Optimizing Water Conservation and Crop Yield: Evaluating the Blue Water Saving Potential of Deficit Irrigation and Mulching in the Nile Basin

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Abstract

This study aims to investigate the potential water savings achieved through implementing deficit irrigation (DI) combined with mulching in the Nile Basin countries. The study analyzes the effects of blue water consumption and water footprint (WF) on various crops in the Nile basin countries. We utilized the AquaCrop-OS model to evaluate the effects of blue crop water use and water footprint of dominant crops. Changes in blue crop water use (CWU) varied between countries and crops, ranging from -34% to -1%. Yield varied in the simulations, with some decreases and some increases compared to the reference (R). The blue water footprint exhibited relative changes ranging from -47% to 35%. The changes in blue water footprint (measured in m^3/y) resulting from deficit irrigation and mulching impacted production while maintaining a constant irrigation area. In South Sudan, for cotton, Deficit irrigation (DI1) resulted in a -12.5% relative decrease in blue WF compared to R. However, the reduction in blue WF was more significant (-37.2% relative decrease) when DI1M compared to R. Other countries also experienced varying reductions in blue WF for crops. These findings show the possibility of saving water while keeping production levels stable. In Egypt, DI1 resulted in an 8.0% reduction in blue WF compared to R. Combining DI1M led to a more significant reduction of 37.2%. This study provides useful information for water conservation decision-makers in the Nile Basin countries.

Keywords: Water conservation, Deficit irrigation, Mulching, Blue water saving, Nile Basin

1. Introduction

Water scarcity is an important global issue, especially in resource-constrained arid and semi-arid countries (UNEP, 2016). Due to population expansion, climate change, and competing water needs, the nations of the Nile Basin in northern Africa experience severe water scarcity (Beyene et al., 2017; McCartney et al., 2017). To maximize agricultural water usage effectiveness, it is crucial to develop sustainable water management practices (UNEP, 2016). Promising strategies include employing mulch to limit evaporation losses and weed development, implementing deficit irrigation techniques, and providing less water than necessary for maximum productivity (Bittelli et al., 2001). The Nile Basin's traditional irrigation methods are inefficient, which calls for the investigation of deficit irrigation and mulching approaches (FAO, 2017; Brouwer et al., 2008). Deficit irrigation promotes crop sustainability in arid areas. According to Ararssa et al. (2019), utilizing deficit irrigation for barley production holds significant promise for enhancing water efficiency.

One possible way to improve water conservation in agriculture is to implement deficit irrigation techniques. By strategically delivering less water than what is necessary for maximum crop yield, deficit irrigation causes controlled water stress to crops at specific growth phases. By balancing the crop water needs with the available water supply, eliminating wasteful water losses, and increasing overall water productivity, this technique encourages efficient water use (Doorenbos & Kassam, 1979). Mulching is a further efficient water-saving method that can be used in along with deficit irrigation. Mulching is the process of adding an organic or synthetic layer to the soil surface around plants to reduce evaporation, prevent weed growth, and improve soil moisture retention. Mulching can help by lowering evaporation losses and reducing weed competition.

For economic growth and food security, the nations of the Nile Basin, such as Egypt, Sudan, Ethiopia, and others, heavily rely on agriculture (FAO, 2017). Traditional irrigation methods in these nations exhibit inefficiencies because of high evapotranspiration rates, water losses from runoff and deep percolation, and insufficient water distribution networks (Brouwer et al., 2008; McCartney et al., 2017). To improve water conservation in the Nile Basin region, it is necessary to investigate and assess the possibilities of deficit irrigation and mulching approaches (FAO, 2017; Brouwer et al., 2008). The study by Kebede, et al., (2019) looks at the management and development of water resources in the Ethiopian Nile Basin.

Many studies have shown that deficit irrigation and mulching positively impact blue crop yield and water usage. The impact of deficit irrigation and mulch application on crop productivity and agricultural water management was analyzed in the studies. The research has revealed crucial information on the benefits, drawbacks, and sustainable water management strategies for optimizing crop yields while preserving water resources. In their study, Sadras and Slafer (2012) examined how environmental factors, particularly deficit irrigation, affect wheat grain filling, yield, and quality. Deficit irrigation techniques reduce blue crop water use while maintaining acceptable crop yield levels.

In the context of the countries in the Nile Basin, this study intends to evaluate the blue water saving potential of deficit irrigation and mulching practices. According to Rockström et al. (2009) and Hoekstra & Mekonnen (2011), blue water refers to freshwater resources that are accessible to humans and are kept in rivers, lakes, and groundwater aquifers. This research offers an alternative perspective by concentrating on the nations of the Nile basin and analyzing the possibilities for blue water conservation through deficit irrigation and mulching. It offers specific insights and suggestions to address specific water conservation issues in this area. This research will provide important light on how well these methods work to reduce water scarcity and support sustainable agricultural water management in all countries of the Nile Basin. The findings of this study will assist in educating policymakers, water resource managers, and farmers on the benefits of these measures to increase water conservation and improve agricultural productivity in the Nile Basin region and to support evidence-based decision-making.

2. Methods and Materials

2.1 Description of the Study Area

The study area focuses on the Nile River Basin countries, one of the world's longest rivers, flowing through several countries in northeastern Africa, including Egypt, Sudan, South Sudan, Ethiopia, Uganda, and others. A complex network of rivers, lakes, wetlands, and groundwater systems that sustain various ecosystems and support the livelihoods of millions of people (UNEP, 2010).

