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Statistical Study of Dry Spells and Their Impact on Rainfed Corn in the Burkinabe Sahel

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Abstract This study aimed at characterizing dry spells and their potential impact in corn rainfed agriculture in the Burkinabe Sahel in order to help managers of rural environments to better plan the corn growing season in this area characterized by high climatic variability. This characterization was made possible through a typology of intra-dekadal dry spells and an inter-dekadal analysis of dry spells with the first-order Markov chains, allowed proposing a mitigation alternative of the effect of dry spells on corn growing. Results showed that climatic risk which arises for rainfed corn production is reduced if sowing was done in the third 10-day period (or dekad) of June. This is justified by the fact that the probability of having two consecutively dry dekads during the most sensitive periods to water stress (i.e the mid-season) was less than 20% while it was over 30% for two consecutively wet dekads. However, because of the increased potential impact of the dry spells longer than 7 days during the mid-season, the coupling of this sowing scenario to supplemental irrigation would be the robust alternative adaptation to climate variability in the Burkinabe Sahel. Nevertheless, subsequent studies can be carried out to quantify this potential impact of dry spells on corn under rainfed farming.

Keywords: *dry spells occurrence, rainfed farming, climatic risk, corn, Sahel, Burkina Faso*

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1. Introduction

Rainfalls in semi-arid areas, particularly in the Sahelian zone are very erratic and characterized by a very high inter-annual variability. This inter-annual variability of rainfall in the Sahel is characterized by its persistence and its magnitude which date back to the years 1966-1968 where the rainfall deficit reached 50% [1]. In the Burkinabe Sahel a reduction of 15-30% of rainfall in the years 1970 and 1980 was reported by [2]. Some authors were able to show that this variability has caused the drying of the Sahelian zone [3,4,5] due to a descent of isohyets of 100 to 150 km southwards for the period 1945-1969 compared to the period 1969-1990 and a persistent degradation of arable lands [6]. This situation makes vulnerable the Burkinabe Sahel farming activity which remains largely rainfed and of which alone further characterization of frequent, and recurrent dry spells during the short rainy season of three months would be one of the better alternatives to establish adaptation scenarios. This characterization is particularly important for growing corn, a high value cereal but little grown in the Burkinabe Sahel because of climatic risk that the crop faced [7]. Although corn is the third most grown cereal in Burkina Faso after sorghum (*Sorghum bicolor*) and millet (*Pennisetum glaucum*) [8], it better uses water than these cereals most preferred in the Sahel due to their higher ability to resist drought. This ability to withstand drought has already been demonstrated by [9,10,11] who have shown that this adaptation emanates from the calibration of the duration of the crop cycle on the dates of start and end of the rainy season. Thus, in view of these conditions, analysis of the rainfall must be done in terms of probability of occurrence for significantly reducing corn farming climatic risk. This is justified by the fact that agricultural option is a bet for agro-climatic conditions. It is therefore essential to establish a correspondence between the risk incurred by the farmer and a climatic risk model to facilitate its decision-making [12]. But the efficient forecasting of certain weather events is not easy. However, authors have already shown in the 1950s [13,14,15] and recently [16,17,18] that the statistical study is an excellent tool for identifying some aspects of the phenomenon. Among these tools, the Markov chain [19,20,21] is one of such tools that allows calculating the probability of occurrence of an event knowing that it occurred in a recent past. The first work on the use of Markov chains in rainfall are from Gabriel and Newman [22]. Thanks to a first-order Markov chain, these authors were able to describe the intermittence of daily rainfall in Tel Aviv. Thus, through this process the persistence and magnitude of drought in the Sahel can be better understood. It is in this way that this study was carried out and aimed at not only analyzing the statistical distribution of dry spells in the Burkinabe Sahel and its impact on the corn growth but also to help agricultural field planners to increase farmers' resilience.

2. Material and Methods

Methodological approach was based on the analysis of dry spells within and between dekads corresponding to a 10-days period. This double analysis allowed not only determining the start of the agricultural season for the corn but also identifying the probability of occurrence of a type of dry through its length.

