frontiers | Frontiers in Sustainable Food Systems

TYPE Editorial
PUBLISHED 14 March 2024
DOI 10.3389/fsufs.2024.1378191

OPEN ACCESS

EDITED AND REVIEWED BY
Ali Shahnazari,
Sari Agricultural Sciences and Natural Resources University, Iran

*CORRESPONDENCE
Patricia Amankwaa-Yeboah
✉ p.amankwaa-yeboah@cropsresearch.org

RECEIVED 29 January 2024
ACCEPTED 27 February 2024
PUBLISHED 14 March 2024

CITATION
Amankwaa-Yeboah P, Yeboah S and Oppong-Sekyere D (2024) Editorial: Water-smart crop farming: a holistic approach to its practice as a climate change adaptation strategy in Sub-Saharan Africa.
Front. Sustain. Food Syst. 8:1378191.
doi: 10.3389/fsufs.2024.1378191

Editorial: Water-smart crop farming: a holistic approach to its practice as a climate change adaptation strategy in Sub-Saharan Africa

Patricia Amankwaa-Yeboah[1]*, Stephen Yeboah[1] and Daniel Oppong-Sekyere[2]

[1]Council for Scientific and Industrial Research- Crop Research Institute (CSIR-CRI), Kumasi, Ghana,
[2]Bolgatanga Technical University, Bolgatanga, Ghana

KEYWORDS

water smart landscape, water conservation, soil conservation, deficit irrigation, climate change

Editorial on the Research Topic
Water-smart crop farming: a holistic approach to its practice as a climate change adaptation strategy in Sub-Saharan Africa

Introduction

The risks associated with climate change, extreme weather, and climate events such as floods and droughts are enormous. These risks tend to seriously affect agricultural productivity and the economies of most Sub-Saharan African countries, which are largely dependent on agriculture. Climate change events such as drought result in water stress (and shortage), and heat stress which directly impacts crop development and yield.

Water-smart crop farming approaches and technologies ensure the conservation (both *in-situ* and *ex-situ*), efficient use, and drainage (in the case of flooding or waterlogging) of agricultural water resources for sustainable crop production. The Research Topic identified some water-smart farming technologies such as irrigation (including supplementary irrigation of rain-fed systems), glasshouse farming, use of water use-efficient technologies such as drought tolerant crop genotypes, remote sensing, weather forecast and moisture monitoring, crop diversification, biological and engineering bases soil, and water conservation measures.

Objectives of the Research Topic and editorial

The Research Topic proposed a collection that centers around water-smart farming approaches for sustainable crop production. The Research Topic was expected to span papers in agricultural water management and conservation as well as ecological approaches for landscape management and aquifer recharge as well as on-farm water and nutrient management. The Research Topic was opened to receive write-ups on emerging technologies and novel approaches to water-smart farming that had the potential to reduce vulnerability and build the resilience of agriculture-dependent communities to climate change impacts. The Research Topic was expected to contribute to the knowledge of water-smart farming systems in Sub-Saharan Africa.

The main aim of this editorial is to explore the highlights of each article publication concerning the Research Topic as well as its novelty and future impact. This editorial also presents summaries of the main findings of the study. The main articles, however, provide a more in-depth analysis and findings of the research activities.

Article 1: "*Soil and water conservation measures to adapt cropping systems to climate change facilitated water stress in Africa*"

This article by Brempong et al. explores the implementation of soil and water conservation measures in assisting cropping systems to adapt to the negative impacts of climate change and variability. The study highlights the extent to which climate change has caused harm over the years, what has been done over the years to battle the implications of climate change on soil water balance, the barriers to the success of adaptation practices, and future research areas. The study adopted the PRISMA guidelines proposed by Kleppel and Frank (2022) as the main framework to review and deduce that crops do not function well under flood and drought conditions. The study further cited examples from Li et al. (2019a,b) that, flooding conditions result in waterlogging, leading to poor soil aeration which affects the respiration of crop roots and other relevant soil microbes which is also likely to completely halt very important crop activities such as root elongation, reduced nutrient uptake and an increase in carbon dioxide buildup in soils. The study also investigated the impacts of drought on soil bacteria and other very important soil microbiota. Heat stress, responsible for reducing the population of important soil microbes also reduces the decomposition rate of soil organic matter. The study also cited the works by Dorau et al. (2018) and Abuarab et al. (2019) as examples of studies that sought to understand the interaction between crop growth and microbial activities. The study also reported that, drought is responsible for heat generation on land surface, causing heat stresses which has the potential to reduce the population of soil bacteria and microbiota and organic matter decomposition within the soil (Tóth et al., 2017; FAO, 2021).