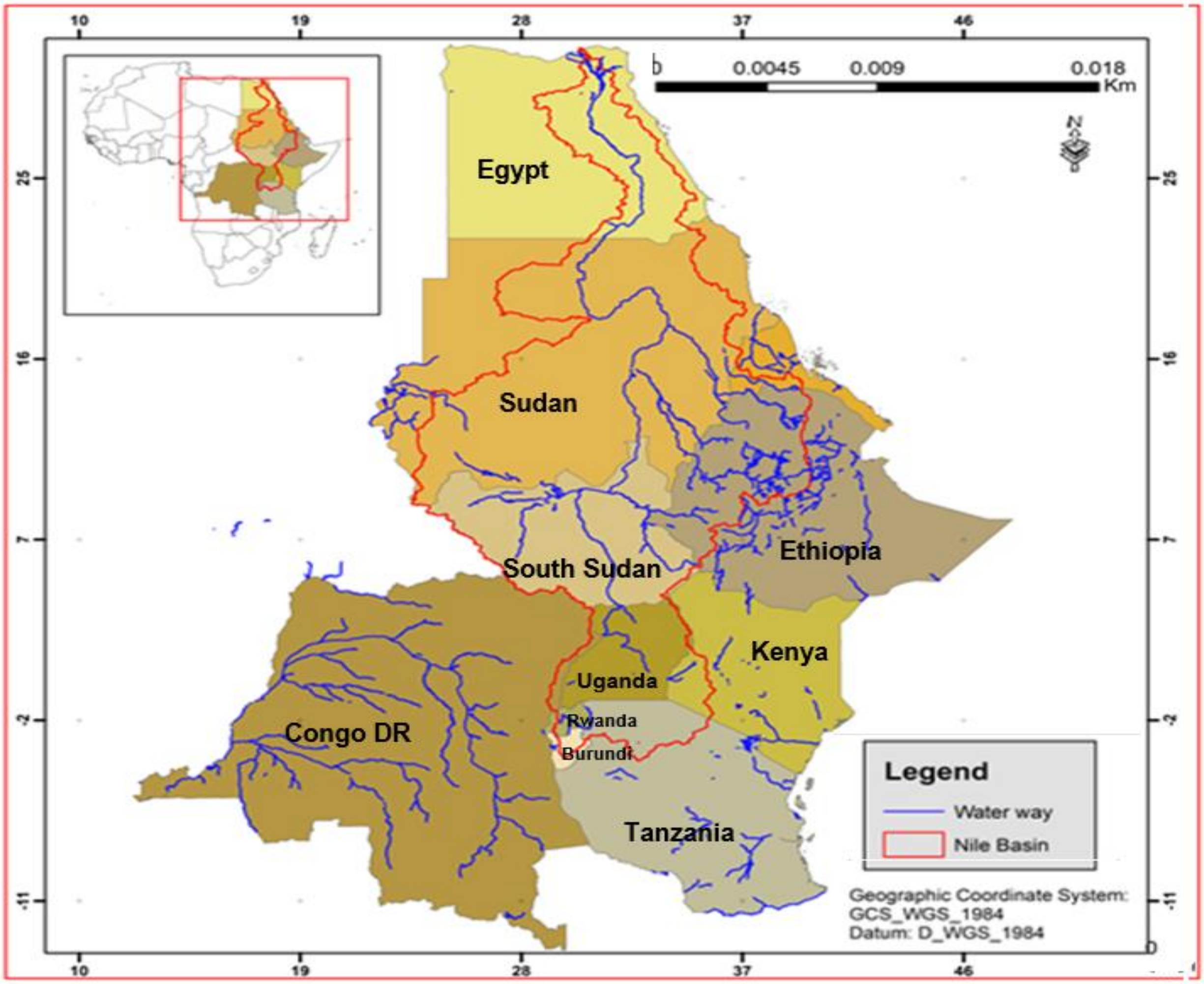

Figure 1. The study area of the Nile River Basin countries

The Nile River Basin countries encompass a region of significant importance regarding water resources and agriculture. Beyene et al. (2020) provide an overview of water resources in the Nile River Basin, addressing challenges such as water scarcity, inefficient use, and competing demands. It emphasizes the importance of sustainable water management and identifies opportunities for improving governance and enhancing regional water security.

Melesse, et al. (2020) present a comprehensive overview of the Nile River Basin, exploring the connections among water, agriculture, and livelihoods. It provides valuable insights into the complex dynamics and interdependencies within the Nile River Basin. The Nile Basin countries share the Nile River and its tributaries, which are essential for agriculture, domestic use, and industry. The region exhibits diverse climatic and hydrological conditions, ranging from arid and semi-arid regions to highland areas with more favorable rainfall patterns. The topography also varies, with flat plains and mountainous regions influencing water availability, runoff patterns, and soil characteristics.

Since a significant portion of the population depends on farming for a living, agriculture is important to the economy of the nations in the Nile Basin. However, due to water scarcity and ineffective water management techniques, sustainable agriculture and water resource management confront difficulties. The Nile basin is an essential transboundary basin due to its limited water supply, but its rapidly expanding population strains its natural resources, notably water. A catastrophe of water scarcity could result when there is an increased water demand; disputes about the relationship between the river and the watershed have also developed.

The amount of rainfall affects the vegetation cover in the Nile basin, with the southern section receiving a greater amount of precipitation than the northern part, which is in the Sahara Desert. A significant percentage of the population relies directly or indirectly on agriculture for their livelihoods, making the area one of the poorest in the world. Agriculture represents the primary water consumed in the Nile basin countries, except for Uganda, and it plays a crucial role in the economy. The actual water consumption for irrigation accounts for 5% of the water withdrawn for industrial, with the remaining fraction constituting the return flow.