2.1. Study Area, Crop and Meteorological Data

The study was made in the Burkinabe Sahel (southern and northern) characterized by an annual rainfall varying between 400 and 600mm and occupying 17.6% of the country (Figure 1). The maximum reference evapotranspiration (ETo) during wet years is 5mm per day and can reach 8mm per day during dry years in the agricultural season.

The dominant soils of the study area are the tropical ferruginous soil with sandy loam texture and low content of organic matter [23]. The useful soil water varied from 2% on leached tropical ferruginous soils moderately deep to 30% on leached tropical ferruginous soils with concretions [24].

The grown corn variety was the *Barka* of which growing season was 80 days. This improved variety and resistant to drought corresponded to those recommended by [25] for areas receiving less than 900 mm of rainfall. The growing season of *Barka* has been divided into four stages: initial, development, mid-season and late season. The duration of each stage was drawn from the work of [26] and was respectively 10, 30, 25 and 15 days. The crop coefficients per dekad were determined through equation (1) on the basis of recommendations of [27].

$$k_{cj} = k_{c\ prec} + \left[\frac{N_j - \sum L_{prec}}{L_{phase}}\right]\left(k_{c\ suiv} - k_{c\ prec}\right) \quad (1)$$

where $k_{c\,j}$, $k_{c\ prec}$ and $k_{c\ suiv}$ respectively means the crop coefficient on day j during a given growth stage then during the previous stage and the following stage, N_j is the number of days considered within the stage (or period), L_{prec} and L_{phase} respectively means the length of the previous stage and the total duration of the considered phase.

These crop coefficients were used to determine the daily water requirements ETc_1 and ETc_2 of corn under optimum soil water condition (Table 1) respectively corresponding to the two extreme values of ETo (5 mm in wet years and 8 mm in dry years) of the study area.

The meteorological data used in this study were the daily rainfall data for the period 1960 to 2018. These data came from the weather station of Ouahigouya and only covered the period from May to October including the growing season. This period is very special in that it contains the 1980s characterized by dry years and the 1990s characterized by an alternating dry and wet years [7]. Also, this long series of 59 years allowed applying the laws of statistical inference after analyzing data quality.

