IMPACTS OF IRRIGATION HETEROGENEITY ON SUGARCANE YIELDS, ENERGY AND WATER USE IN SUB-SAHARAN AFRICA

Final Year Student Progress Report

Submitted to the Sue White Fund

By

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May, 2024

1. Research Context Background

Grown in more than 100 countries, sugarcane is an internationally important crop. It is the source of 80% of the sugar consumed globally, 40% of the bio-ethanol and electricity. Thus, sugarcane is a significant contributor to the economy of many countries around the world. In 2020, global sugarcane production was estimated to be around 1.98 billion tons with Brazil, India and China being the world's top three cane producers. Globally, cane yield has increased from 50.26 t/ha in 1961 to 70.64 t/ha in 2020, representing an average yield increase of 0.4 t/ha per year over that period. The sugarcane production trends in Africa, over the same period, indicate an overall average production increase of over a 1.0 million t/year. However, unlike the global trend, the African yield trend over the same period shows an average reduction of 0.03 t/ha per year (Figure 1) - an indication that the increased total production tonnage has been due to an expansion in the overall harvested area.

Africa has high potential for agricultural production due to its suitable soils; available water resources for supplementary irrigation; wet and hot summers that are suited for plant growth; cool, sunny and dry winters that provide excellent conditions for conversion to sucrose and low costs of production (cost of labour is relatively low). Africa is also strategically close to European markets, and thus an important region for agricultural expansion.

In many African countries, irrigation is a requirement for improved sugarcane yields. However, sugarcane is considered to be among high-water demanding crops with average crop water requirements ranging between 18,000 and 20,000 m^3/ha. Thus, the expansion of the harvested area to increase cane production (tonnage), in the African case, would require more water volumetrically. This would likely intensify competition for water resources among already existing competing sectors including manufacturing industries, hydro-power generation, domestic water supplies, and for environmental flows protection. Thus, the expansion of irrigated sugarcane to increase cane production has implications that are more significant for irrigated agriculture compared to the production increase due to improved crop yield.

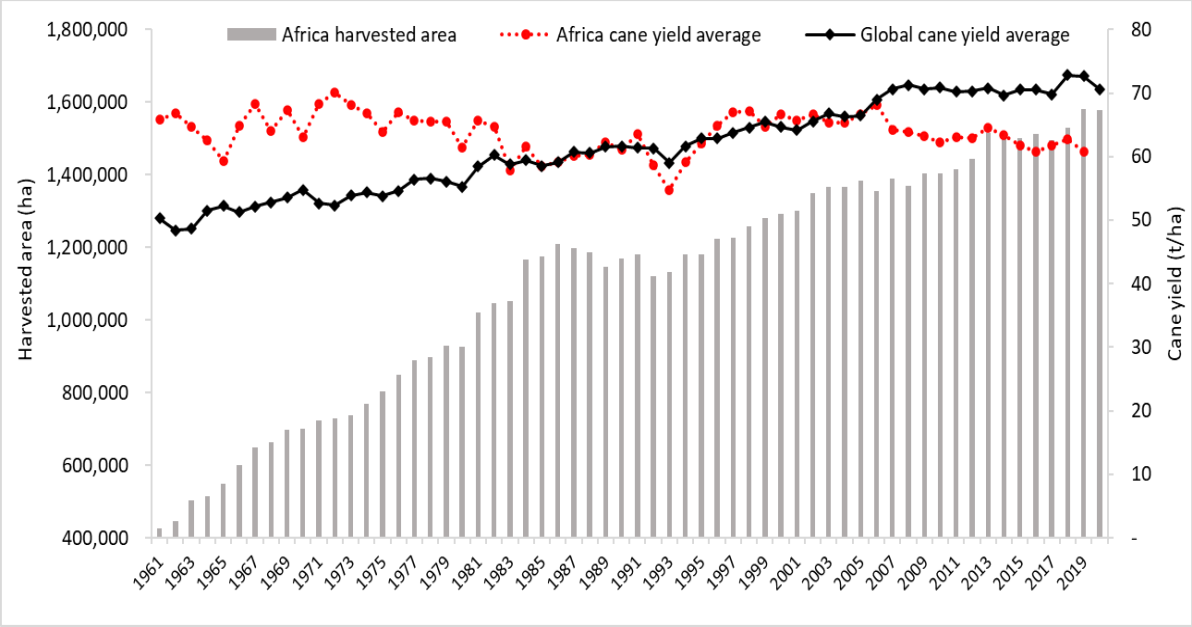

Figure 1: Reported cane yields (t/ha) and harvested areas (ha) between 1961 and 2020 (source: FAOSTAT, 2022)

Although sub-Saharan Africa (SSA) is not considered water poor, as it contains about 9% of the world's freshwater resources coupled with low per capita rate of water withdrawals, irrigated sugarcane production has great potential to alter local water balances, thus impacting on the dynamics, quality, and quantity of water supplies for competing uses at the watershed scale and beyond. Both sugarcane production and sugar processing can have significant impacts on water resources with an estimated water consumption of about 209 m^3/ton, making sugar production a major consumer of freshwater resources. In India, the world's second-highest sugarcane producer, irrigated production has led to extreme water shortages impacting on the long-term sustainability of the country's sugar industry. Thus, the dependence on expansion of the cane cultivated area to support increased sugarcane production is not a sustainable option.

Understanding the impacts of future climate variability and drought risk on the reliability of water for irrigation and identifying appropriate technology and management options to improve water and energy efficiencies to improve yields are among the key challenges and priorities facing the agricultural sector in SSA. While crop yields are also impacted by local agro-climate variability and other factors including soil variability; irrigation system performance, including irrigation uniformity, has also been shown to have a major bearing on crop yields and irrigation water use.

