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Modeling of Maize Yields in the South-Sudanian Zone of Burkina Faso - West Africa

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Abstract: The objective of this study is to evaluate the share of the variation of maize yield explained by rainfall records in the purpose of simple modeling of the yields in the western part of the south-Sudanian area of Burkina Faso. The analysis of the data by the model of simple linear regression showed that during the first two months which follow sowing, the maize yield is not very affected by the rainfall variability. On the other hand the variability of the rainfall of the third month after sowing strongly affects the maize yield. This influence of the rainfall is strongly related to the amount of nitrogenized manure applied to the crop. It would then be possible under the agro- pedo- climatic conditions of this study to simulate maize yields with a certain precision based on the simple rainfall records.

Key words: Water deficit · Nitrogen fertilizer · Maize · Sudano-Sahelian zone · Burkina Faso

INTRODUCTION

The forecast of food crops yields in the countries of the Sahelian and Sudano-Sahelian areas constitute a major concern for the authorities and decision- makers in charge of cereal stocks management, the control of their flow and the triggering of food aid. The statistical techniques founded on the studies and surveys are largely used to achieve this goal. They are however expensive and sometimes time-consuming, so that the final estimates can be diffused only several months after harvest. Basing on the methodological data of the agronomic research and adapting them to the regional computerized context of the problem, a hydrous diagnosis tool of the crops was developed in the framework of a collaboration between the Regional Center of Training and Implementation in Agro-weather and Operational Hydrology (AGRHYMET) and the Center of International Co-operation in Agronomic Research for the Development [1-4]. Which is based on the simulation of water balance makes it possible to estimate the yields two months before harvests (as from August 31). Just like the DHC system, a great number of other tools of decision-making aid were developed in last decade. In spite of their potential, these tools of decision-making aid are not currently used on a large scale in sub-Saharan Africa [5]. The availability of reliable data remains one of the major constraints. The requirement in data is sometimes enormous and their collection often requires much time and means. In addition, certain tools are difficult to use without training or access to a service of assistance.

The main constraints of the production systems in the Sudano-Sahelian area are the low level of soil fertility [6-9], varieties of low productivity, low technical level of farmers, lack of equipment, low and random rainfall [10-12]. It is primarily the temporal distribution of the rain which determines the potential yield. Rainfalls determine the capacity of the crops to use the nutritive elements [1, 13].

Dry episodes of about ten to fifteen consecutive days occur in 80% of the cases during the grains vegetative and formation phases, causing a fall of the yields of the principal food crops of the Sahelian areas, like millet and sorghum [14, 15]. Several researchers showed a negative correlation between the hydrous deficit and several parameters like the height of the maize plants and the number of grains [12, 15].

This reduction of the number of grains is due to a bad synchronization between the date of apparition of the bristles and the thesis [16]. An early drought occurring two weeks before flowering can reduce the grain yield of 25%, but if it intervenes during flowering, the yield is reduced from 50 to 60%. If this drought intervenes two to three weeks after female flowering, the yield is reduced by

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21%. The most crucial drought period of maize is 5 days before and female flowering. On the other hand, if this drought occurs precociously at the moment of the vegetative phase, it does not have any negative effect on the yield unless it is not very severe resulting in the death of the plants. Many work in experimental conditions and in farmers' environment showed that the regional fluctuation of food average yield in Sudano-Sahelian area can be explained by the analysis of water balance and the appreciation of a simple agro- climatic indicator which is the product of the indexes of satisfaction of water requirements for the crop in progress in the cycle and at the time of the phase of high sensitivity

The objective of this study is to evaluate the share of the variation of maize yield explained by rainfall records in the purpose of simple modeling of the yields in the western part of the south-Sdanian area of Burkina Faso.

MATERIALS AND METHODS

Location of the Study Sites: Work of experimentation in farmers' fields was completed in Houndé and Sidéradougou, two localities of Burkina Faso located in the South-Sudanian climatic area with a pluviometry varying between 900 and 1100 mm (Fig.1). The dominant soils are washed tropical ferruginous soils with a geochemistry characterized by the accumulation of ferric hydrates associated to very few aluminum oxides. The soils of Sidéradougou are sandy in texture and the organic carbon content and total nitrogen are lower (Table 1).

The Experimental Device: In order to obtain a diversity of pluviometric conditions, ten tests were established by varying the dates of sowing over two consecutive years. The site of Houndé included four tests (two each year and that of Sidéradougou six tests (two in the 1st year and four in the 2nd year). Each test consists of six blocks of Fisher including each one four treatments (N0, N40, N80, N120) which correspond to four nitrogen doses brought to the bolting in the form of urea (46 % N) between 30 and 35 days after sowing. The various nitrogen doses applied are as follows: 0, 40, 80 and 120 kg of nitrogen per hectare according to treatments.