2.2 Data

The methods employed in this study included data collection and simulations for five primary irrigated crops in the Nile basin countries: maize, sorghum, wheat, cotton, and potato. Various global data sources were utilized to estimate the crop water footprint, including precipitation, reference evapotranspiration, temperature, and soil data. The MIRCA 2000 dataset provided information on each crop's irrigated and rain-fed harvested areas, which was adjusted to align with FAO's national-level total harvested area. The initial soil moisture was established by executing the model with soil moisture set to field capacity throughout the entire period.

2.3 Technique

The five dominant crops' water footprint (WF) was estimated for 2011-2015 in Nile Basin countries. To assess potential blue water savings, we utilized the AquaCrop-OS plugin model, an open-source version of FAO's AquaCrop model, applied at a spatial resolution of 5x5 arc minutes for all selected crops and grid cells.

First, we conducted simulations based on current agricultural practices, referred to as the reference case. This involved standard full irrigation practices without mulching. Secondly, we simulated a scenario within the irrigated areas, implementing deficit irrigation and mulching. The water-saving potential was computed by comparing the blue water footprint between the reference case and the scenario. The mulching technique employed in this study involved 100% organic mulching, which comprised naturally decomposable materials.

To ensure the dataset's accuracy, countries with negligible irrigated areas like ERI and COD were removed, along with the exclusion of Ethiopia PDR due to double counting with Ethiopia. Former Sudan (SDN former) was also deleted from all tables due to double-counting of irrigated area. The DI2 strategy showed a significant drop in yield compared to the reference, indicating a deviation from the typical deficit irrigation approach towards more supplemental irrigation. Former Sudan (SDN former) was removed from all tables due to the double-counting of irrigated areas. The calculation of Blue Consumptive Water Use (CWU) only considered ET blue from irrigation, excluding capillary rise. The simulations were performed using the AquaCrop-OS plugin model, an open-source version of FAO's AquaCrop model. The model was implemented at a spatial resolution of 5x5 arc minutes for all selected dominant crops. Two scenarios were simulated: the current agricultural practices (reference case) and a scenario with deficit irrigation and mulching in irrigated areas. The water-saving potential was computed as the difference between the blue water footprint in the reference and scenario.

2.4 Selection of Crops

Our crop selection for analysis is based on their significant contribution to the irrigated area in Nile basin countries, accounting for 41% of the total (Portmann et al., 2010). The crops were selected based on their significance and potential for water conservation. We focused on major irrigated crops: maize, sorghum, wheat, cotton, and potato. These crops offer the greatest potential for blue water savings: wheat (14.5%), maize (13.1%), cotton (6.9%), and sorghum (6.7%). However, we excluded rice (9.8% of the irrigated area) due to its cultivation as paddy rice on inundated fields, which makes deficit irrigation and mulching impractical. Additionally, we included potatoes (2.0% of the irrigated area) as they are an important staple crop in the Nile basin, allowing us to examine the effects of deficit irrigation on potato yields. By focusing on these specific crops, we aimed to assess the effectiveness of various irrigation and water management techniques in optimizing water usage and improving overall sustainability in crop production.

To evaluate the crops' sensitivity to water stress, we considered the irrigated areas of various crops over a 30-season period, using the most recent 30 years of data. We focused on crops identified as sensitive to water stress by the Food and Agriculture Organization (FAO). Additionally, the analysis accounted for blue consumptive water use (CWU), specifically ET blue from irrigation, while excluding capillary rise. The consideration of blue CWU, irrigation, and blue CWU capillaries was suggested. The next steps involved simulating crops using the D1 strategy combined with mulching, resulting in the D1M scenario. As suggested by Portman, the inclusion of winter wheat was considered, and results for D1and mulching (D1M) were added.

2.5 Deficit irrigation strategies and mulching technique

In this study, we focused on evaluating deficit irrigation strategies and the effectiveness of mulching techniques. We conducted experiments to determine the optimal type, thickness, and application method for organic mulching. Subsequently, we integrated mulching with deficit irrigation simulations to evaluate their combined water-saving potential. To develop deficit irrigation strategies, we consider the selected crops' water requirements and tolerance to water stress. These strategies defined irrigation thresholds and timings based on crop growth stages and soil moisture levels. We then implemented deficit irrigation simulations using these strategies. In AquaCrop, the simulation of water stress response encompasses three thresholds of soil moisture depletion (Steduto et al., 2009b), which correspond to changes in canopy expansion, stomatal closure, and accelerated senescence.

Our analysis encompassed the preparation of a dataset and the execution of simulations for five primary irrigated crops (maize, sorghum, wheat, cotton, and potato) in the Nile basin countries. Four simulations were performed, representing different scenarios for the irrigated areas of these crops. The first scenario, labeled as Reference (R), represented full irrigation without mulching. It involved refilling the fields to field capacity (FC) when soil moisture content reached 50% of the total available water. The second scenario was Deficit irrigation strategy one (D1). We also conducted stricter deficit irrigation strategy two (D2) simulations, allowing for increased water stress compared to D1. However, after evaluating these simulations, we observed excessive yield decline in several countries with D2, leading us to select D1 for further analysis.

Furthermore, we evaluated different irrigation and mulching options to assess their impact on yield and water management. These options included full irrigation without mulching, deficit irrigation option one without mulching, stricter deficit irrigation option two without mulching, and the most effective deficit irrigation option (either 1 or 2) with organic mulching. The results of these simulations provided valuable insights into the effectiveness of each approach and the role of mulching in enhancing water efficiency and crop productivity. By reducing water evaporation and improving soil moisture, mulching effectively controls weed growth, enhances conservation agriculture, and integrated nutrient management practices (Ngosong et al., 2019).

