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Response Of Three Sugar Cane Varieties To Water Inputs: Linear Regression Analysis Of The Relationships Between Yields, Rainfall, And Irrigation

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Abstract

Sugarcane is the primary industrial crop in northern Côte d'Ivoire. Production of this crop in this region is closely linked to several factors, the most important of which are variety and irrigation. The objective of this study is to determine which variety optimizes production when irrigation is available, with a view to increasing productivity. The methodological approach consisted of collecting data on rainfall, irrigation, and yields for three sugarcane varieties over five sugarcane growing seasons. Yield data were subjected to multi-criteria analysis, while sugarcane's response to rainfall and irrigation was studied using regression analysis. All varieties grown under irrigation recorded higher yields than the same varieties grown under rain-fed conditions. The R579 variety recorded the highest yield increase of 52.9%. This variety is most productive when water is available. The highest irrigation efficiency was recorded for the FR8069 variety, at 0.024 t/h/mm. This variety makes the best use of each unit of water applied.

Keywords: Irrigation Efficiency; Multi-Criteria Analysis; Irrigated System, Regression, Data

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is cultivated on an industrial scale on approximately 30,000 ha in northern and central-western Côte d'Ivoire. This crop plays an important role in the Ivorian economy because it helps combat rural exodus and provides more than 24,000 direct and indirect jobs. In northern Côte d'Ivoire, sugarcane cultivation faces water shortages **[1]**.

Indeed, according to Brou, rainfall in this area is the lowest in the whole country. It is insufficient to meet the plant's water requirements, which are estimated at around 1,500 mm of water. The crop is therefore grown under irrigation in order to provide the quantities of water needed to make up for water deficits and stabilise production. Water is the primary factor limiting sugarcane production, Konan et al., (2). Alongside this factor, the variety is also important. Thus, to increase production and make Ivorian sugar more competitive, efforts are also being made in the area of variety selection through the importation of elite varieties. The varieties grown are diverse and are imported in the form of cuttings from foreign sugarcane-producing countries such as Mauritius, Brazil, Réunion and France. These varieties, which exhibit remarkable agronomic qualities in their country of origin, are highly sensitive to major climatic constraints, particularly drought, which affects yields when they are grown in Côte d'Ivoire. It is necessary to identify varieties capable of achieving high yields under irrigated conditions. This identification requires evaluation methods that enable the determination of how the varieties respond to environmental variations. As irrigation is a costly input, agronomists, economists and engineers need to understand how yield responds to irrigation, Saied et *al*., (3).

However, in Côte d'Ivoire, research into water supply and water management at the plot level is limited and remains insufficient to fully resolve the problems associated with irrigation and to improve its efficiency in sugarcane production. In this context, the innovation of this study lies in the use of regression analysis as a tool for the quantitative characterization of the response of sugarcane varieties to water supply. The regression analysis method is significant as it enables a comparison of the varieties' sensitivity to water availability and their performance under irrigated conditions within the agroclimatic conditions of Ferké 2. It is a complementary approach to conventional methods of varietal analysis, providing indicators that help to improve varietal selection and optimize irrigation water use. This study aims to identify the varieties that maximize yields under irrigation, thereby

improving production and enhancing the management of irrigation water.

MATERIALS AND METHODS

Geographic Location and Climate

The Ferké 2 sugar complex is located in northern Côte d'Ivoire between, on the one hand, 9° 14' and 9° 35' north latitude and, on the other hand, 5° 15' and 5° 24' west longitude, with an average elevation of 325 m above sea level. The complex is situated on the east bank of the Bandama River, 610 km from Abidjan, halfway (40 km) between the cities of Ferkessédougou and Korhogo. The area has a subhumid tropical climate with two seasons: a dry season, from November to March, and a wet season, from April to October. The dry season is marked by a period that is very favorable for sugarcane maturation. This is the harmattan season, which lasts from mid-November to mid-February, with daily temperature fluctuations exceeding 20°C and relative humidity sometimes reaching 30 to 35%. The air is dry and hot during the day and cold at night due to its low moisture content**.**

Plant Material

The plant material used consists of three varieties of sugarcane (*Saccharum officinarum* L.) from three different countries: the R579 variety, which is native to Reunion Island; the FR8069 variety, from Guadeloupe; and the SP711416 variety, imported from Brazil. These varieties exhibit remarkable agronomic characteristics in their countries of origin.

