International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Address: IIASA, Schlossplatz 1, A-2361 Laxenburg, Austria
Email: repository@iiasa.ac.at **Telephone:** +43 (0)2236 807 342

YSSP Report
Young Scientists Summer Program

EVALUATION OF POTENTIAL FOR EXPANSION OF IRRIGATED RICE PRODUCTION IN THE EXTENDED LAKE VICTORIA BASIN

Author: Anna Amankwah-Minkah
Email: aaminkah@gmail.com

Approved by

Supervisor: Mikhail Smilovic (WAT)
Co-Supervisor: Sylvia Tramberend (WAT)
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Abstract

The Lake Victoria Basin has the potential to meet rice demand in East and Central Africa. Current irrigation production and yield rates are low and attention is turning to expansion of irrigated rice production. Some studies have demonstrated sustainability of increased production of irrigated rice. This study analyzed the potential for increased production of irrigated rice in the extended Lake Victoria Basin. It assessed the existing scenario and evaluated expansion under individual and combined scenarios of increased irrigation and inputs in rice production areas using land use and other data from the Global Agro-Ecological Zones (GAEZ) system. The analysis was done in Python environment for all rain-fed, rice producing areas with sufficiently suitable land and for the optimal growing season. Yield differences for the different scenarios were superimposed on shape files of the basin. These were used to generate choropleth maps and bar charts to visualize the variation in increased yield for individual sub-basins as well as the overall increase for the basin. The results showed that there is potential for up-scaling rice production given the inclusion of irrigation and inputs. Irrigation will be of more benefit in a few of the sub-basins, particularly in the North East of the basin. It was recommended that a general improvement in agricultural management practices will significantly enhance the yields and close the yield gap.

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About the author

Anna Amankwah-Minkah is a lecturer at the Department of Civil Engineering, Bolgatanga Technical University, Upper East Region, Ghana. She is also a final year doctoral student at the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. (Contact: aaminkah@gmail.com)

Introduction

Background

The Lake Victoria Basin has been touted as having the potential to meet rice demand in East and Central Africa. Current irrigation production and yield rates are low and attention is turning to expansion of irrigated rice production. Some studies have demonstrated sustainability of increased production of irrigated rice. Expansion of rice production is justified by growing population and increasing demand but requires efficient and sustainable use of available, finite resources. This study evaluates the potential for expansion of irrigated rice production in the extended Lake Victoria Basin. It also gives recommendations on how irrigated rice production can be expanded according to sustainable water management practices.

Study area

Lake Victoria is the largest fresh water lake in Africa and second largest in the world. It covers an area of 68,800 square kilometers and is located in 3 countries namely, Kenya (6%), Tanzania (51%) and Uganda (43%). 80% of water in the lake comes directly from rainfall and 20% from smaller rivers. It is the main reservoir of the Nile River.