The study investigated the extent and impact of drought using studies by Peña-Gallardo et al. (2019). Consequently, the role soil infiltration and permeability play in ensuring water balance and susceptibility to water stress was critical to water smart crop production (Ramesh and Iqbal, 2022). As part of the study, the results obtained were compared to the studies by Li et al. (2019a) where they accessed the yield of maize at different anomaly scales of 12 different crop models. The results showed that maize when cultivated under full irrigation and zero irrigation schemes. The results are further explained by the studies of Song et al. (2019) and Brempong et al. (2022). They reported that the soil infiltration rate and permeability are largely influenced by certain physical characteristics such as soil texture, structure, porosity and organic matter content. Further reports indicate that soil compaction, deforestation and land clearing result in reduced soil infiltration and permeability (Chakraborty and Mistri, 2017; Khodadadi et al., 2021).

The study further makes mention of some notable conservation practices such as land/seedbed management (such as tilling and sowing across slopes, ridge/furrow planting, usage of bunds), the use of suitable farm implements (i.e., minimum or zero tillage operations, sub-soilers, no-till planters) as a vital way of conserving the soil moisture as proposed by Patel et al. (2018). Simple technologies such as tied ridging and bunded basins (Amankwaa-Yeboah et al., 2023) are similarly cost-effective technologies that can be easily adapted in most cropping systems Other notable mentions are agronomic practices such as diversified crop rotation, and surface residue retention. The study reported that leaving crop residues on the surface of soils, no-till, and zero tillage adds organic matter after the decomposition of the plant materials which improves the water-holding capacity of soils in drought conditions.

The study highlights rainwater harvesting as an efficient means of conserving water in flood-prone and high-rainfall areas. The aim of harvesting excess water is to use the water as a means of irrigation during drought periods. They also come with additional benefits like using them as aquatic habitats and for fisheries. They can range from simple catchments to complex infrastructure depending on individual requirements. The study finally concludes that the implementation of conservation technologies, usage of some agronomic practices, and retention of plant residues on the surface of the soil have the potential to adapt cropping systems to water stress in changing climatic conditions.

Collectively, the research contributed to the common goal of ensuring water security, water smart agriculture, in that, the engineering inventions reported by Patel et al. (2018) have made it possible to undertake cost effective and energy saving agricultural operations without necessarily having to till the land. According to the studies by Linderhof et al. (2022), there have been several breakthroughs in Sub-Saharan Africa, however, there seems to be a trade-off'/gap between research and on-field adoption and implementation. Also, the socioeconomic conditions of the target groups are not fully captured in the study. Socioeconomic conditions may vary depending on the heterogeneity and the biases in participant selection. This goal of ensuring food security in the midst of changing climatic conditions cannot be achieved by the government alone, other major stakeholders should also see the need to help battle the negative impacts of climate change.

Article 2: "*In-field assessment of the variability in water and nutrient use efficiency among potato farmers in semi-arid climate*"

Franke et al. introduces the concept of irrigation, its relevance and the rate of adoption in African agricultural practices. It further reiterated that the adoption and usage of irrigation in Africa is marginally low except South Africa which cultivates most of its crops under a form irrigation (Mutambara et al., 2016; Backeberg, 2018; Nakawuka et al., 2018). The study investigated water and nutrient management in irrigated potato-based production systems in semi-arid climates. In this study, the researcher assessed twenty potato fields under irrigation across two potato production regions in South Africa (i.e., the interior of South Africa covering the North West Province and the very western part of the Free State Province and the Sandveld region within the Western Cape Province. As reported by several works, sustainable production of irrigated crops in arid regions necessitates a shift toward optimizing water and nutrient utilization while minimizing leaching risks (Ierna et al., 2011; Hendricks et al., 2014). Steyn et al. (2016), reiterated that the disparities in water and nutrient use efficiencies among potato growers in South Africa, even within similar agroecological zones, underscore the significance of crop management practices in ecological sustainability and economic viability. This study focused on quantifying water and nutrient inputs, outputs, and efficiencies in irrigated potato systems, alongside assessing deep drainage and nutrient losses through leaching. Additionally, the role of follow-up crops in mitigating nutrient losses is evaluated. By conducting detailed in-field measurements, this research also aimed to enhance water and nutrient management strategies for sustainable potato production in semi-arid climates.