Technical Equipment

Monthly rainfall is measured using rain gauges located at a height of 1.5 m above ground level. The rain gauges are attached to the plots to accurately measure the amount of rainfall on each plot. The study covered 150 plots of 2,500 hectares each year.

METHODS

Data collection

This study was carried out over the course of five sugar-cane harvests between 2010–2011 and 2014–2015

Determination of Rainfall Amounts

Rainfall measurements are taken at three times during the day (7:00 a.m., 12:00 p.m., 5:00 p.m.). Rainfall inputs are determined by summing the rainfall recorded on each of the sugarcane plots. This total is calculated based on readings taken at the rain gauge associated with that plot. The daily rainfall total is calculated by summing the three recorded rainfall values. The results are recorded in a database to assess monthly rainfall.

Assessment of Irrigation Water Volumes

Irrigation was provided in accordance with the plants' water requirements. These requirements were assessed using the climatic water balance equation, calculated over a ten-day period:

$R + I = ETM$

$I = ETM - R$

Where:
R: Rainfall recorded over the period
I: Irrigation rate required for the following period
ETM: Maximum evapotranspiration calculated over the period

Once the water requirement had been determined, the volume of water supplied to each plot was calculated based on the flow rate of the existing irrigation system and the daily irrigation duration, as indicated by the following formula:

$$\mathbf{V}\ (\mathbf{i}) = \mathbf{Q} \times \mathbf{di}$$

Where:
V(i): Volume of water supplied to an irrigated plot on day i (m^3),
Q: Flow rate of the existing system (m^3/h),
di: Daily irrigation duration (h)

Total amount of rainwater and irrigation water received per plot

The total amount of water received by each plot includes the volumes supplied by irrigation and those from recorded rainfall. Irrigation rates were calculated based on the volumes of water delivered by the various irrigation systems. The total water application rate (DT) is calculated using the following formula:

$$W_T = \frac{V}{S} + R$$

Where:

W_T: Total water input per plot (mm),
V: Volume of irrigation water supplied to the plot (m^3),
S: Area of the irrigated plot (ha),
P: Rainfall recorded by the rain gauge associated with the plot (mm)

Sugarcane Yields by Plot

The sugarcane yield of a given plot is the ratio of the cumulative sugarcane production from that plot as weighed on the factory's weighbridge for the various trailer loads to the plot's area**:**

$$Yield\ (t/ha) = 10\frac{Tyield}{S}$$

Where:
Tyield: Total sugarcane yield from a plot (t)
S: Harvested area (ha)

Determining Irrigation Efficiency and Yield Gain

Irrigation efficiency is determined using the following formula:

$$IE = \frac{Yi - Yr}{I}$$

Yi = irrigated yield, Yr= rainfall yield, I= amount of irrigation water

The efficiency gain (EG) is determined by the following formula:

$$EG = \frac{Yi - Yr}{Yr}$$

Yi = irrigated yield Yr= rainfall yield

Database Creation and Statistical Analysis of the Data

Data on yield, varieties, rainfall and irrigation water volumes were collected over five sugar-cane growing seasons (2010–2011 to 2014–2015) and were used to create a single database. The plots were numbered and the varieties grown were identified. Thus, the database contains, for each plot, the amount of water supplied via irrigation, rainfall, the total water received per plot (rainfall + irrigation), the irrigation system, the variety grown and the area under cultivation. Principal Component Analysis (PCA) was used for multivariate analyses of variety yields. To this end, the yields of irrigated and non-irrigated varieties (which received only rainfall) were plotted on a factorial plot and analyzed. Regression analyses were carried out to determine the relationships between the amounts of water supplied and the yields of the different varieties. The statistical analyses were performed using STATISTICA software, version 8.0.