Soil surface was plowed by animal haulage to 20 cm. A uniform basic manure based on complex manure N, P, K, S, B of formula 14, 23, 14, 6, 1, respectively is applied to thinning (10 days after sowing) to all the treatments at a dose of 150 kg ha^{-1} or one dose of 21 (N), 34,5 (P_2O_5), 21(K_2O), 9 (S) and 1,5 (B_2O_3) kg per hectare.

The elementary plot and the square of yield respectively measure 80 and 24 m². Complex manure and the urea fertilizer are applied along the sowing line then manually buried the maize is sown in aligned and thinned seed holes with two plants per seed hole. The lines are in distant 80 cm and the seed holes 40 cm. The variety of maize used is the SR22. The physiological maturity of the grains is reached 100 days after sowing. The maintenance of the plots is ensured by manual weeding.

Data Acquisition and Statistical Analysis: The daily pluviometer statements are acquired using an automatic weather station established in each site. The agronomic data relate to the maize-grain yields obtained during harvest from the squares of yield of 24 m² of each elementary plot. The yield is expressed in kg ha^{-1} at 15 % of moisture.

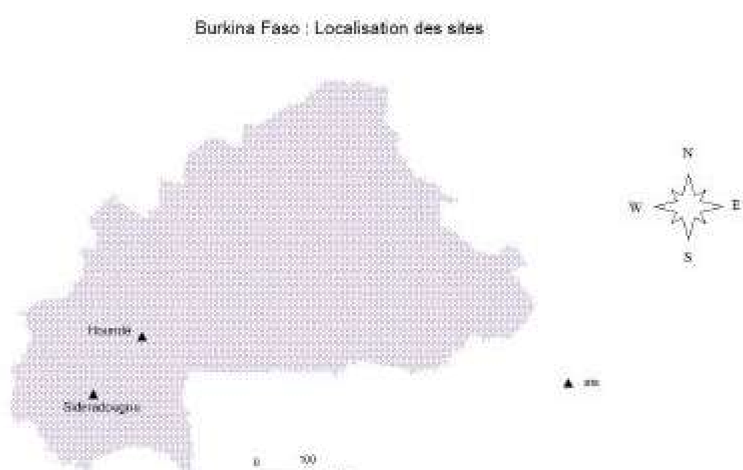

Fig. 1: Map of localization of the study sites

Table 1: Characteristics of the soils of the horizon 0-20 cm of the two sites

Parameters	Site of Houndé	Site of Sidéradougou
Clay %	14.4	7.5
Fine silt %	5.5	2.8
Coarse silts %	20.5	5.1
Fine sand %	3.5	30.1
Coarse sand%	13.1	40.6
Texture	Loam	Sand
pH water	5.90	6.20
pH KCl	5.95	5.00
Organic carbon (%)	0.77	0.55
Total nitrogen (%)	0.06	0.05
P Olsen-Dabin (ppm)	20.4	16.3

Table 2: List of the studied variables

List of explanatory variables
First month after sowing
rainD1: Sum of rains of the 1 st 10 days after sowing
rainD2: Sum of rains of the 2nd 10 days
rainD3: Sum of rains of the 3rd 10 days
rainM1: Sum of rains of the 1 st month after sowing
Second month after sowing
rainD4: Sum of rains of the 4 th 10 days after sowing
rainD5: Sum of rains of the 5 th 10 days
rainD6: Sum of rains of the 6 th 10 days
rainM2: Sum of rains of the 2nd *month after sowing*
Third month after sowing
rainD7: Sum of rains of the 7th 10 days après semis
rainD8: Sum of rains of the 8 th 10 days
rainD9: Sum of rains of the 9 th 10 days
rainM3: Sum of rains of the 3 rd month after sowing
Fourth month after sowing
rainD10: Sum of rains of the 10 th 10 days
Whole cycle Sowing-Maturity
Rain Cycle: Sum of rains from sowing to maturity (0-100 jas)

The statistical analyses were carried out with the software [17]. The analysis of the data consisted in using simple linear regressions. It is about a statistical approach which makes it possible to summarize the relation existing between a dependent random variable Y (or variable to be explained) and one or more random variables (explanatory variable) [18]. The maize-grain yields for the various levels of fertilization constitute the variables to be explained. They are four: Rdt N0, Rdt N40, Rdt N80, Rdt N120 which corresponds respectively to the yields of maize in grain for the treatments N0, N40, N80 and N120, respectively. The explanatory variables are fourteen. They are pluviometric variables (Table 2).