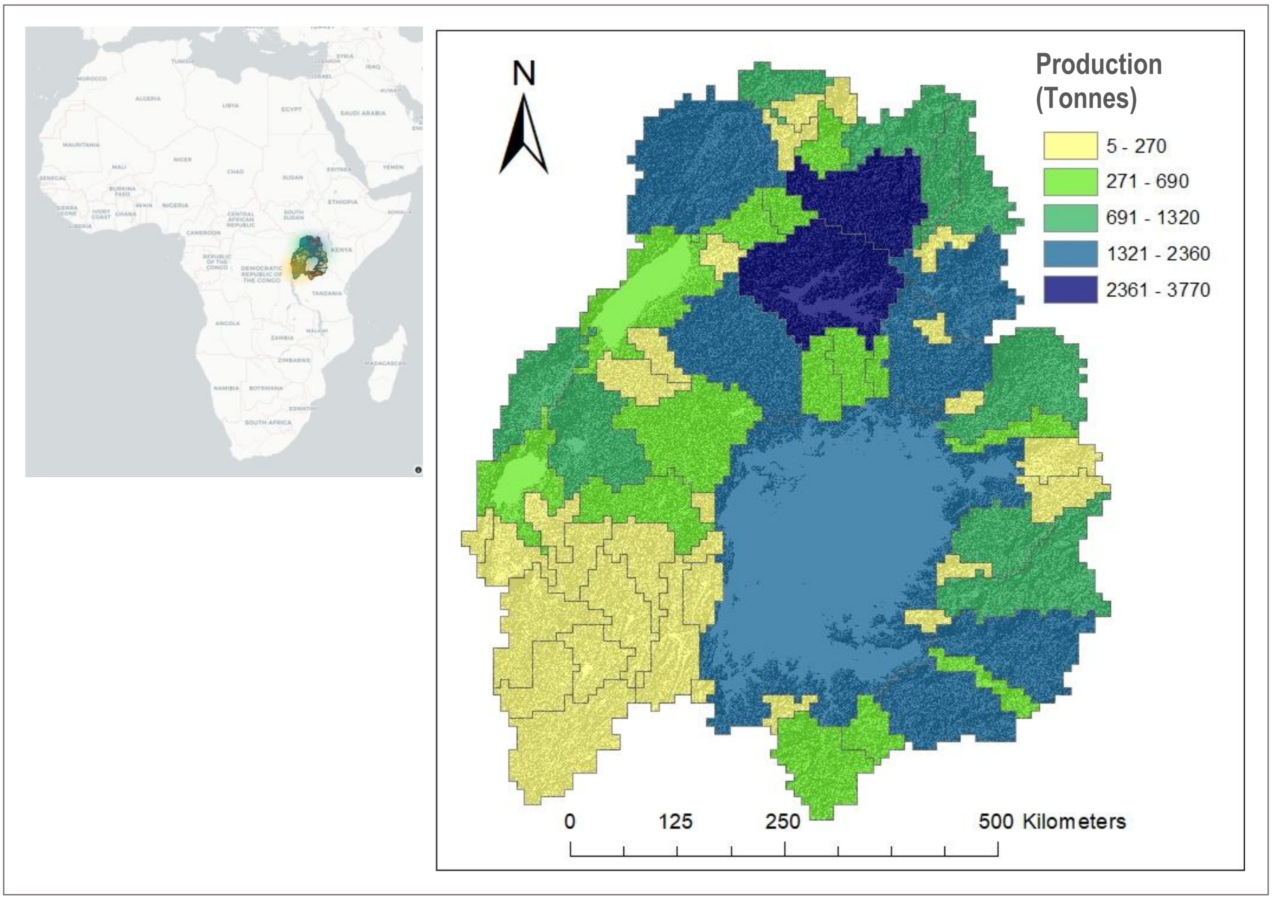


Figure 1 Fig.1 Potential Irrigated Rice Production (Intermediate Inputs, Year Round Production)

The Lake Victoria Basin (LVB) has an area of about 194,000 square Kilometers and is shared by five riparian countries namely Tanzania (44%), Kenya (22%), Uganda (16%), Rwanda (11%) and Burundi

(7%). The basin has a mean annual rainfall of 1,850mm and mean annual temperature of 25.4°C. Increasing population and economic growth have led to many ecological and environmental changes in the basin. Some of the key environmental problems in LVB are pollution, declining natural resources, low agricultural productivity, pest and diseases.

Rice production and Sustainable Intensification:

Rice is the most cultivated cereal after maize and wheat in the Lake Victoria Basin area. It is a staple in the diet of the urban population. It is commonly grown by small-holder farmers. In Kenya for instance, about 95% is irrigated paddy rice whilst 5% is rain fed. Current yields range from 1.5-2.5 MT/ha and are low compared to the global average (4.5MT/ha). (Kilimo Trust, 2014). With the growing population and corresponding growing demand the Lake Victoria Basin has the potential to provide rice for East and Central Africa.

Pretty et al (2018) define Sustainable Intensification (SI) as "an agricultural process or system where valued outcomes are maintained or increased while at least maintaining and progressing to substantial enhancement of environmental outcomes." They go on to explain that SI incorporates the principles of increasing output or yield without the cultivation of more land (and thus loss of non-farmed habitats), in which increases in overall system performance incur no net environmental cost. The concept of sustainable development is development that meets the needs of today without compromising the ability of future generations to meet their own needs (Lele, 1991). Different schools of thought exist on the meaning of intensification in agriculture. It is seen variously as growing more with less; increasing yield per unit land area (or other resource such as water) as opposed to increasing land area cultivated; increasing irrigation and/or inputs; increasing cropping intensity (number of crops) per unit of resource; and changing from low-value crops or commodities to high value ones. (Struik and Kuyper, 2017; Smith et al, 2017). Pretty et al (2018) view SI as open, emphasizing outcomes rather than means, applying to any size of enterprise, and not predetermining technologies, production type, or particular design components. Sustainability is then ensured by minimizing the negative impacts of intensification on the ecology/environment. Sustainable intensification often requires greater skill and knowledge by the farmers, for example on the benefits of inputs and their impact on the environment. It also requires that farmers have access to farm credit, storage and improved marketing skills.