The paper highlights the various processes such as crop rotation and other crop field management (such as, soil sampling, irrigation, and precipitation, drainage and leaching). The study also highlights the importance of soil physico-chemical parameters to water smart crop production. In this vein, sampled and analyzed soils in the interior of the study area had pH to be neutral while soils in the Sandveld region had a pH slightly acidic. This variability in soil pH was attributed to the historical usage of P fertilizers, bringing to the fore, the need for nutrient management for sustained production. The study also reports that the water use efficiency of potatoes in the Sandveld region tended to be higher than other regions of interest. Water demand in the same region also tended to be lower due to the lower rate of evapotranspiration. In our contest of exploring water-smart farming options, this was seen as highly significant for water conservation and its use efficiency.

Potato cultivation is influenced by various factors including soil composition, water availability, nutrient dynamics, and environmental conditions. In regions like the interior and Sandveld, where sandy soils prevail, managing nutrient leaching becomes crucial due to low organic carbon content. Seasonal water dynamics, characterized by irrigation and rainfall patterns, significantly impact crop growth and yield. Nutrient management, particularly nitrogen and phosphorus application rates, plays a vital role in optimizing yield while minimizing environmental impacts such as leaching. Understanding these dynamics is essential for sustainable potato production, ensuring food security, and mitigating environmental degradation.

Incorporating water-smart agriculture practices into potato cultivation can significantly enhance sustainability and resource efficiency. By optimizing irrigation schedules, utilizing drip irrigation systems, and implementing mulching techniques, farmers can minimize water wastage and improve water-use efficiency. Additionally, adopting precision agriculture technologies such as soil moisture sensors and remote sensing can aid in making informed decisions regarding irrigation scheduling, thereby conserving water while maintaining optimal crop growth. Furthermore, integrating water-saving practices with nutrient management strategies, such as precision application of fertilizers, can further enhance resource efficiency and reduce environmental impacts. Overall, embracing water-smart agriculture practices in potato cultivation not only promotes sustainable water management but also contributes to increased productivity and resilience in the face of climate variability.

Article 3: "*Combining deficit irrigation and nutrient amendment enhances the water productivity of tomato (Solanum lycopersicum L.) in the tropics*"

In this article, Amankwaa-Yeboah et al. delve deeper into the effects of water and nutrient management on the growth and yield of tomato (*Solanum lycopersicum L.*) in tropical conditions. Here, the article introduces tomato as one of the most irrigated crops globally as reported by Arah et al. (2015). It is reported in this article that local farmers tend to provide tomatoes with more water than they require, leading to excessive irrigation and utilization of water, an important global resource. The article investigated the effects of different deficit irrigation regimes and nutrient amendments on the growth and yield of tomato. As reported by Al-Ghobari and Dewidar (2018), deficit irrigation techniques over the years have been found to have the potential to increase water use efficiency in places with limited water availability.

The study employed the DSSAT Cropping Systems Models (CSMs) to investigate the combined effects of deficit irrigation and nutrient amendments on tomato production under controlled environment agriculture. These models are instrumental in simulating crop responses to variations in meteorological conditions, soil qualities, and management practices, aiding in the assessment of future climate scenarios (Jones et al., 2003; Hoogenboom et al., 2019).

Conducted in a screen house at the CSIR-Crops Research Institute in Ghana, the experiment utilized a split-plot design with three main irrigation schedules (50%, 75%, and 100% of crop water requirement) and three subplot nutrient treatments (inorganic fertilizer, organic compost, and no fertilizer). This design results in nine treatment combinations, replicated thrice, with three potted plants per replicate (Amankwah-Yeboah et al.). Agronomic practices included nursing tomato seedlings in the screen house, transplanting them into buckets filled with sterilized black soil, staking for support, and applying insecticide and weed control measures. Nutrient amendments involve the application of inorganic fertilizer or organic compost at a rate of 90 kg N/ha, with adjustments made to ensure the availability of nutrients throughout the growing season. As part of the study, timely irrigation schedules were determined using the CROPWAT 8.0 model, estimating crop water requirements based on location-specific climate, soil, and crop data. The model helps in optimizing irrigation scheduling to meet the crop's water needs while maximizing water use efficiency (Savva and Frenken, 2002). The use of the DSSAT model in this research contributed to identifying resource-efficient research pathways for water-smart technology development.