To evaluate the impact of water stress on the crops, we employed the ACEA framework, which consisted of four stages: sowing to 10% crop cover (CC), 10% CC to maximum CC, maximum CC to start CC decline and starting CC decline to maturity. Each stage had a specific interpretation, and the upper threshold for water stress-stomatal closure (rho_sto) varied for different crops. Moreover, we adopted an irrigation setup based on the identified effective deficit irrigation strategy. This strategy included different test scenarios (T1 to T6), ranging from the least strict to the most strict. For each scenario, parameters such as surface wetting percentage and soil moisture depletion thresholds triggering irrigation in drought-sensitive and drought-tolerant phases were considered as a percentage of total available water (TAW). Finally, the analysis covered a range of Nile basin countries, including Burundi, Egypt, Kenya, Eritrea, Rwanda, Sudan (former), the United Republic of Tanzania, Uganda, and Ethiopia.

3. Results and Discussion

The following section presents the results and discussion of the research findings. It encompasses the analysis of data obtained from simulations conducted under various scenarios and interpreting and exploring these findings. The results provide valuable insights into the effects of deficit irrigation, organic mulching, and their combined application on factors such as blue consumptive water use, crop yield, and blue water footprint. Additionally, the discussion examines the implications and significance of these results, considering their potential for water conservation, sustainability, and agricultural practices.

This section presents the outcomes of our simulations conducted under diverse scenarios, encompassing two fundamental concepts. Firstly, we analyze the impact of deficit irrigation on blue consumptive water use (CWU), crop yield, and blue water footprint (WF) throughout 2011-2015 (average). This examination allows us to evaluate the additional effect of incorporating organic mulching with deficit irrigation. Secondly, we provide comprehensive information on the absolute value of the blue water footprint in cubic meters per year (m^3/y) and the relative savings achieved through the implementation of deficit irrigation and deficit irrigation combined with organic mulching. According to comparable studies by Nouri et al. (2019), the combination of organic mulch and drip irrigation led to the greatest reduction in the blue water footprint. This study suggests that less irrigation water is being used.

3.1 Effect of deficit irrigation and mulching on blue crop water use (CWU) in mm/y)

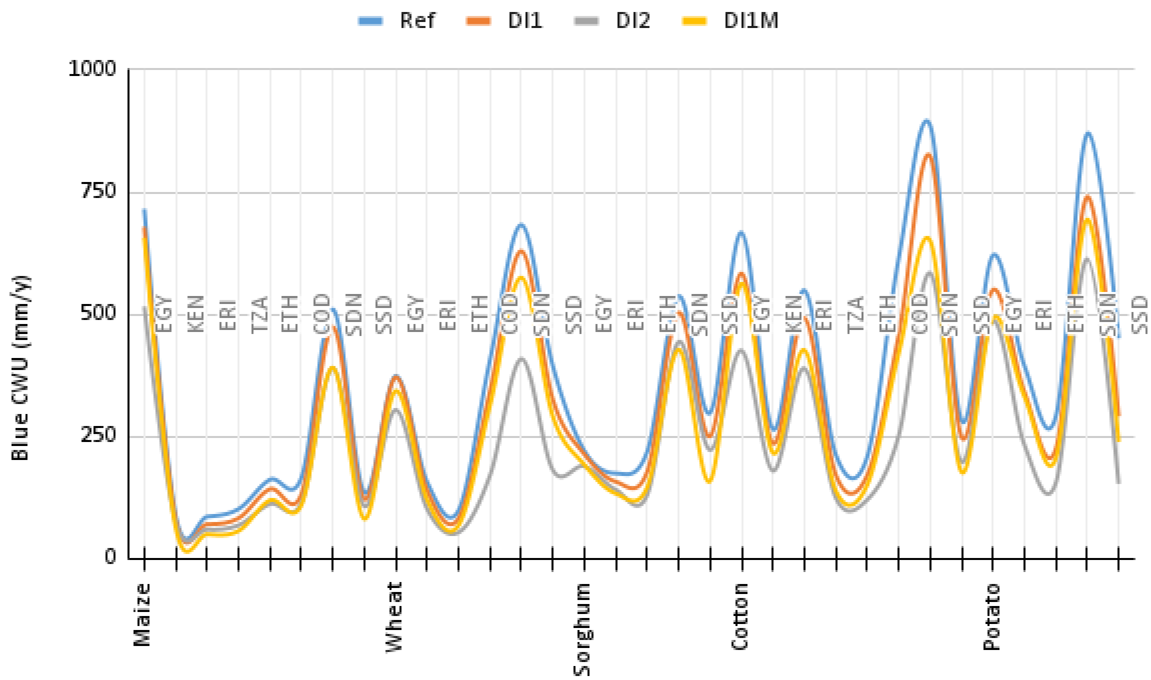

Figure 2. Effect of Deficit Irrigation and Mulching on Blue Crop Water Use (CWU)

Based on the provided data on the five crops, deficit irrigation, and mulching are the two main scenarios used to save water in various countries. Based on the findings of the result, it reveals that among the countries listed, Egypt stands out with the highest crop water use reference value of 715.61mm/y, indicating its relatively high potential yield for maize. Sudan (SDN) experiences the most significant water deficit for maize cultivation, as evidenced by the highest deficit values in both D1 (473.7mm/y) and D2 (390.91mm/y). However, it is worth noting that organic mulching (D1M) shows promise in reducing the deficit values across all countries, highlighting the potential benefits of implementing organic mulching techniques. Maize, in Egypt, maintains its prominence with the highest reference value (373.65mm/y) for wheat, suggesting favorable conditions for its cultivation. Conversely, Sudan (SDN) faces significant water deficits in wheat production, as indicated by the highest deficit values in both D1 (629.25 mm/y) and D2 (575.13 mm/y). However, deficit irrigation with mulching (D1M) exhibits a positive impact on reducing water for wheat in all countries, offering a potential solution to mitigate the scarcity.