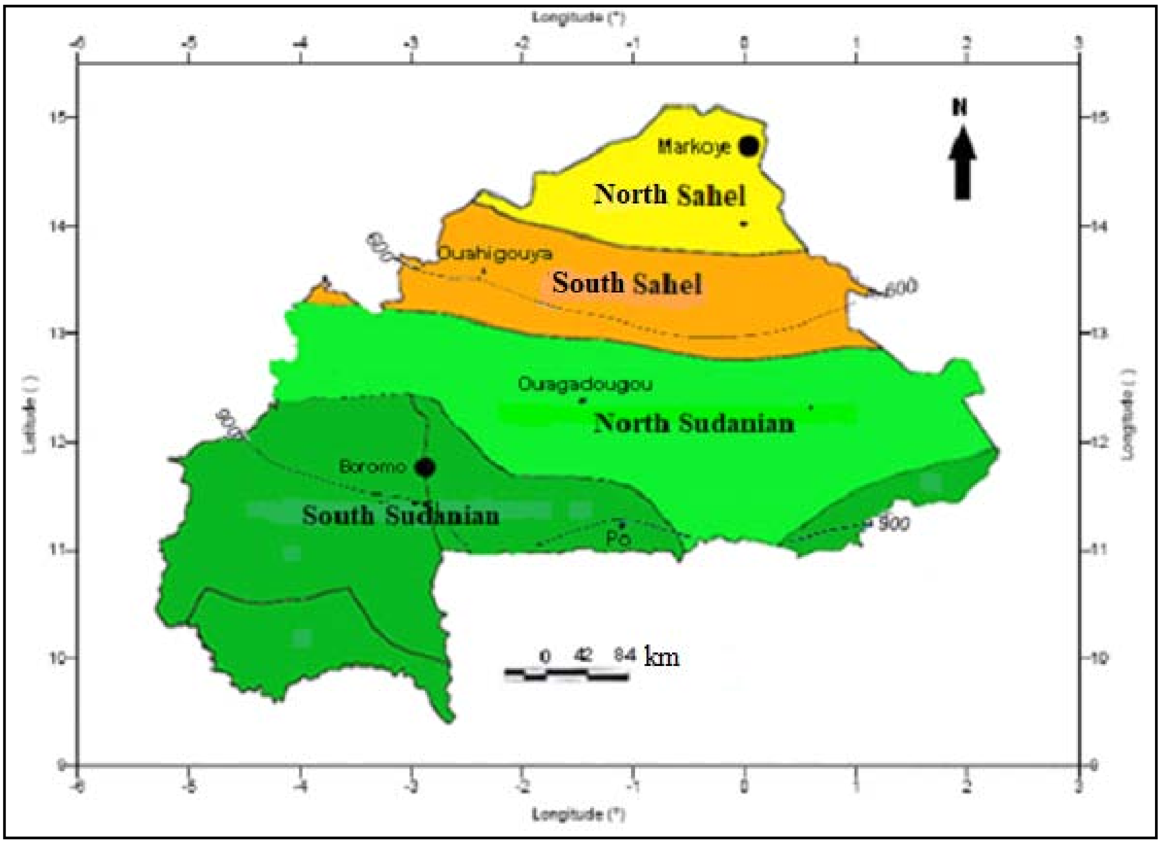


Figure 1. Location of the study area in Burkina Faso (**Source**: Meteorology Service (Burkina Faso))

Table 1. Maximum crop evapotranspiration and crop coefficient by period

	Initial		Development			Mid-season		Late season
Length of stage (day)	15		30			25		10
Length of period (day)	15	25	35	45	55	65	70	80
Kc	0.15	0.48	0.82	1.15	1.15	1.15	1.15	0.48
ETC_1 (mm d^{-1})	0.75	2.42	4.08	5.75	5.75	5.75	5.75	2.42
ETC_2 (mm d^{-1})	1.20	3.87	6.53	9.20	9.20	9.20	9.20	3.87

2.2. Determination of Dry Spells and Climatic Risk Analysis during Corn Development

To analyze the historical satisfaction level of the corn water requirements under standard conditions, the percentage of agricultural seasons allowing satisfying these water requirements was determined. For this purpose, the daily rainfall of the period from 1960 to 2018 was multiplied by a coefficient of 0.8 to determine the effective rainfall. Sowing scenarios were implemented by dekad, and fixed in the middle of each considered dekad. From these dates, the cumulative effective rainfall was calculated for each corn growth stage and compared to the total corn water requirements during the considered phase in order to identify a possible water shortage.

To study the impact of dry spells on the corn development, a typology of dry spells was made during the crop season on the basis of an analysis of intra-dekadal rainfall. Intra-dekadal analysis of dry spells was done under INSTAT+ software focused on four classes of dry spells isolated on the basis of their length: "> 5 days"; "> 7 days" and "> 10 days". The daily rainfall threshold for the study of dry spells was calibrated to a useful agronomically rainfall of 10 mm in order to satisfy at least the crop evapotranspiration under the standard conditions [28]. This intra-dekadal analysis was also extended to each growing corn stage and allowed to highlight the potential impact of long dry sequences during each stage.

2.3. Statistical Model for Analyzing Inter-Dekadal Dry Spells

The analysis was based on the Markov chains concerned by conditional probabilities with two states describing better short-term persistence of a phenomenon. This method has been widely discussed by several authors [12,29,30]. It stipulates that the forecast of a future event knowing the present, does not depend on additional information from its past for its accuracy but all the necessary information is in its current state. Yet, rainfall logged during a given day is only a random event dependent on the probability that the previous day is dry or wet. The Markov process is of order n if the rainfall of the day j depends on the j-1, j-2, and j-n previous days.