Given the growth in development in the LVB over the years, expanding cultivated land may not be practical. There has also been a buildup of environmental issues such as pollution, declining natural resources, low agricultural productivity and pests and diseases amongst others. In seeking to evaluate expansion of rice production within the basin the following definition for sustainable intensification was adopted for this study: producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and flow of environmental services. (Pretty, 2008; Royal Society, 2009; Conway and Waage, 2010; Godfray et al, 2010).

Objectives

This study sought to address the following objective: to explore the potential for increasing rice production sustainably under different levels of intensification:

- Evaluate existing scenario, identify potentially irrigable land
- Evaluate expansion under individual and combined scenarios of increased irrigation and inputs in rice production areas

Methods and Data

Data Collection

Data on land utilization types (LUT) was obtained from the Global Agro-Ecological Zones system (GAEZ), developed by the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the International Institute for Applied Systems Analysis (IIASA). The GAEZ system uses an inventory of land resources to assess feasible agricultural land-use options and to quantify expected production of cropping activities relevant in a particular agro-ecological context, for specified management conditions and levels of inputs (Fischer et al, 2012).

Data was obtained for land class and utilization types, cropping, vegetation type, extents, suitability classes, potential production and potential yield. Land areas where agriculture/cropping and irrigation were already taking place were considered for this study. Analysis was done for all land cover types (total cropping area) with the exception of wetlands and forests. The calculated yield of each LUT was dependent on water source and the intensity of input and management assumed to be applied. Three generic levels of input/management are defined in GAEZ namely low, intermediate, and high input level. (See Box 1 below).

Input/Management Levels in GAEZ

Low level inputs

Under a low level of inputs (traditional management assumption), the farming system is largely subsistence based. Production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars), labor intensive techniques, and no application of nutrients, no use of chemicals for pest and disease control and minimum conservation measures.

Intermediate level inputs

Under an intermediate level of input (improved management assumption), the farming system is partly market oriented. Production for subsistence plus commercial sale is a management objective. Production is based on improved varieties, on manual labor with hand tools and/or animal traction and some mechanization, is medium labor intensive, uses some fertilizer application and chemical pest disease and weed control, adequate fallows and some conservation measures.

High level inputs

Under a high level of input (advanced management assumption), the farming system is mainly market oriented. Commercial production is a management objective. Production is based on improved or high yielding varieties, is fully mechanized with low labor intensity and uses optimum applications of nutrients and chemical pest, disease and weed control.

(Fischer et al, 2012)

Land suitability types were categorized into very suitable (VS), suitable (S), moderately suitable (MS), marginally suitable (mS) and not suitable (NS). Both very suitable (VS) and suitable (S) lands were designated as sufficiently suitable and the study that cultivation to be conducted on this category of land. Irrigation was also categorized, from the economic point of view, into low investment irrigation systems (no pumping, no storage) and fully mechanized systems. The low investment systems were considered in the study as these will be adopted more easily by the farmers. Other data collected were shape files of the sub-basins and lakes in the LVB, as well as data on discharge and precipitation.

Analysis

Yield differences based on management and level of inputs were obtained from the Global Agricultural Ecological Zones (GAEZ) model. In keeping with sustainable intensification principles, analysis was done for all rain-fed, rice producing areas with sufficiently suitable land and for the optimal growing season. The potential for expansion of rice production for the same area of land currently cultivated was evaluated by setting up scenarios based on a combination of different levels of inputs and source of water (rainfall or irrigation or both). The following relations were used in the computations:

i) Increase in Production: $G = Ar(Yir-r)+(Air-Ar)(Yir)$

where, A= area, Y= yields; ir= irrigated + intermediate inputs, r= rain fed + low inputs

ii) Gains made in yield: $(Pir-Pr)/Air$

where, Air= area, P= Production; ir= irrigated + intermediate inputs, r= rain fed + low inputs

iii) Potential for intensification: *water available x gains x 100*

The yield differences were superimposed on the basin and lake shape files and used to generate choropleth maps and bar charts to visualize sub-basins of marked increase in yield as well as the overall increase for the basin.