RESULTS

Yields analysis of Three Sugarcane Varieties

The projection of the yields for the three varieties onto the 1×2 factorial plane of the normalized principal component analysis is shown in Figure 1. Axis 1 accounts for 76.35% of the variance, and Axis 2 accounts for 23.61%. Axes 1 and 2 explain 99.96% of the variance and are the most relevant (Figure 1). They are used to describe the differences in yields among the varieties.

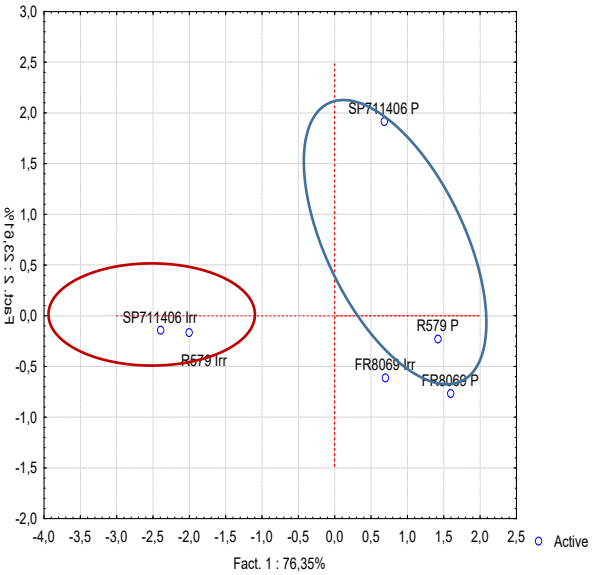


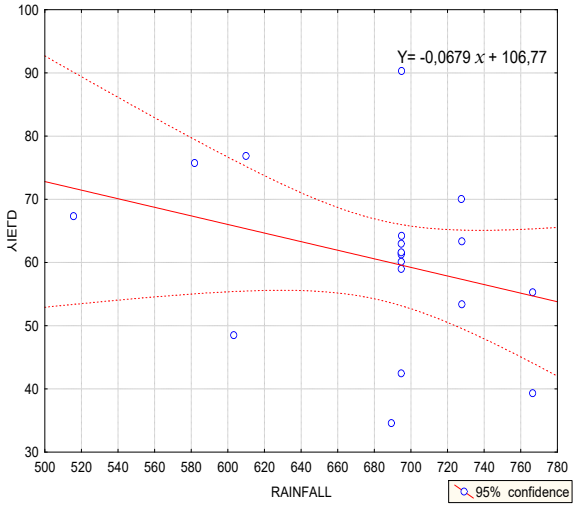
Figure 1: Projected yields of the different varieties under rainfed and irrigated conditions in the PCA factorial design

Projection yields onto the factorials plane allowed us to distinguish two group of individuals. The irrigated varieties, with negative coordinates on axis 1, had high yields, while the rain-fed varieties, with positive coordinates on axis 1, had low yields. However, the R579 and SP711406 varieties recorded higher yields than FR8069 under irrigated conditions. The SP711406 variety under rainfed conditions achieved a higher yield than the other two varieties. The FR8069 variety recorded average yields under both rainfed and irrigated conditions.

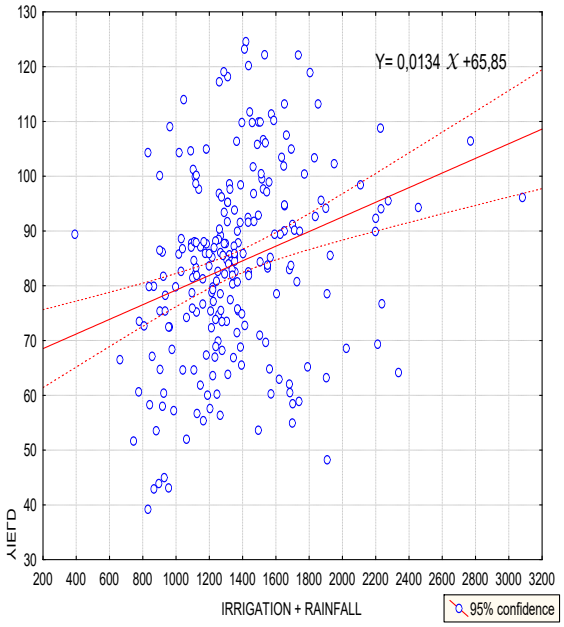
Analysis of variety yields as a function of rainfall and rainfall plus irrigation