Consider a set of n random variables $X_i (i = 1, 2, 3, \ldots, n)$ representing a sequence of n days which may take each one state: d if the day is dry or w if the day is wet. The probability $P(x_1, x_2, x_3, \ldots\ldots, x_n)$ that the sequence $(x_1, x_2, x_3, \ldots\ldots, x_n)$ occurs in supposing that it is constant from year to year in the use of Markov chains involves conditional probabilities. Thus, in probability theory, multiplication law allows writing:

$$\begin{aligned} &\mathbf{P}(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3, \ldots, \mathbf{x}_n) \\ &= \mathbf{P}(\mathbf{x}_1) \times \mathbf{P}(\mathbf{x}_2 / \mathbf{x}_1) \times \mathbf{P}(\mathbf{x}_3 / \mathbf{x}_2, \mathbf{x}_1) \\ &\quad \times \ldots \times \mathbf{P}(\mathbf{x}_n / \mathbf{x}_{n-2}, \mathbf{x}_{n-1}) \end{aligned} \tag{2}$$

where $P(x_1)$ is a priori probability and $P(x_n / x_{n-2}, x_{n-1})$ are the posteriori (or conditional) probabilities.

In the case of a process depending only on the state of the previous day, the equation (2) becomes:

$$\begin{aligned} &\mathbf{P}(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3, \ldots, \mathbf{x}_n) \\ &= \mathbf{P}(\mathbf{x}_1) \times \mathbf{P}(\mathbf{x}_2 / \mathbf{x}_1) \times \mathbf{P}(\mathbf{x}_3 / \mathbf{x}_2) \\ &\quad \times \ldots \times \mathbf{P}(\mathbf{x}_n / \mathbf{x}_{n-1}) \end{aligned} \tag{3}$$

This sequence is known as the Markov chain of first order in which the conditional probabilities represent the transitions probabilities from a state to another. It is called second order if the state of the day j (d or w) depends on the state of the previous day and the state of the two days before. In this case, these are the three terms of equation (2) which are taken into account in the calculation of the probability of occurrence of a given sequence.

2.4. Application of Markov Chains to Dekadal Rainfall

Within the context of this study, a dekad representing a 10-day period was considered dry if the measured rainfall is below the threshold of 50 mm calibrated on the basis of the water requirements of *Barka* under growing standard conditions [27]. In the case where the ten-day rainfall is greater than 50 mm, the dekad has been declared as wet [28]. This threshold of 50 mm has been determined for the mid-season phase using the maximum daily reference evapotranspiration (5 mm) and the corn crop coefficient kc equal to 1.15 [31]. The mid-season including flowering, pollination, and grain filling stages is the most sensitive phase to water stress and justifies its choice for developing robust adaptation scenarios. Thus, the probability of having for example two dry dekads framed by two wet dekads under an initial condition (wd) defined as being a dry dekad preceded by a wet dekad corresponds according to the equation (4):

$$\begin{aligned} dekad_2 &= P(wd, d, w) = P(d / wd) \times P(w / dd) \\ &= P_{wdd} \times P_{ddw} \end{aligned} \tag{4}$$

For three dekads this equation becomes:

$$\begin{aligned} dekad_3 &= P(d / wd) \times P(w / dd) \times P(w / dd) \\ &= P_{wdd} \times P_{ddd} \times P_{ddw}. \end{aligned} \tag{5}$$

In generalizing to n dry dekads we have:

$$dekad_n = P(d/wd) \times \underbrace{P(d/dd) \times .. \times P(d/dd)}_{n-2\ fois} \times P(w/dd) \quad (6)$$

$$= P_{wdd} \times P_{ddd}^{n-2} \times P_{ddw}$$

where: P_{wdd} is the probability to have two dry dekads after a wet dekad, P_{ddd} is the probability to have a dry dekad after two dry dekads and P_{ddw} is the probability to have a wet dekad after two dry dekads.

The first order Markov chain was used in this study to analyze the interaction between the dekads in terms of their wet or dry state. This choice is due to the fact that in the implementation of the Markov modeling, problems estimation increases with the order as already shown [32]. In this fact, the INSTAT + software (version 3.37) capable of implementing the Markov chains to the second order was used for the determination of transition probabilities.

3. Results

The results of this study were presented in three sections. The first section was devoted to the climatic risk analysis of corn through the historical satisfaction level of its water requirements. The next two sections are respectively devoted to the statistical distribution of dry spells and their potential impact on the corn growth.