The study threw light on the importance of deficit irrigation and its adoption as a water-smart farming approach. The study concluded in part that the use of nutrient-holding mineral fertilizers such as NPK can maximize productivity with full crop water requirement since water is needed for nutrient transport, however, the concomitant use of organic fertilizers and deficit irrigation can promote water use efficiency in crop production, making production more water-smart. In the long run, this research study goes a long way to ensure that water and other very important resources are utilized to their maximum potential. The results of this research also provided insights into optimizing water and nutrient management practices for tomato production, both in controlled environments like greenhouses and potentially in open-field agriculture. By simulating crop responses under various scenarios, the study aimed to inform future research directions and develop recommendations for sustainable water and nutrient use in tomato cultivation. Promoting the technology in areas of over-irrigation and utilization also ensures conscious and sustainable use of water resources. In all, this study meets the overall objective of ensuring water-smart agricultural practices.

Article 4: "*Water smart farming: review of strategies, technologies, and practices for sustainable agricultural water management in changing climate in Africa*"

The review by Frimpong et al. highlights the relevance of the adoption of water-smart practices in agriculture. In the face of changing climatic conditions, it is vital to ensure the conservation of excess water for use during periods of water scarcity. This study provided a thorough framework for enhancing agricultural water management and encouraging water-smart farming techniques. It highlights the importance of water-smart cropping as a natural response to climate change adaptation and how it may protect water supplies for coming generations. This paper also presents key findings on the practices that seek to conserve water or cut the amount of water usage while ensuring crop productivity at different levels of production. It sheds more light on the strategic planning of water resource management and allocation. It also provides valuable insights into the adoption of small-scale irrigation techniques that are budget-friendly to smallholder rural farmers. In as much as climate change may pose a great threat to soil water balance, this paper proposes that climate-smart water solutions such as alternate wetting and drying, cover cropping intercropping with leguminous crops may likely increase water use efficiency for root and tuber crops (Owusu Danquah et al., 2022).

According to Frimpong et al., there are varying ways water smart technologies can be implemented. This paper highlighted some ensures that can be put in place to implement these smart techniques. Among such mentions was the need to educate smallholder farmers to adopt advanced irrigation techniques such as the drip irrigation system which seeks to reduce waste water recorded on the field. Consequently, the paper suggested that farmers should plant drought-resistant crops that can withstand the harsh realities of water scarcity and as well adopt the adjustment of planting dates and times as the climatic conditions demand. This will likely go a long way to improve water use efficiency and crop yield. As part of the remedies, rainwater harvesting techniques were mentioned as a very important way of managing the water resources available for future usage (Oteng-Darko et al., 2018).

Other alternate innovative water-smart approaches suggested in the paper include floating agriculture, vertical farming, micro-irrigation and deficit irrigation. In this paper, it is also worth noting that water-smart cropping practices may lead to yield penalties and reduced crop yield potential in agroecological zones where water is not the primary limiting factor. One of the reasons why these climate-smart efforts have not paid off could be attributed to the use of improved varieties and fertilizers without following good agronomic practices (Awio et al., 2022).

Prioritizing techniques to increase the uptake of water-smart crop farming methods, particularly in areas with limited resources, as well as looking into adoption incentives and knowledge transmission channels are some of the future research goals. It is imperative to strike a balance between crop-centric methods and water-saving measures and to carry out thorough evaluations of their effects on livelihoods, production, and environmental sustainability. It should be highlighted, too, that in some agroecological zones where water is not the dominant limiting factor, a heavy emphasis on water conservation may result in yield penalties (FAO, 2022). To promote inclusive and equitable development, comparative studies across areas, gender, and youth involvement must all be taken into account. The study's contextualization in the West African region and its heavy emphasis on water conservation are among its limitations, which may restrict its generalizability to other locations. All things considered, the successful application of water-smart crop farming necessitates a sophisticated strategy that takes into account regional differences, strikes a balance between crop-centric tactics and water-saving imperatives, and promotes rigorous research to help bring about significant change in global agricultural practices. This study has significantly contributed to the knowledge of climate and water smart agriculture by providing insights into the best agronomic practices, water management techniques and resource-efficient measures that can be adopted by each small holder farmer. However, the study may be biased toward West Africa and cannot be used as a generalization for other parts of the continent.

Conclusion

These four articles published by various researchers aim at investigating sustainable ways of conserving water for agricultural productivity. They contribute to our understanding of the extent of the threats posed by climate change in the past years and the future implications. They also focus on soil and water conservation practices, efficient irrigation methods, and nutrient management practices. As part of the Research Topic, sustainable water conservation practices such as rainwater harvesting techniques, and small-scale irrigation are proposed. The synthesis emphasizes how critical it is to ensure that adaptive solutions to improve the resilience and effectiveness of agricultural systems in addition to mitigating the negative effects of climate change are continually researched and developed. The knowledge gained from these studies is like a beacon pointing the way toward a more sustainable and adaptable water-smart future for agriculture in Africa as we find ourselves at the crossroads of environmental uncertainties and agricultural demands.