Variety R579

The yields of variety R579 as a function of rainfall on the one hand, and irrigation combined with rainfall on the other, are shown in Figure 2. The slope is negative, at -0.0679, when the crop is grown under rain-fed conditions, and positive, at 0.0134, when the crop is grown under irrigation. Yield is improved under irrigation. The y-intercept is high under rain-fed conditions, at 106.77. Under irrigated conditions, the y-intercept has fallen to 65.85



A. Regression line showing the yield of variety R579 as a function of rainfall

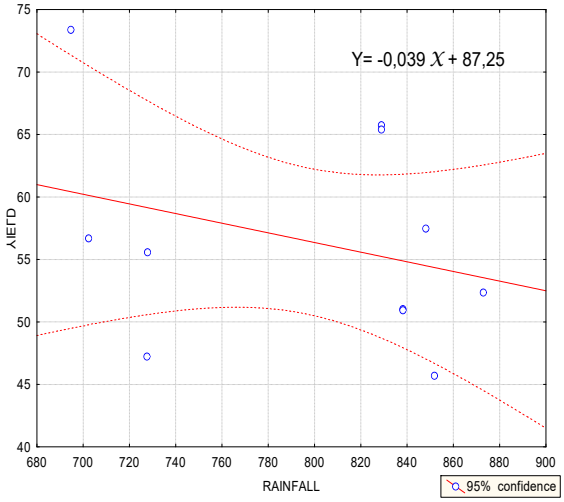


B. Regression line showing the relationship between the yield of variety R579 and rainfall and irrigation

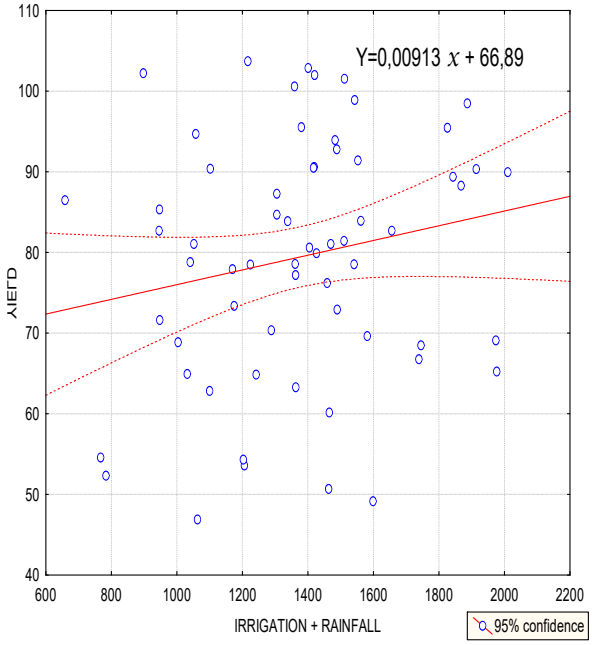
Figure 2: Regression lines for the yield of variety R579 as a function of rainfall and irrigation plus rainfall

Variety FR8069

Variety FR8069 shows contrasting results depending on the irrigation regime (Figure 3). Under rain-fed conditions, the slope is negative, at -0.039, whilst under irrigated conditions, the slope is positive, estimated at 0.00913. Irrigation improves the variety's yield. The y-intercept is positive in both rain-fed and irrigated conditions. However, under rain-fed conditions, the y-intercept is higher, at (87.25), than the value recorded under irrigated conditions (66.89).