3.1. Satisfaction Level of Corn Water Requirements

Figure 2 summarizes satisfaction level of corn water requirements under standard conditions depending on the sowing dekad.

The results showed that for a daily ETo of 8 mm, the number of years of which corn evapotranspiration (ETc) was met in climatic conditions of the study area is very low (2 to 13%) during the mid-season regardless of the sowing dekad. This proportion was 56% for an ETo of 5 mm when sowing was made in the appropriate period (third dekad of June) and 19% for late sowing (second dekad of July). For the other corn development stages, water requirements were met 6 to 100% for an ETo of 8 mm and 19 to 100% for an ETo of 5 mm. Notwithstanding this, a climatic risk arises for growing corn in the Burkinabe Sahel especially during the most sensitive stage (mid-season). This demonstrates the need for establishment an adaptation scenario to avoid this water deficit in order to reduce yield losses and moreover ensure food security. The analysis of the distribution of dry spells within the agricultural season can be one of the alternatives to mitigate this climatic risk from on the moment it will allow determining appropriate sowing periods.

3.2. Statistical Distribution of Intra-Dekadal Dry Spells

The characterization of the crop is not limited only to the phenomena that occur at the beginning and the end of the agricultural season as already investigated many authors [33,7,34]. This should also interest in the evolution of the parameters that most affect the harmonious development of crop. In this sense, the study of the statistical distribution of dry periods within the agricultural season is a fundamental fact in agricultural planning. Figure 3 summarizes the dekadal occurrence of long dry spells for 59 agricultural seasons.

The analysis of the distribution of dry sequences showed that the drier dekad were at the beginning (May) and at the end (October) of the agricultural season. The second 10-days period of August showed low probabilities for the three types of considered dry sequences. During this dekad and a part of the third, the probability of having two weeks without significant rainfall of 10 mm was zero while it ranged from 44 to 60% for dry sequences of 5 to 10 days. This implies that even during the rainiest months of the year (July and August), the occurrence risk of water stress is not negligible and only supplemental irrigation can alleviate this situation.

This dekadal analysis was certainly vital information for planning agricultural activities but it remains somewhat informative. Indeed, the climatic conditions of a given dekad are influenced by those that prevailed in the previous dekad. This inter-dekadal consideration of dry sequences is a robust tool to better calibrate the sowing dates. For this purpose, Figure 4 summarizes the transition probabilities of the first-order Markov chain.