Table 1 Description of Agronomic Practices

Scenario	Agronomy	Inputs	Water	Farming type
1	Traditional	Low	Rain fed	Traditional management largely subsistence based farming
2a	Market	Intermediate	Rain fed	Partly market oriented farming; use of some fertilizers, pest control and conservation measures
3a	Traditional+ Irrigation	Low	Irrigation	No inputs and pest control but no water constraints throughout the year (e.g. wetland rice production??)
4	Test	n.a.	n.a.	Test run to identify the aggregate effect of using either intermediate input or irrigation as management option
5	Market+ Irrigation	Intermediate	Irrigation	Market orient farming in small and medium farms

The analysis was carried out in Python Jupyter Notebook using the Geopandas, Pandas, Plotly, Matplotlib and Numpy packages. Five scenarios were generated in Jupyter Python to quantify potential yield and five scenarios for gains in yield in the various sub-basins in response to varying conditions of rainfall, irrigation and level of input usage. A description of the scenarios is given in Tables 1 and 2.

Table 2 Description of Agronomic Practices – Gains in Yield

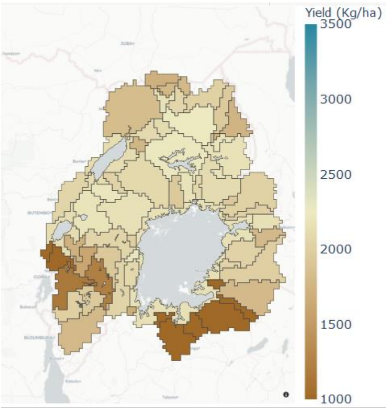
Scenario	Description
2b	Gains realized from inclusion of only inputs at the intermediate level
3b	Gains realized from inclusion of only irrigation
4	Maximum gains realized from using either irrigation or inputs
5a	Gains realized from inclusion of both irrigation and inputs
5b	Maximum gains realized from including both irrigation and inputs versus including only one

Results and Discussions

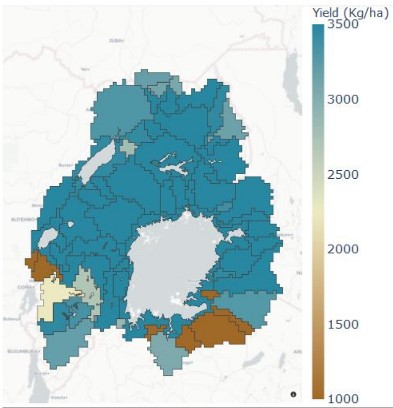
The study set out to investigate the existing scenario and to identify areas of potential for intensification under different scenarios of irrigation and use of an intermediate level of inputs. The following maps present the results obtained.

Potential Yields

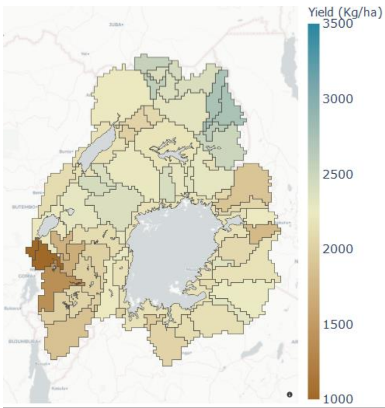
In the Scenario 1 the results show potential yields across the basin of 1700 Kg/ha. This is realized with low inputs and no irrigation. In Scenario 2a there is the inclusion of an intermediate level of inputs but not irrigation and this leads to an increase in potential yields of 3100 Kg/ha. The inclusion of only irrigation in Scenario 3a results in an increase in potential yields to 2100Kg/ha, but not as much as in Scenario 2a. The highest potential yields are associated with Scenario 5 where there is the inclusion of both irrigation and an intermediate level of inputs. (See Figure 2)