Author contributions

PA-Y: Conceptualization, Writing – original draft. SY: Supervision, Writing – review & editing. DO-S: Supervision, Validation, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abuarab, M. E., El-Mogy, M. M., Hassan, A. M., Abdeldaym, E. A., Abdelkader, N. H., El-Sawy, B. I., et al. (2019). The effects of root aeration and different soil conditioners on the nutritional values, yield, and water productivity of potato in clay loam soil. *Agronomy* 9, 418. doi: 10.3390/agronomy9080418

Al-Ghobari, H. M., and Dewidar, A. Z. (2018). Integrating deficit irrigation into surface and subsurface drip irrigation as a strategy to save water in arid regions. *Agric. Water Manage.* 209, 55–61. doi: 10.1016/j.agwat.2018.07.010

Amankwaa-Yeboah, P., Yeboah, S., Asibuo, J. Y., Adomako, J., Darko, C., Agyeman, K., et al. (2023). Tied ridging enhances soil water conservation and productivity of common bean (Phaseolus vulgaris). *Agro-Science* 21, 41–48. doi: 10.4314/as.v21i4.7

Arah, I. K., Kumah, E. K., Anku, E. K., and Amaglo, H. (2015). An overview of post-harvest losses in tomato production in Africa: causes and possible prevention strategies. *J. Biol. Agric. Healthc.* 5, 78–88. doi: 10.1155/2016/6436945

Awio, T., Senthilkumar, K., Dimkpa, C. O., Otim-Nape, G. W., Struik, P. C., and Stomph, T. J. (2022). Yields and yield gaps in lowland rice systems and options to improve smallholder production. *Agronomy* 12:552. doi: 10.3390/agronomy12030552

Backeberg, G. (2018). *Estimating Irrigated Area and Water Use from Remote Sensing Data*. Pretoria: Grain SA.

Brempong, M. B., Yeboah, S., Marno, P., Addo-Danso, A., Keteku, A. K., Agyeman, K., et al. (2022). Enhancing common bean tolerance to short-term droughts at the reproductive stage using a soil fertility management approach. *J. Exp. Agric Int.* 44, 56–74. doi: 10.9734/JEAI/2022/v44i112053

Chakraborty, K., and Mistri, B. (2017). Estimation of soil compaction from bulk density and its effect on crop production: a case study of burdwan-I block, West Bengal. *Indian J. Spatial Sci.* 8, 101–107.

Dorau, K., Luster, J., and Mansfeldt, T. (2018). Soil aeration: the relation between air-filled pore volume and redox potential. *Eur. J. Soil Sci.* 69, 1035–1043. doi: 10.1111/ejss.12717

FAO (2021). *Drought and Agriculture*. Land and Water. Available online at: http://www.fao.org/landwater/overview/en/ (accessed January 26, 2024).

FAO (2022). *Water Efficiency, Productivity and Sustainability in the NENA Regions (WEPS-NENA)*. Rome: Food and Agricultural Organization of the United Nations.

Hendricks, G. S., Shukla, S., Obreza, T. A., and Harris, W. G. (2014). Measurement and modeling of phosphorous transport in shallow groundwater environments. *J. Contam. Hydrol.* 164, 125–137. doi: 10.1016/j.jconhyd.2014.05.003

Hoogenboom, G., Porter, C. H., Boote, K. J., Shelia, V., Wilkens, P. W., Singh, U., et al. (2019). "The DSSAT crop modeling ecosystem," in *Advances in Crop Modelling for a Sustainable Agriculture* (Burleigh Dodds Science Publishing), 173–216.