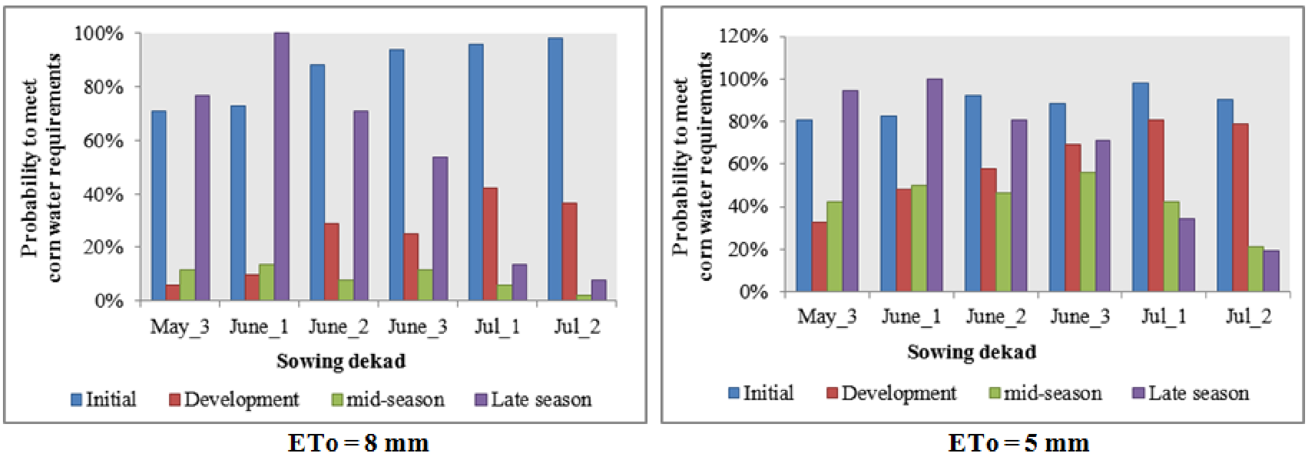
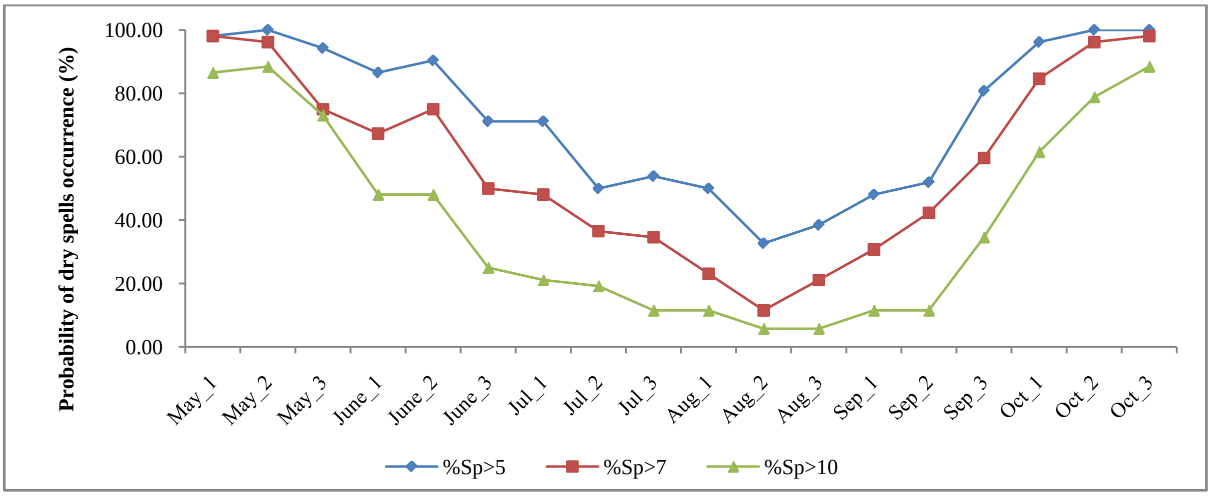
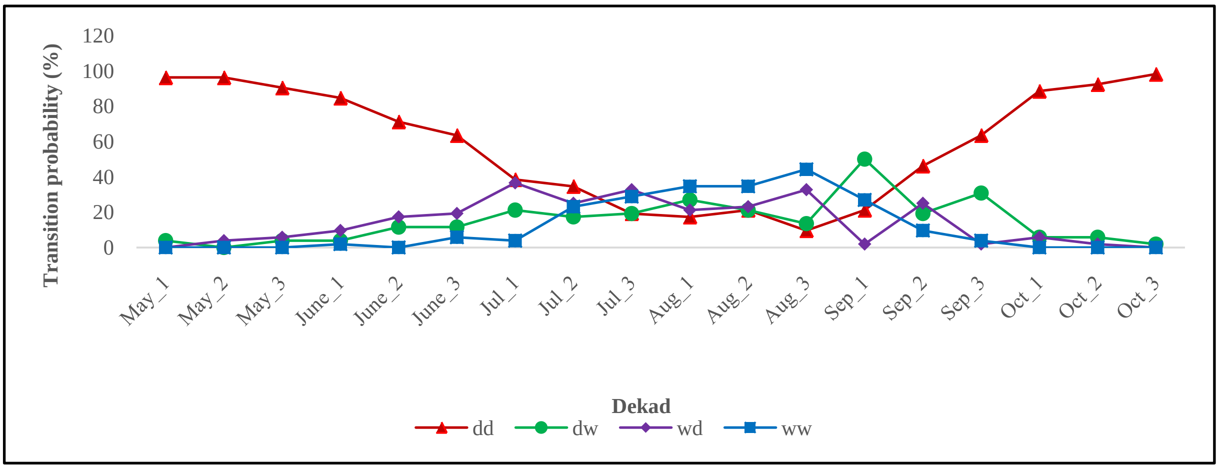


Figure 2. Historical evolution of the satisfaction level of corn water requirements according to the ETo and the sowing dekad



Note: "%Sp > n" means the probability of having a dry sequence more than n days (n = 5, 7, 10).