List of the Variables to Explain:

Rdt N0: Yield in grain of maize cultivated without nitrogen input at the bolting

Rdt N40: Yield in grain of maize cultivated with 40 kg ha^{-1} of nitrogen input at the bolting

Rdt N80: Yield in grain of maize cultivated with 80 kg ha^{-1} of nitrogen input at the bolting

Rdt N120: Yield in grain of maize cultivated with 120 kg ha^{-1} of nitrogen input at the bolting

RESULTS

Among the whole of the explanatory variables which have a relationship statistically significant (P = 0, 05) with the yields of the maize grain there are three variables which can be retained (Table 3): Rain Cycles, RainM3 and RainD8. They are respectively the sum of the rains from sowing to maturity, the sum of the rains of the third month after sowing and the sum of the rains of the 8th 10 days (8 X 10 days). The yield of maize in absence of nitrogenized manure is not very related to these three variables. The relation is not even significant with the variables RainM3 and Rain Cycles.

For a given explanatory variable, the explained variance is in relation with the dose of nitrogenized manure: the variance explained by the Rain Cycle variable varies between 47.7 and 51.4 % according to the doses of nitrogenized manure, the RainM3 variable ranged between 50.7 and 82.3 % of the total variability of the yield according to the level of the nitrogenized manure. The variance explained by the RainD8 variable varies between 40.0 and 70.1%. The RainM3 variable seems the most interesting variable. Generally for a given explanatory variable, the variance of the yield explained by the variable is all the more high as the level of the nitrogenized manure is high.

In absence of nitrogenized fertilization, only the sum of the rains of 8th period (10 days) explains in a significant way the total variation of the yields of the treatment N0 (40%). With a low dose of nitrogenized fertilization (N40), it is the variable RainM3 which explains more the variability of the yields (50.7 %). When the dose of nitrogenized fertilization is optimal (N80), it is the RainM3 variable which explains more the variability of the yields (70.8 %). When the amount of the nitrogenized manure is high (N120), all the three pluviometric variables (Rain Cycle, RainM3, RainD8) show a significant linear relationship with the yields. The sum of the rains of the third month alone explains 82.3 % of the total variability of the yield of the N120 treatment.

Table 3: Share of the variability of the yields of maize explained by the rain according to the level of nitrogen zed fertilization

Yield to be explained	Pluviometric variable	Explained variance (V%)	*Prob*>F
Gathered yields			
Rdt N0	RainD8	40.0	0.029
Rdt N40	Rain Cycle	51.4	0.020
Rdt N40	RainM3	50.7	0.013
Rdt N40	RainD8	40.1	0.029
Rdt N80	Rain Cycle	48.1	0.026
Rdt N80	RainM3	70.8	0.001
Rdt N80	RainD8	66.1	0.003
Rdt N120	Rain Cycle	47.7	0.027
Rdt N120	RainM3	82.3	<0.001
Rdt N120	RainD8	70.1	0.002
Yields according to increasing doses of nitrogen zed manure			
Rdt N40	Rain Cycle	51.4	0.020
Rdt N80	Rain Cycle	48.1	0.026
Rdt N120	Rain Cycle	47.7	0.027
Rdt N40	RainM3	50.7	0.013
Rdt N80	RainM3	70.8	0.001
Rdt N120	RainM3	82.3	<0.001
Rdt N0	RainD8	40.0	0.029
Rdt N40	RainD8	40.1	0.029
Rdt N80	RainD8	66.1	0.003
Rdt N120	RainD8	70.1	0.002

Table 4: Estimate of the yields of maize according to the dose of nitrogen zed manure applied at the phase of bolting

Without nitrogenized fertilization (N0)	
RdtN0 = 12.758 rainD8 + 1098.1,	R^2= 0. 47, Prob>F = 0.029
Moderate dose (N40)	
Rdt N40 = 8.4562 Rain Cycle - 1735, 4,	R^2=0.51, Prob>F = 0.020
Rdt N40= 10.045 RainM3 +1289, 6,	R^2=0.56, Prob>F = 0.013
Rdt N40 = 26.354 RainD8+ 1578, 7,	R^2=0.48, Prob>F = 0.029
Optimal dose of nitrogen (N80)	
Rdt N80 = 8.1315 Rain Cycle – 811.4,	R^2=0.48, Prob>F = 0.026
Rdt N80 = 11.465 RainM3 + 1836.8,	R^2=0.74, Prob> F = 0.001
Rdt N80 = 32.016 RainD8 + 2081.5,	R^2=0.70, Prob> F = 0.003
Strong dose (N120)	
Rdt N120 = 10.846 Rain Cycle – 2146.5,	R^2= 0.48, Prob>F = 0.027
Rdt N120 = 16.378 RainM3 + 1228.9,	R^2= 0.84, Prob>F = <0.001
Rdt N120 = 43.94 RainD8 + 1657.5,	R^2= 0.73, Prob>F = 0.002

Because of these relations, linear regressions from X to Y for the significant explanatory variables were established (Table 4). The best estimates of yield from the rainfall records are carried out under conditions where the doses of nitrogenized manure are satisfactory (higher than 80 kg ha^{-1}), in other words when the nitrogen is not a limiting factor. When the nitrogen is a limiting factor, the yield is not directly related to the pluviometric variables.