Although uniform water application on its own is not a guarantee for improved yields since it is also possible to have uniform under- or over-irrigation, improved yields are often associated with uniform application of adequate water.

Current irrigation systems performance gaps and the extent to which irrigation uniformity improvements might change yields, as well as the relationships between improving irrigation efficiency and energy consumption within sugarcane production in the SSA context were among the identified key research gaps. Therefore, there was an urgent need to develop a better understanding of the impacts of irrigation heterogeneity on cane yields, water and energy uses and the economic viability of implementing irrigation uniformity improvements to increase sugarcane yields for cane production in SSA. Quantifying the potential agronomic benefits (increased yields), water use efficiency (improved water productivity), environmental benefits (energy use) and economic benefits (increased revenues and reduced costs) as a result of improving irrigation uniformity in sugarcane production in SSA is critically important to support improved irrigation management decision making in the face of increasing water scarcity.

2. Research Aim and Objectives

Despite significant potential for agricultural expansion, SSA's agricultural productivity remains low. Implementation of interventions that improve irrigation uniformity have potential yields benefits. However, the extent to which the implementation of such irrigation uniformity improvements impacts on cane yields, irrigation water and energy use as well as economics of irrigated cane production remains unknown. Thus, the overall aim of this PhD research was to evaluate the agronomic, environmental and economic impacts of improving irrigation uniformity in sugarcane production in SSA.

The research specifically set out to address the following key questions:

i. Are there irrigation related opportunities for improving cane yields, water and energy use and productivity in SSA?

ii. How does irrigation non-uniformity impact on cane yields, water and energy use and water productivity?

iii. How does implementation of interventions to improve irrigation uniformity in the sugarcane industry in sub-Saharan Africa impact on the agronomic and economic benefits?

3. Approach to the Research

Initially, a benchmarking study was conducted to identify opportunities to improve cane yields and water productivity and reduce irrigation water and energy use. Cane yield response to water, the impacts of irrigation non-uniformity and the relative cost and benefits of improving irrigation uniformity were then modelled using a novel integration of biophysical crop, water balance and economic modelling approaches. The cane yields were modelled for varying water applications and irrigation uniformity using the DSSAT Canegro model coupled with a water balance model. A unique integration of a water balance model with in-built water distribution uniformity capabilities and DSSAT model enabled the simulation of impacts of irrigation uniformity on water use and cane yields at field scale. The relative financial costs and benefits of implementing different interventions to improve irrigation management were then evaluated using a spreadsheet-based economic model.

4. Brief Research Findings

The research findings showed that there were opportunities to improve the performance of irrigated cane production in SSA – currently characterised by lower-than-expected yields ranging between 83.9 and 108.9 t/ha, high irrigation water uses and lower than potential water productivity – ranging between 5.0 and 7.8 kg/m^3. It was also established that improving irrigation uniformity leads to improved cane yields, reduced irrigation water and energy use – on average a percentage improvement in irrigation uniformity could improve yields by 0.2 – 0.5 t/ha and could reduce irrigation and energy use by 3%. These potential yield improvements (due to improved irrigation uniformity) coupled with a reduction in water and energy use could potentially lead to increased revenues of between 23,300 and 70,900 MK/ha (*c*£18 – 65/ha) and a reduction in irrigation-related costs by 3,700 MK/ha (*c* £3/ha).

4. Research Project Impacts

Overall, the research has provided new valuable insights into the impacts of irrigation heterogeneity on cane yields and addressed existing knowledge gaps relating to how existing irrigation management practices in the sugarcane industry in SSA can be

improved, without the need for transformational shifts to precision irrigation technologies. The findings provide the basis for improving cane yields, irrigation water and energy use and productivity in both commercial and smallholder cane production across SSA.

It is, thus, recommended that there is a need for farmers to always operate irrigation with improved level of irrigation uniformity while ensuring proper irrigation scheduling approaches. The implementation of irrigation uniformity improvement interventions and adopting correct irrigation scheduling methods would likely reduce irrigation water use, improve yield average at field level which in turn will improve water productivity and reduce energy requirements for irrigation. The improvement of water productivity and reduction of irrigation water use and energy requirements would maximise crop yield benefits from irrigation and reduce irrigation operation costs, respectively.

Apart from being an invaluable an enabler for exposure and interaction with scientists and experts in the field of water resources management for me, as an individual, the research has also established new insights while confirming findings of works of other people regarding irrigated cane production (including cane yield trends in SSA, cane yields and water supply relationships and irrigation yield benefits). For example, the research established the impact of irrigation uniformity on cane yields, energy and irrigation water uses, water losses (surface run-off and deep percolation) and labour costs using a unique combination of different models – both the methodological approach and the findings are novel to the research. The research provides elaborate insights on agronomic, environmental and economic impacts of irrigation non-uniformity in irrigated sugarcane production. Thus, it is invaluable resource, for the SSA region in general and the local communities in particular, in the in the urgent need for improving cane yields, saving water and energy.

The PhD study at the esteemed Cranfield University and the knowledge and expertise acquired through this study would go a long way in promoting sustainable irrigated agriculture in Malawi and beyond. I would like to embark on consultancy and outreach programs that now I have successfully completed my PhD studies – necessary steps are at an initial stage. Thus, the research and sponsorship from Sue

White Fund has made me grow in my career and I am sincerely grateful to the Sue White Fund for affording me this lifetime opportunity.