Figure 3. Probability of long dry sequences occurrence per dekad



dd = a dry dekad (d) preceded by a dry dekad (d); dw = a wet dekad (w) preceded by a dry dekad (d); wd = a dry dekad (d) preceded by a wet dekad (w); ww = a wet dekad (w) preceded by a wet dekad (w)

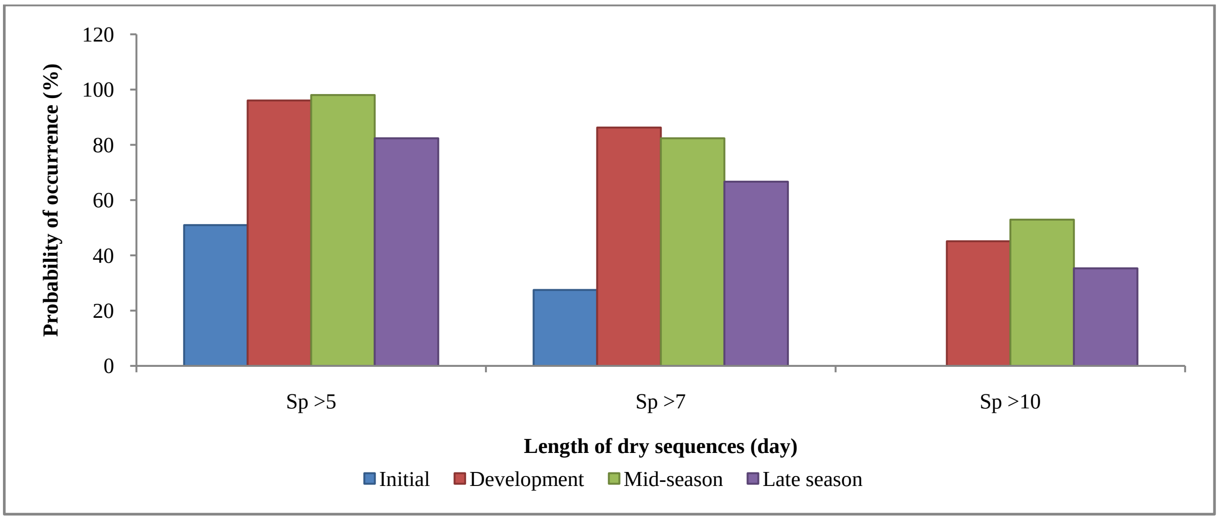
Figure 4. Transition probability of the first-order Markov chains

Analysis of transition probability revealed that the probability of having two consecutives dry dekads (dd) was very high (60-96%) at the beginning (May-June) and at the late (September-October) of the agricultural season. This probability reached its minimum in the third dekad of July (19%) and August (13-17%). In contrast, a wet dekad succeeding to an also wet dekad (ww) have a relatively high probability of occurrence in the month of August (35-44%). Thus, the driest dekads preceded by a dry or wet dekad appeared at the beginning and at the end of the season while the wettest dekads preceded by a dry / wet dekad were met over the period of the mid-July to August. These statistical results allowed inferring that for a precocious variety (<90 days), the sowing date is potentially in the third dekad of June. This period will allow the overlap of the most sensitive growth stages to water deficit and the wettest periods of the agricultural season.