DISCUSSION

This area of Burkina Faso which is most favorable to the culture of maize is nevertheless prone to droughts intervening during the farming season. The results show that the variability of the first two months pluviometry after sowing does not affect to a significant degree the variability of the yields of maize whatever the level of nitrogenized fertilization.

On the other hand, the third month after sowing which corresponds to the reproductive phase of this variety of maize is sensitive to the variability of pluviometry. These results are in conformity with the many work carried out in the Sudano-Sahelian area of West Africa, Shelly *et al*. [1] , Albergel *et al*. [19] and Achard[20].The nitrogen zed fertilization influences the relation between the sum of the rain of the 3rd month and the yield. The more significant of nitrogen zed manure is, the stronger connection, showing that the production is limited under these conditions by water supplies. Under the conditions of good fertility of the soil, crops better upgrade rain water resources. On the other hand, under the conditions a nitrogenized nutrition deficit, the variability of the yields is slightly explained by the sum of the rains of maize reproductive period [21]. It is interesting to note that during this reproductive phase occurring in the third month after sowing it is particularly the eighth period (10 days) which is the period most sensitive to the water stress. It corresponds in fact to flowering. One can note that the last 10 days, (from 91 to 100 days after sowing) is not a period very sensitive to the hydrous deficit since in several tests which did not record any rain. It corresponds to a phase where water requirements for the plant are very weak. Sultan *et al*. [22] and Diallo and Rodriguez [23] reported that the drought can reduce the yield of maize by 25, 50 and 21 % according to whether it occurs right before, during or after the appearance of the bristle. An early drought occurring during the vegetative period of maize does not have a negative effect on the yield except if the drought is too severe, leading to plants death and a fall of the population density. A moderated drought during the vegetative period can involve the development of a dense and major root system, leading to an increase in yield. The yield is very affected if the dry sequence occurs at the time of the phases of flowering and filling of the grains during which the plant is very sensitive to the hydrous stress. The drought period the most crucial to maize is 5 days before and/or after female flowering was reported by Chopart and Kone [16], Cortier [24], Chopart *et al*. [25] and Struif [26].

The improvement of soil fertility constitutes is a method to increase the efficiency of water. A good pluviometry increases also the efficiency of manures. Indeed it is the one that determines the dissolution and infiltration of manure and the transport of nutriments to the roots is a function of the soil moisture content. For a given pluviometry, the recovery of manure is however determined by other factors like the state of the organic matter of the soil and other elements, Diallo and Rodriguez [23]. According to Keulen and Van Breman [27] and Brower [28] one very often wonders if, in the Sahel, the agricultural production is more limited by water than by one of the nutritive elements. All over the area, the agricultural production is not continuously limited only by one of the nutritive elements or only by water. In the same area, the nutritive elements can limit the growth of the seedlings during one year and water can limit it another year. Even during the same season, water and the nutritive elements can be alternated to limit the agricultural production if the rains are temporarily insufficient.

CONCLUSION

Drought during the rainy season in the Sudano-Sahelian area is a permanent data of the climate. The risks of water shortage at the time of germination, flowering or seeds formation are frequent and can affect negatively on the yields in a variable way. This study made it possible to end up at the following conclusions:

Whatever the level of nitrogenized fertilization, it is the sum of the rains recorded during the third month after sowing that explains more the variability of the yields of maize. It is thus the most relevant indicator to assess the quality of crops supply in water or the quality of the rainy season. Then following the sum of the rains of the 8^{th} period of 10 days, in other words the sum of the rains of the 2^{nd} 10 days of the 3^{rd} month.

Considering these two variables (nitrogen zed fertilization level and the sum of the rains of the 2^{nd} 10 days of the 3^{rd} month), one can notice that the relationship with the yields is more close as the dose of nitrogenized manure is higher. In other words, the relation between the yield and the pluviometric variable is more significant as the level of satisfaction of the requirements in nutritive elements for crops particularly the nitrogenized ones, is significant. The correlation is weaker as the soil is sufficiently poor. The coefficient of correlation between the yield and one of these variables can thus be a good indicator for an indirect appreciation of the nitrogenized fertility of the soil.

From the above-mentioned, it is possible to propose a simple model of estimate maize yields under the specific conditions of the cotton area of the West of Burkina Faso. Subject to a validation, it has the advantage of being an easy tool of simulation of the yields but also for diagnosis: a high coefficient of correlation between the yield and the rain of the third month after sowing means that the yield is limited only by water, a weak correlation indicates that the soil shows a nitrogen deficiency.

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