C. Regression line showing the relationship between rainfall and the yield of variety FR8069

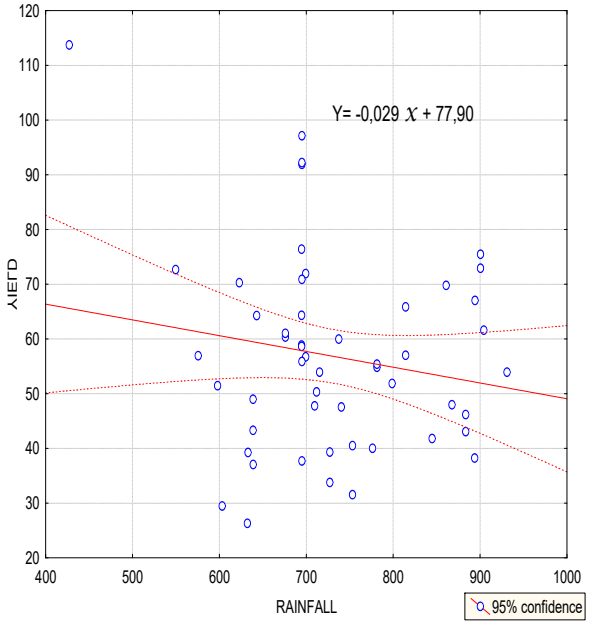


D. Regression line showing the yield of variety FR8069 as a function of rainfall and irrigation

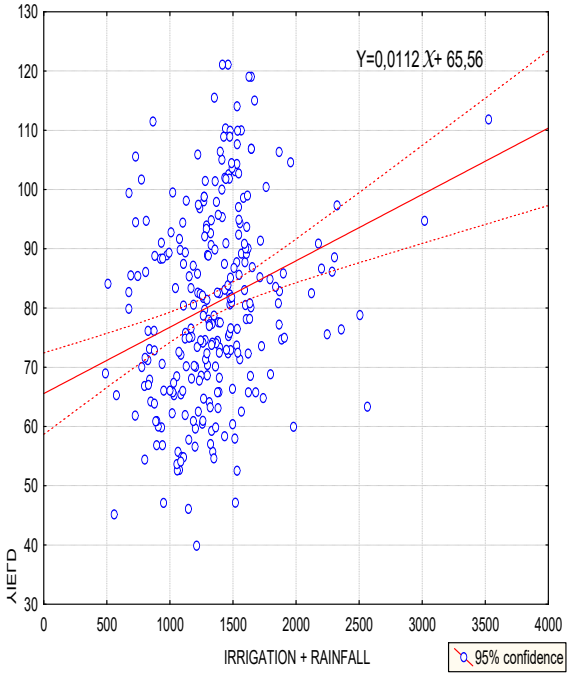
Figure 3: Regression lines for the yield of variety R579 as a function of rainfall and irrigation plus rainfall

Variety SP711406

Variety SP711406 also has a negative slope of around -0.029 under rain-fed conditions and a positive slope of 0.0112 under irrigated conditions (Figure 4). The y-intercept changes from 77.90 under rain-fed conditions to 65.56 under irrigated conditions. The positive slope observed under irrigated conditions reflects an improvement in yield with water supply.



E. Regression line showing the relationship between rainfall and the yield of variety SP11406



F. Regression line showing the relationship between yield of variety SP11406 and rainfall and irrigation

Figure 4: Regression lines for the yield of variety R579 as a function of rainfall and irrigation plus rainfall

All these varieties have negative slopes under rain-fed conditions; however, variety R579, with a significant negative slope of (–0.0679), is sensitive to excessive rainfall, whilst variety SP711406, which recorded a less negative slope of (-0.029), is tolerant to excessive rainfall; yield is fairly stable under rain-fed conditions. Between these two values lies the FR8069 variety, which occupies an intermediate position with a negative slope of (–0.039). Under irrigation, all the varieties' slopes are positive. Water supply improves the yield of all three varieties; however, variety R579 has a higher slope than the other two, at 0.0134, whilst variety SP711406 has a slope of 0.0112. The lowest slope was observed for variety FR8069, at 0.0091. Variety R579 is the most productive under irrigation, followed by variety SP 711406, whilst FR 8069 is less productive under irrigation.

Determination of Irrigation Efficiency and Yield Gain

The highest yield increase was observed in variety R579, with a value of 52.9 per cent (Table I). The other two varieties, SP711406 and FR8069, showed broadly similar yield increases of 43 and 42 per cent respectively. With regard to irrigation efficiency, the lowest values were recorded for the R579 variety at 0.017; the highest value of 0.024 was obtained for the FR8069 variety, whilst the SP11406 variety recorded an intermediate value of 0.019.