3.3. Impact of Dry Spells on Corn Development

For the corn variety *Barka* with short cycle (80 days), the different classes of above analyzed dry sequences have affected differently each corn growth stage. Indeed, the analysis of Figure 5 showed that the probability of having a given type of dry sequence was most important during stages of development and reproduction (mid-season) of corn. This probability decreased gradually for dry sequences of increasing length but increasing the risk of water stress during the mid-season. The occurrence of dry spells of 5 to 7 days will not affect corn yield if at the beginning of the sequence, the soil water content is equal to the water content at the field capacity. This is true because [26] highlighted that on the most tillable soils, six days suffice to empty of half the water reserve of the soil in the Burkinabe Sahel. However, water stress occurring in the most sensitive corn growth stage (mid-season) for a dry sequence of more than seven days significantly affect the physiology of corn and moreover its yield. Thus, with a view to supplement the rain during those long dry spells in the Burkinabe Sahel, supplemental irrigation, the only complementary alternative is to focus on mid-season.

Thus, this analysis coupled with one made on the satisfaction level of the corn water requirements showed that mid-season is the most vulnerable growth stage at the effects of dry spells and simultaneously the one that benefits from favorable water condition if sowing date was in the third dekad of June.



Note: Sp > n is a dry spell of more than n days (n = 5, 7 and 10).

Figure 5. Risk of long dry sequences in corn growth

4. Discussion

The analysis of chronological series of Rain is a way of apprehending the drought process in the Sahel as already shown [4] through a study conducted in Niger. This allows to study the impending climate risks and to develop adaptation scenarios that can be used as a decision support tool. In this sense, the statistical analysis of series of rainfall and its involvement in rainfed maize farming in semi-arid zone [35] is one of the alternatives to characterize the agricultural season [36] in order to avoid significant crop losses. Thus, the statistical analysis of the agricultural season carried out in this study showed that a climatic risk arises for corn farming rainfed in the Burkinabe Sahel and only supplemental irrigation would be the best alternative. However, the success of such a project for which water sources are very limited due to the little dense river system of the Burkinabe Sahel [26], will depend on the timing of the appropriate period of sowing for reducing the risk of water stress especially in mid-season and limited supplemental irrigation depth. Thus, this statistical study of dekadal dry spells and their impact in corn farming rainfed, allowed isolating the third dekad of June and in the worst-case the first of July as appropriate corn sowing periods in the Burkinabe Sahel. These results corroborate those of [33,34,37].

Indeed, [33] setted the average date of the beginning of the rainfall in the Burkinabe Sahel at June 29 and a rainy season agronomically useful at September 15 for an average duration of growing season of 90 days. On the basis of the index of contribution of the rainfall, [37] showed that the appropriate time for sowing corn in the Sudano-Sahelian zone of Burkina Faso is the month of June (June 5). This can cause a slight delay in the Sahel region of Burkina Faso as shown this study, which has setted this period in the third and the first dekad of June and July respectively. The study by [34] showed for three countries in semi-arid areas of sub-Saharan Africa (Burkina Faso, Niger, Chad) as the starting date of the vegetative growth period is between the second dekad of May and the third of June. This corroborates the appropriate sowing period setted in this study.

At all, this study carried out in the Burkinabe Sahel showed that the introduction of corn in cereal field depends on the implementation of adaptation strategies to climate variability. In this sense, the promotion of a precocious variety like *Barka* is an alternative which should add the appropriate setting of the sowing period. However, the promotion of technologies targeting water harvest at the field for practicing supplemental irrigation would be a complementary alternative to the appropriate sowing period as already shown [26] in the same area. This supplemental irrigation on-farm from rainwater harvesting structures will allow Sahelian farmers to diversify their cereal crops by introducing corn. This can generate significant income since in Burkina Faso; about 34% of corn production is marketed against only 15% for the other most cultivated dry cereals (sorghum and millet). This culture, most coveted in the large cities is an important asset to become a cash crop compared to other dry cereals. Moreover, in rural areas, this crop is of crucial importance in times where the stock of sorghum and millet is finished (at the beginning of the growing season).

5. Conclusion

This study of setting climatic parameters of decision support to better plan corn farming rainfed in the Burkinabe Sahel allowed setting the appropriate sowing period in the third dekad of June. This strategy of sowing reduces the risk of water stress during the most sensitive period of maize (mid-season) where the observed probability was about 80% for dry spells of more than seven days. However, the development of supplemental irrigation coupled with sowing scenario is the best alternative adaption to climatic risk for ensuring the food security of Sahelian households of Burkina Faso.

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