Ierna, A., Pandino, G., Lombardo, S., and Mauromicale, G. (2011). Tuber yield, water and fertilizer productivity in early potato as affected by a combination of irrigation and fertilization. *Agric. Water Manage.* 101, 35–41. doi: 10.1016/j.agwat.2011.08.024

Jones, J. W., Hoogenboom, G., Porter, C. H., Boote, K. J., Batchelor, W. D., Hunt, L. A., et al. (2003). The DSSAT cropping system model. *Eur. J. Agron.* 18, 235–265. doi: 10.1016/S1161-0301(02)00107-7

Khodadadi, M., Alewell, C., Mirzaei, M., Ehssan-Malahat, E., Asadzadeh, F., Strauss, P., et al. (2021). Deforestation effects on soil erosion rates and soil physicochemical properties in Iran: a case study of using fallout radionuclides in a Chernobyl contaminated area. *Soil Disc.* 2021, 1–41. doi: 10.5194/soil-2021-2

Kleppel, G. S., and Frank, D. A. (2022). Structure and functioning of wild and agricultural grazing ecosystems: a comparative review. *Front. Sust. Food Syst.* 6:945514. doi: 10.3389/fsufs.2022.945514

Li, Y., Guan, K., Schnitkey, G. D., DeLucia, E., and Peng, B. (2019a). Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States. *Global Change Biol.* 25, 2325–2337. doi: 10.1111/gcb.14628

Li, Y., Niu, W., Cao, X., Wang, J., Zhang, M., Duan, X., et al. (2019b). Effect of soil aeration on root morphology and photosynthetic characteristics of potted tomato plants (*Solanum lycopersicum*) at different NaCl salinity levels. *BMC Plant Biol.* 19, 1–15. doi: 10.1186/s12870-019-1927-3

Linderhof, V., Cervi, W. R., van Oosten, C., Duku, C., Witte, E., Derkyi, M., et al. (2022). *Rainwater Harvesting for Irrigation for Climate-Resilient and Circular Food Systems: The case of Ghana's Bono East Region (No. WCDI-22-204)*. Wageningen: Wageningen Centre for Development Innovation.

Mutambara, S., Darkoh, M. B., and Atlhopheng, J. R. (2016). A comparative review of water management sustainability challenges in smallholder irrigation schemes in Africa and Asia. *Agric. Water Manage.* 171, 63–72. doi: 10.1016/j.agwat.2016.03.010

Nakawuka, P., Langan, S., and Barron, J. (2018). A review of trends, constraints and opportunities of smallholder irrigation in East Africa. *Global Food Secu.* 17, 196–212. doi: 10.1016/j.gfs.2017.10.003

Oteng-Darko, P., Frimpong, F., Sarpong, F., and Amenorfe, L. P. (2018). Promoting smallholder irrigation for food security – A review. *Afr. J. Food Integr. Agric.* 2, 1–7.

Owusu Danquah, E., Danquah, F. O., Frimpong, F., Dankwa, K. O., Weebadde, C. K., Ennin, S. A., et al. (2022). Sustainable intensification and climate-smart yam production for improved food security in West Africa: a review. *Front. Agron.* 4:858114. doi: 10.3389/fagro.2022.858114

Patel, A., Singh, R. C., and Singh, D. (2018). *Farm Machinery for Conservation Agriculture*. Available online at: https://www.biotecharticles.com/Agriculture-Article/Farm-Machinery-for-Conservation-Agriculture-4462.html (accessed October 17, 2022).

Peña-Gallardo, M., Vicente-Serrano, S. M., Domínguez-Castro, F., and Beguería, S. (2019). The impact of drought on the productivity of two rainfed crops in Spain. *Natural Hazards Earth Syst. Sci.* 19, 1215–1234. doi: 10.5194/nhess-19-1215-2019

Ramesh, V., and Iqbal, S. S. (2022). Urban flood susceptibility zonation mapping using evidential belief function, frequency ratio and fuzzy gamma operator models in GIS: a case study of Greater Mumbai, Maharashtra, India. *Geocarto Int.* 37, 581–606. doi: 10.1080/10106049.2020.1730448

Savva, A. P., and Frenken, K. (2002). *Crop Water Requirements and Irrigation Scheduling*. Harare: FAO Sub-Regional Office for East and Southern Africa, 132.

Song, L., Jin, J., and He, J. (2019). Effects of severe water stress in maize growth processes in the field. *Sustainability* 11:5086. doi: 10.3390/su11185086

Steyn, J. M., Franke, A. C., Van der Waals, J. E., and Haverkort, A. J. (2016). Resource use efficiencies as indicators of ecological sustainability in potato production: a South African case study. *Field Crops Res.* 199, 136–149. doi: 10.1016/j.fcr.2016.09.020

Tóth, Z., Táncsics, A., Kriszt, B., Kröel-Dulay, G., Ónodi, G., and Hornung, E. (2017). Extreme effects of drought on composition of the soil bacterial community and decomposition of plant tissue. *Eur. J. Soil Sci.* 68, 504–513. doi: 10.1111/ejss.12429