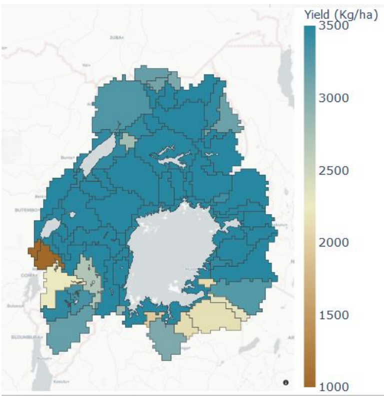
Scenario 1: Rain-fed, suitable land, low inputs, no irrigation



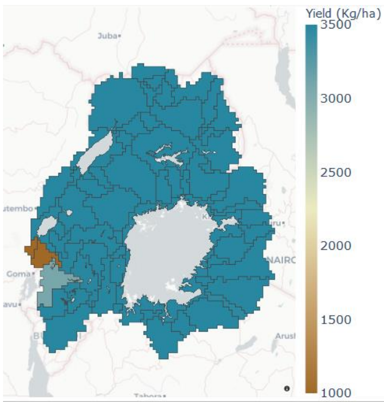
Scenario 2a: Inclusion of only inputs (intermediate)



Scenario 3a: Inclusion of only irrigation



Scenario 4: Max Yield (irrigation or inputs)



Scenario 5: Both inputs and irrigation

Figure 2 Potential Yield for Different Scenarios of Irrigation and Inputs

Overall, Scenarios 2a and 5 show higher potential yields than average annual yields reported for Tanzania (1500 Kg/ha), Uganda and Kenya (2500 Kg/ha) (Kilmo Trust, 2014). Variation of potential yield across the basin for the various scenarios and corresponding yield values are shown in the Figure 3 and Table 2.

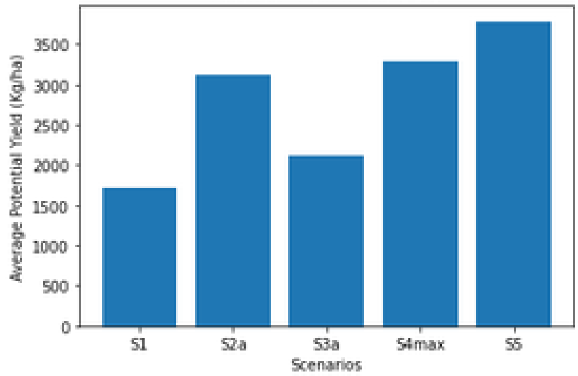


Figure 3 Potential Yield in the LVB

Table 3 Average Potential Yield (Kg/ha)

Scenario	Ave. Yield (Kg/ha)
1	1,720
2a	3110
3a	2,130
4max	3290
5	3,790

Potential Gains

The results show that both Irrigation and inputs result in potential gains in yield. The inclusion of only irrigation only gave the lowest gains (410 Kg/ha; Scenario 3b). Potential gains in yield resulting from use of inputs alone (1,390 Kg/ha; Scenario 2b) is more than 100% the gains realized from irrigation alone. The highest potential gains in yield resulted from inclusion of both inputs and irrigation (2,070 Kg/ha; Scenario 5a). See Figure 4 and Table 4.

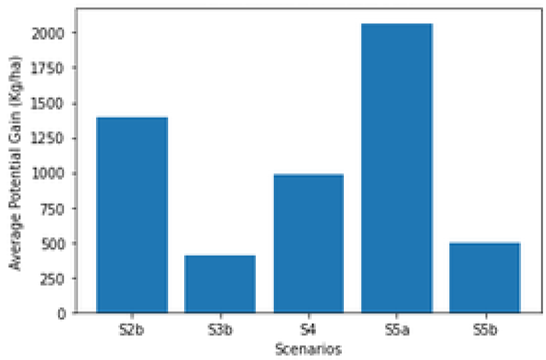


Figure 4 Gains in Yield in the LVB

Table 4 Average Potential Gains in Yield

Scenario	Gains (Kg/ha)	Percentage
2b	1,390	0.81
3b	410	0.24
4	990	0.58
5a	2,070	1.20
5b	500	0.29

Discussions

The potential yields from Scenario 1 are similar in magnitude to rates reported in literature albeit slightly higher. The potential yields for scenarios 2a, 3a and 5 show that including irrigation or an intermediate level of inputs or both will lead to increased output. The scenarios seem to suggest that the inclusion of inputs results in higher potential yields than the inclusion of only irrigation. This may be a testament to the need to improve agricultural management practices within the basin. The highest potential yields are realized when both an intermediate level of inputs and irrigation are included, indicating that both conditions are required for increase in potential yield.