Table I: Irrigation efficiency and yield gains for three varieties

VARIETES	IRRIGATION EFFICIENCY (t/ha/mm)	YIELD INCREASE (%)
FR8069	**0.024**	**42**
R579	**0.017**	**52.9**
SP711406	**0.019**	**43**

DISCUSSION

The rain-fed plots had the lowest yields over the course of the five harvest seasons. Rainfall alone cannot meet the water requirements of sugar cane **[4]** in Ferké. The irrigated plots recorded the highest yields. These results demonstrate the need for irrigation to optimize sugar cane yields. Moreover, these observations are not specific to the Ferké 2 sugar complex. Indeed, in several African countries, notably Burkina Faso, Sudan and South Africa, sugar cane is grown under irrigation **[5]**. Thus, the yield increases of between 42 and 52.9 per cent are similar to those obtained by **[6]** when Narayanamoorthy studied the impact of drip irrigation in India: the case of sugarcane.

The positive slopes for the varieties under irrigated conditions and the negative slopes under rain-fed conditions reflect a change in the plant's water uptake behaviour. Indeed, positive slopes indicate that irrigation satisfies water requirements whilst limiting water deficits. These findings confirm the results presented above. Negative slopes show that excessive rainfall can affect the yield of different sugarcane varieties. Heavy rainfall can lead to waterlogged soils,

reduce root aeration and promote the leaching of nutrients

It is not only the volume of rainfall that affects yield, but also its distribution throughout the growing season and how well it matches the plant's water requirements **[7]**. The higher yields achieved with the R579 variety are due to its ability to make the most of the irrigation water supplied daily to make up for water deficits. This variety performs well, with high yields in irrigated plots and acceptable yields under rain-fed conditions. It has adapted to the growing conditions at the Ferké sugar complex. These results are identical to those reported by **[8]** Cultivating it under irrigation over large areas will increase yields. However, the FR8069 variety, which recorded the lowest yield increase, achieved the highest agronomic efficiency; this suggests that the FR8069 variety makes better use of every drop of water supplied than the R579 variety. These results show that a significant increase in yield is not synonymous with efficient water use. This distinction between the two concepts is crucial for regions where water resources are limited.

The FR8069 variety is therefore well-suited to areas with limited water resources and where irrigation costs are high. The results obtained are similar to those of **[9]**, who showed that irrigation efficiency can vary among several commercial sugarcane hybrids when water availability is limited. In the context of Ferké 2, crop varieties appear to be a key factor in increasing agricultural productivity, on a par with irrigation **[10]**. When high-performing varieties are used and irrigation is managed appropriately, yields increase **[11]**. The R579 variety is the most advantageous in the Ferké 2 context due to its high yield gain and good response to irrigation water. However, FR8069 could become an attractive alternative in village plantations that are not irrigated. These results confirm that irrigation and yield gain are two complementary indicators. Using them together enables the identification of high-performing varieties within a sustainable water resource management framework.

CONCLUSION

Varieties grown under irrigation recorded higher yields than those grown under rain-fed conditions. The results of the regression analysis show that, under irrigation, the slopes for all varieties are positive, whereas under rain-fed conditions they are negative. Irrigation improves the yield of varieties, particularly when it is well distributed and applied at times when the plants' water requirements are high. The R579 variety is the most productive when water is available. The FR8069 variety recorded the highest irrigation efficiency reflecting more efficient use of irrigation water. The R579 variety should be used to increase production under controlled irrigation conditions, particularly with high-performance irrigation systems such as centre-pivot irrigation, whilst the FR8069 variety should be used in areas where there is no irrigation and the crop relies on rainfall, or in areas where irrigation is supplementary (irrigation takes place only during half of the plant's growth cycle, with the plant relying on rainfall for the other half). These results show that the choice of varieties should not be based solely on yield but on the plants' ability to use water resources efficiently. These results provide a scientific basis for guiding variety selection and optimising irrigation strategies at Ferké 2.

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