When considering sorghum cultivation, Egypt again takes the lead with the highest reference value (220.92 mm/y). Sudan (SDN) emerges as the country experiencing the most pronounced water deficits, as evidenced by the highest deficit values in both D1 (502.9 mm/y) and D2 (427.63 mm/y) for sorghum.

However, the implementation of organic mulching (D1M) showcases a noticeable effect in reducing water deficits, particularly in Sudan (SDN) and South Sudan (SSD).

Egypt continues to dominate, boasting the highest reference value (667.04 mm/y) for cotton production. Similarly to other crops, Sudan (SDN) faces the highest deficit in both D1 (823.8 mm/y) and D2 (651.11 mm/y), highlighting the significant water scarcity involved in cotton cultivation. Nevertheless, organic mulching (D1M) proves to be effective in alleviating water deficits for cotton in all countries, with notable impacts observed in Sudan (SDN) and South Sudan (SSD).

Once again, Egypt has the highest reference value (620.86 mm/y) for potato cultivation. As expected, Sudan (SDN) also registers the highest deficit values in both D1 (805.42) and D2 (693.96 mm/y), signifying substantial water deficits during potato production. However, organic mulching (D1M) can potentially reduce water deficits for potatoes across all countries. Overall, the data reveals the existence of water deficits in various countries across different crops. Implementing techniques such as organic mulching can offer some relief by mitigating these deficits.

3.2 Effect of deficit irrigation on blue water footprint

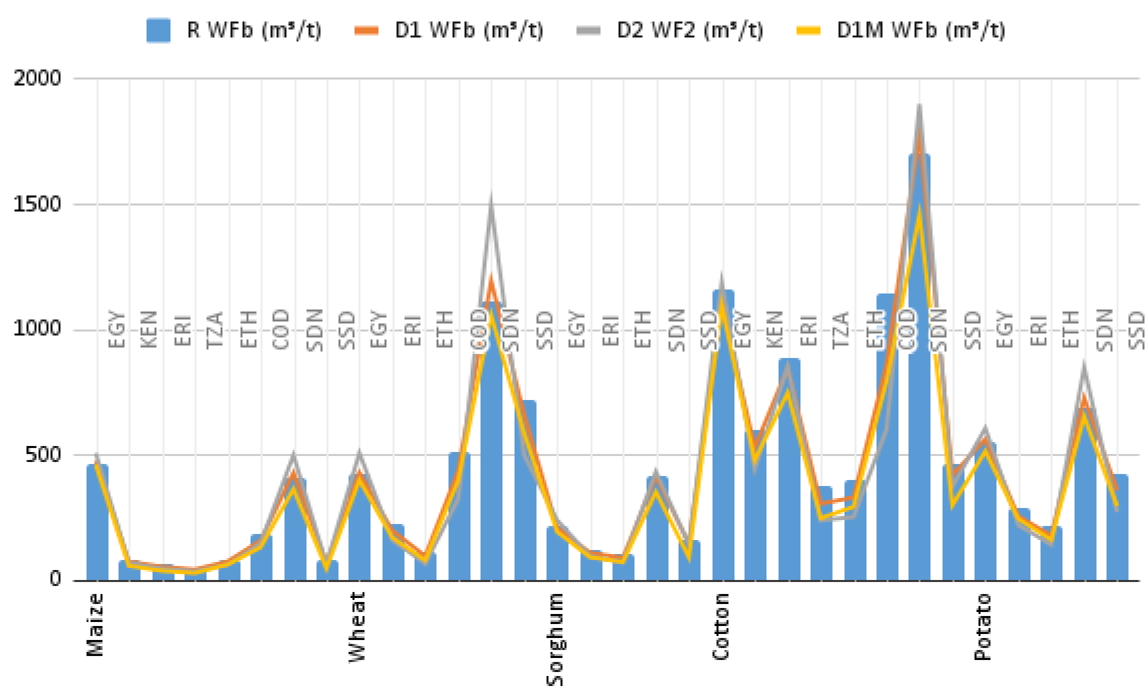

Figure 3. Effect of deficit irrigation on blue water footprint

In terms of maize, deficit irrigation (D1) and mulching (D1M) in Egypt demonstrated improved blue water conservation; however, in Kenya, both deficit irrigation techniques (D1, D2) and mulching (D1M) resulted in lower conservation. Regarding wheat, all irrigation techniques in Egypt showed similar conservation, while in Eritrea, deficit irrigation techniques (D1, D2, D1M) led to lower conservation. In Ethiopia, deficit irrigation (D1, D2) and mulching (D1M) had mixed effects. For sorghum, deficit irrigation (D1, D2) and mulching (D1M) in Egypt showed similar conservation, while in Eritrea, deficit irrigation and mulching led to lower conservation. Sudan and South Sudan experienced lower conservation with deficit irrigation. In terms of cotton, deficit irrigation and mulching had similar conservation in Egypt, while in Kenya, all techniques showed similar conservation. In Eritrea, deficit irrigation techniques resulted in lower conservation, and Tanzania experienced lower conservation with deficit irrigation. Sudan had higher conservation with deficit irrigation, whereas South Sudan saw lower conservation. Finally, for potatoes, deficit irrigation (D1) and mulching (D1M) in Egypt improved conservation, while in Eritrea, all deficit irrigation techniques resulted in lower conservation. In Ethiopia, deficit irrigation (D1, D2) and mulching (D1M) led to lower conservation. Sudan and South Sudan experienced lower conservation with deficit irrigation.