This shows that potential for up scaling irrigated rice production does exists under the conditions of inclusion of irrigation and intermediate inputs. In a few of the sub-basins the scenarios suggest that irrigation is more important than inputs for increasing yields. This may be due to very low water availability in these sub-basins. The significant benefits overall are that the margin of gains in terms of yield is more than 50% for Scenarios 2a and 5.

Limitations of the study

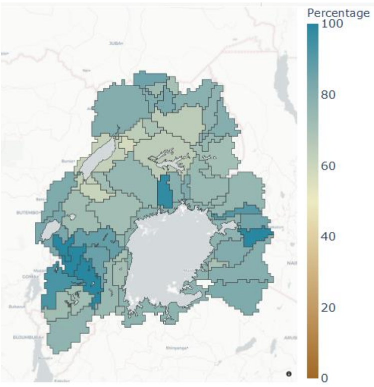
The study assumes an optimum growing season which may not be the case for many farmers. In addition, this study assumes that only cropland is used for cultivation, whereas in realty some wetlands and forest areas being used.

Conclusion and Recommendation

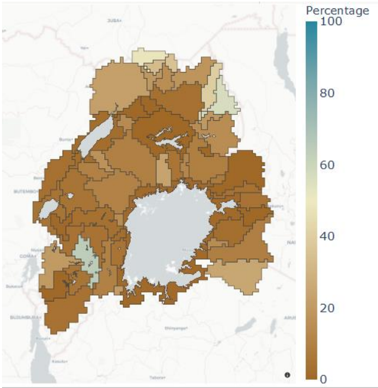
The study has shown that there is potential for up-scaling rice production exists – with inclusion of irrigation and inputs. Irrigation will be of more benefit in a few of the sub-basins, particularly in the North East of the basin.

Generally, an improvement in agricultural management practices will significantly enhance the yields and close the yield gap

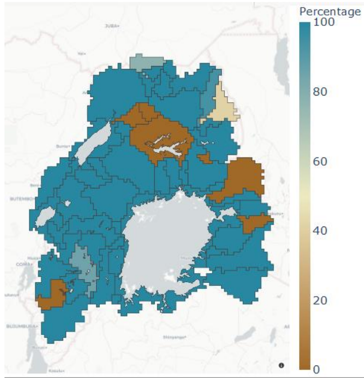
Appendix A1 Potential Gains in Yield for Different Scenarios of Irrigation and Inputs



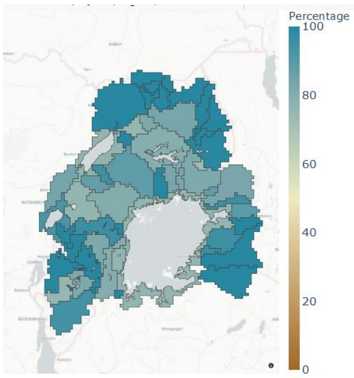
Scenario 2b: Gains with inputs only



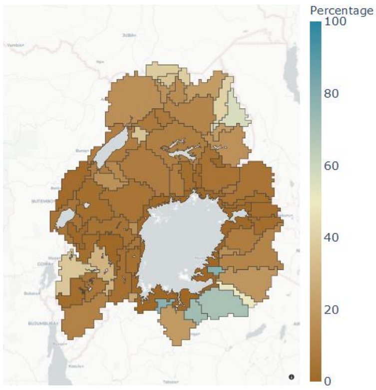
Scenario 3b: Gains with irrigation only



Scenario 4: Gains with irrigation or inputs



Scenario 5a: Gains with both irrigation and inputs



Scenario irrigation or inputs versus including both

Irrigation and inputs are both shown to result in potential gains in yield. The lowest gains are realized with the inclusion of only irrigation (410 Kg/ha; Scenario 3b). Potential gains in yield resulting from use of inputs alone (1,400 Kg/ha; Scenario 2b) is more than 100% the gains realized from irrigation alone. The highest gains in yield result from inclusion of both inputs and irrigation. (2,070.00 Kg/ha; Scenario 5a)

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