacts of turfgrass irrigation management. *J. Agron. Crop Sci.,* 204: 333-346. https://doi.org/10.1111/jac.12265

Grant, N., Elemental Solutions (2008). A critique of the CSH water efficiency requirements. NBT Consult for the Good Homes Alliance.

Hatfield, J.L., Sauer, T.J., and Prueger, J.H. (2001). Managing soils to achieve greater water use efficiency: a review. *Agron. J.,* 93: 271-280. https://doi.org/10.2134/agronj2001.932271x

Ibragimov, N., Evett, S.R., Esanbekov, Y., Kamilov, B.S., Mirzaev, L., and Lamers, J.P. (2007). Water use efficiency of irrigated cotton in Uzbekistan under drip and furrow irrigation. *Agric. Water Manag.,* 90: 112-120. https://doi.

org/10.1016/j.agwat.2007.01.016

International Bank for Reconstruction and Development, (2022). "Water in Agriculture." Date Accessed: 23/02/2023 https://www.worldbank.org/en/topic/water-in-agriculture#1

International Cotton Advisory Committee, (2022). "Production of Cotton Lint in '000 Metric Tonnes (Season 2021/22)." Date Accessed: 23/02/2023 https://www.icac.org/DataPortal/DataPortal?Year=2021/22%20proj

Jayakumar, M., Surendran, U., and Manickasundaram, P. (2015). Drip fertigation program on growth, crop productivity, water, and fertilizer-use efficiency of BT cotton in semi-arid tropical region of India. *Commun. Soil. Sci. Plant Anal.,* 46:293-304. https://doi.org/10.1080/00103624.2014.969403

Kooistra, K., Termorshuizen, A.J., and Pyburn, R. (2006). The sustainability of cotton: Consequences for man and environment. Science Shop Wageningen University & Research Centre, Wageningen, Netherlands.

Kouser, S., and Qaim, M. (2014). Bt cotton, damage control and optimal levels of pesticide use in Pakistan. *Environ. Dev. Econ.,* 19: 704-723. https://doi:10.1017/S1355770X1300051X

Kumar, P.S., Prasanth, S., Harish, S., and Rishikesh, M. (2021). Industrial water footprint: case study on textile industries. In: Muthu, S.S. (Ed.), Environmental Footprints and Eco-design of Products and Processes. Springer, Singapore, pp. 35-60.

Manalil, S., Coast, O., Werth, J., and Chauhan, B.S. (2017). Weed management in cotton (*Gossypium hirsutum* L.) through weed-crop competition: A review. *Crop Prot.,* 95: 53-59. https://doi.org/10.1016/j.cropro.2016.08.008

Mehari, H. (2019). Review on: impact of climate change on crop water requirement in Ethiopia. *Int. J. Novel Res. Life Sci.,* 6: 24-34.

Mehta, R., and Pandey, V. (2016). Crop water requirement (ETc) of different crops of middle Gujarat. *J. Agrometeorol.,* 18(1): 83-87. https://doi.org/10.54386/jam.v18i1.906

Mekonnen, M.M., and Hoekstra, A.Y. (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrol. Earth Syst. Sci.*, 15: 1577-1600. https://doi.org/10.5194/hess-15-1577-2011

Okafor, C.C., Madu, C.N., Ajaero, C.C., Ibekwe, J.C., Nzekwe, C.A., Okafor, C., Madu, C., Ajaero, C., Ibekwe, J., and Nzekwe, C. (2021). Sustainable management of textile and clothing. *Clean Technol. Recycl.,* 1: 70-87.

Oosterbaan, R. (1988). Effectiveness and social/environmental impacts of irrigation projects: a criticial review. ILRI Annual Report. International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, pp. 18-34.

Pfister, S., Bayer, P., Koehler, A., and Hellweg, S. (2011). Environmental impacts of water use in global crop production: hotspots and trade-offs with land use. *Environ. Sci. Technol.,* 45: 5761-5768. https://doi.org/10.1021/es1041755

Quezada, C., Fischer, S., Campos, J., and Ardiles, D. (2011). Water requirements and water use efficiency of carrot under drip irrigation in a haploxerand soil. *J. Soil Sci. Plant Nutr.,* 11: 16-28. http://dx.doi.org/10.4067/S0718-95162011000100002

Richards, R., Rebetzke, G., Condon, A., and Van Herwaarden, A. (2002). Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Sci.,* 42,:111-121. https://doi.org/10.2135/cropsci2002.1110

Schumacher, A.G.D., Pequito, S., and Pazour, J. (2020). Industrial hemp fiber: A sustainable and economical alternative to cotton. *J. Clean. Prod.,* 268: 122180. https://doi.org/10.1016/j.jclepro.2020.122180

Seckler, D., Molden, D., and Sakthivadivel, R. (2003). The concept of efficiency in water-resources management and policy. Water productivity in agriculture: Limits and opportunities for improvement. CABI Publishing Wallingford UK, pp. 37-51.

Stone, L.R. (2003). Crop water use requirements and water use efficiency. 15th annual Central Plains irrigation conference and exposition proceedings, February 4-5, 2003, Colby, Kansas. Colorado State University. Libraries.

Surendran, U., Sushanth, C., Mammen, G., and Joseph, E. (2015). Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: A case study in Palakkad district of humid tropical Kerala, India. *Aquat. Procedia,* 4:1211-1219. https://doi.org/10.1016/j.aqpro.2015.02.154

Verma, R.D. (1986). Environmental impacts of irrigation projects. *J. Irrig. Drain. Eng.,* 112: 322-330. https://doi.org/10.1061/(ASCE)0733-9437(1986)112:4(322)

Voora, V., Larrea, C., and Bermudez, S. (2020). Global market report: cotton. JSTOR.

World Wildlife Fund, "Sustainable agriculture: Cotton." Date Accessed: 23/02/2023, https://www.worldwildlife.org/industries/cotton#:~:text=20%2C000%20liters,food%20crop%20in%20the%20world

World Wildlife Fund, "Threats: Water Scarcity." Date Accessed: 28/02/2023, https://www.worldwildlife.org/threats/water-scarcity