3.2 Effect of deficit irrigation on crop yield: relative yield change

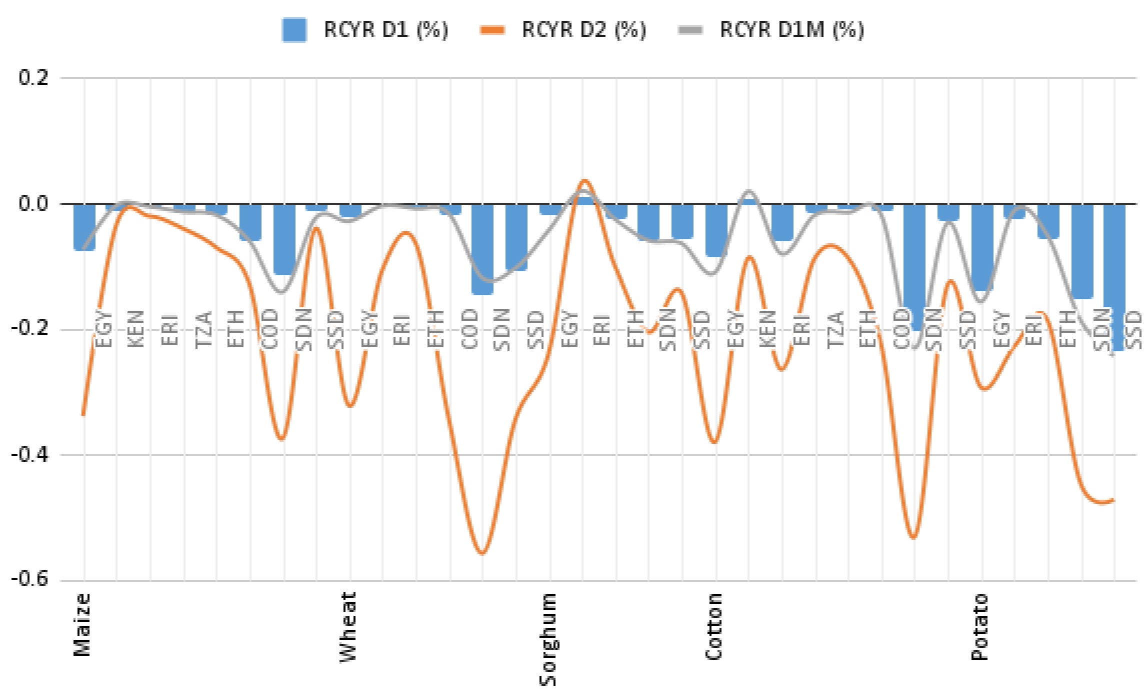

Figure 4: Effect of deficit irrigation on crop yield: relative change in simulated yield compared to the reference (%)

The highest percentage changes observed represent significant impacts on crop yield, whether negative or positive, compared to the reference. Negative changes indicate a decrease in yield, while positive changes indicate an increase in yield for specific crops, countries, and scenarios. These changes are represented as relative changes in simulated yield compared to the reference (%). The Relative change in simulated yield compared to R (%) for scenarios D1, D2, and D1M represents the ratio of the simulated yield for each scenario to the simulated yield (in tons per hectare) under the reference case.

Figure 3, provides a visual representation of the percentage change in crop yield compared to the reference value. A higher positive percentage indicates a greater increase in yield compared to the reference, while a higher negative percentage indicates a larger decrease in yield. For example, when we consider the crop Maize in Egypt (EGY) under Scenario D2, the RCYR D2 (%)value is -34%, indicating that the simulated yield of maize in Egypt under Scenario D2 is 34% lower than the reference yield. For example, Cotton in Sudan (SDN) under Scenario D2 has an RCYR D2 (%) value of -38%, indicating that the simulated cotton yield in Sudan under Scenario D2 is 38% lower than the reference yield. Similar interpretations can be made for other crops and countries based on their respective percentage values. Similar research was conducted by Abebe et al. (2015), who compared several management strategies, such as furrow irrigation, full irrigation, and no mulching, against a reference situation. According to the study, changing from the reference method to drip irrigation or subsurface drip irrigation (SSD) reduced consumptive water footprint (WF) by 8–10% on average.

On the other hand, a higher positive percentage indicates a larger increase in yield. For instance, in the crop Cotton, Kenya (KEN) under Scenario D1M, the RCYR D1M (%) value is 2%, indicating that the simulated cotton yield in Kenya under Scenario D1M is 2% higher than the reference yield. This pattern can be observed for other crops and countries as well. It is important to note that different crops, countries, and scenarios may exhibit varying levels of sensitivity to deficit irrigation and mulching practices. These results highlight areas where implementing these practices has had the most notable effects on crop productivity. Further analysis and investigation into the 'changes' underlining factors can provide valuable insights for agricultural decision-making and potential interventions. Factors such as irrigation methods, mulching, or other agricultural practices specific to each scenario, crop, or country may play a role in these yield variations.

3.4 Yield Changes under Deficit Irrigation for Different Crops and Countries

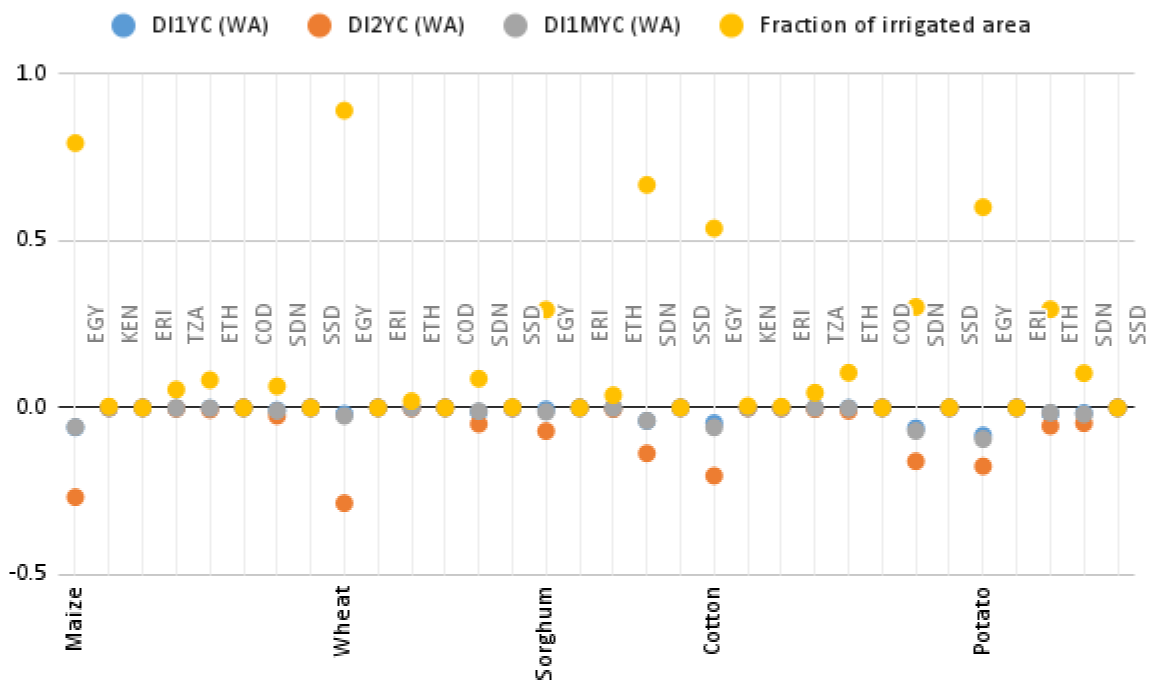

Figure 5. Relationship between the fraction of irrigated area and yield change (weighted average) under various scenarios

Among the analyzed crops, maize exhibits a decreasing trend in yield under deficit irrigation practices. In Egypt (EGY), both deficit irrigation (D1) and deficit irrigation with organic mulching (D1M) result in negative weighted-average yield changes, indicating a decrease in yield. Notably, Sudan (SDN) experiences the highest yield reduction with D2, emphasizing the sensitivity of maize yields to deficit irrigation in this region.

Moving on to wheat, negative yield changes are observed in both Egypt (EGY) and Sudan (SDN) across all irrigation scenarios. However, the magnitude of the decrease is relatively lower compared to maize. Egypt stands out with the highest yield reduction under D2, while Ethiopia (ETH) shows a similar pattern with less significant changes.

Egypt (EGY) demonstrates small negative yield changes across all irrigation scenarios for sorghum. Sudan (SDN) stands out with the highest yield reduction under D1. The weighted-average yield changes for deficit irrigation with organic mulching (D1M) remain relatively smaller across all countries, suggesting a potential mitigation effect of organic mulching on sorghum yields.

In the case of cotton, negative yield changes are observed in Egypt (EGY) and Sudan (SDN) for all irrigation scenarios. Egypt experiences the highest reduction in yield under D1, while Kenya (KEN) and Tanzania (TZA) display minimal yield changes. Ethiopia (ETH) shows a moderate decrease in cotton yield, highlighting the varying sensitivity of cotton crops to deficit irrigation across different countries.

Finally, deficit irrigation negatively impacts potato yields in Egypt (EGY) and Sudan (SDN) for all irrigation scenarios. Eritrea (ERI) exhibits the smallest yield changes among the countries analyzed. Notably, the largest reduction in potato yield is observed under D1 in Sudan, underscoring the substantial impact of deficit irrigation on potato production. These findings emphasize the diverse effects of deficit irrigation on crop yields, with negative yield changes indicating decreased production. The variation across crops, countries, and irrigation scenarios highlights the importance of considering local conditions and selecting appropriate irrigation strategies to optimize agricultural productivity.

The collective area encompasses the total blue water footprint. This visual representation allows for a comprehensive understanding of the variations in water usage across crops and scenarios within the given environment. Analyzing the table shows that Egypt consistently exhibits the highest blue water footprints for most crops, indicating the region's need for effective water management strategies. Conversely, Eritrea consistently displays the lowest blue water footprints across all crops. These findings highlight the need to prioritize efficient water utilization practices, such as deficit irrigation and mulching, to minimize the blue water footprint and enhance sustainability in agriculture within the Nile Basin countries.

3.5 Impact of Deficit Irrigation and Mulching on crop yield (t/ha)

Based on the provided data presents the study's key findings on the effect of deficit irrigation and mulching on Blue water conservation (WF (m^3/t) for five different crops across various countries. Can you please discuss the main observations from the data and make possible conclusions.

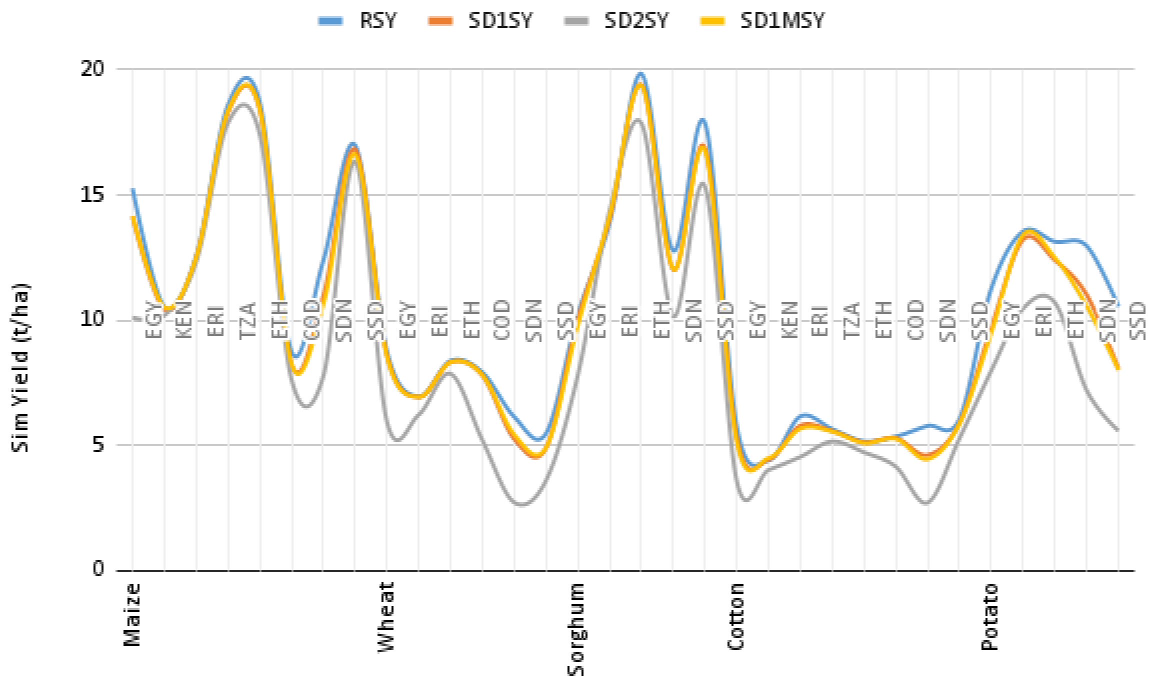

Figure 6. The data analysis reveals the impact of deficit irrigation and mulching on crop yield under deficit irrigation conditions across various countries.

The data includes several abbreviations used to denote yield values: RSY represents Reference Simulated yield (t/ha), SD1SY corresponds to Scenario deficit irrigation one simulated yield (t/ha), SD2SY represents Scenario deficit irrigation two simulated yield (t/ha), and SD1MSY indicates Scenario deficit irrigation and mulching simulated yield (t/ha). It's important to note that these abbreviations signify distinct simulated yield values for the corresponding scenarios.

In the case of maize, the inclusion of mulching in Egypt slightly improved the yield from 15.27 t/ha under deficit irrigation alone (SD1SY) to 14.14 t/ha with mulching (SD2SY). Similar trends were observed for maize in Kenya, Eritrea, Tanzania, Ethiopia, Congo, Sudan, and South Sudan, where mulching resulted in marginal yield improvements. For wheat, mulching (SD1MSY) generally led to higher yields compared to deficit irrigation alone (SD1SY). Egypt, Eritrea, Ethiopia, Congo, Sudan, and South Sudan showed increased wheat yields when mulching was applied. In the case of sorghum, mulching (SD1MSY) positively affected yield under deficit irrigation conditions. Countries such as Eritrea, Ethiopia, Sudan, and South Sudan experienced higher sorghum yields with mulching. Regarding cotton, mulching (SD1MSY) generally led to higher yields than deficit irrigation alone (SD1SY). Countries including Egypt, Kenya, Eritrea, Tanzania, Ethiopia, Congo, Sudan, and South Sudan witnessed varying yield improvements with mulching. For potatoes, mulching (SD1MSY) positively impacted yield, surpassing the yields obtained through deficit irrigation alone (SD1SY). Egypt, Eritrea, Ethiopia, Sudan, and South Sudan experienced increased potato yields with mulching.

Overall, the data indicates that mulching, in combination with deficit irrigation, has the potential to enhance crop yields. However, further analysis considering factors such as soil characteristics, climate conditions, and management practices is necessary to understand the optimal strategies for implementing deficit irrigation with mulching in different agricultural contexts.

Conclusions

Deficit irrigation and organic mulching effectively mitigate water deficit in crop production, with organic mulching showing promise in water conservation. Water deficit levels vary across countries and crops; Egypt and Sudan typically achieve their maximum yield potential with lower deficits than other countries. Organic mulching positively influences crop yield under deficit irrigation, enhancing productivity and mitigating water scarcity. Crop yield changes vary across crops, countries, and scenarios, emphasizing the need for tailored approaches. The conservation of blue water is influenced by irrigation techniques and mulching, requiring proper water management practices for agricultural activities. Sustainable crop production relies on appropriate water management strategies, including deficit irrigation and mulching. These findings highlight the potential benefits of these practices in addressing water scarcity and promoting sustainability. Further research can provide valuable insights for optimizing crop productivity and conserving water resources.

Author Contributions: All Authors set up the research, analyzed and interpreted the results and contribute to write the paper.

Declarations Conflict of Interests: No funding was received to assist with the preparation of this manuscript.

Data availability

The datasets generated during and/or analyzed in the course of the current study are available from the corresponding author on reasonable request.

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