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Impacts of the variation of climatic parameters on the yield of millet in the department of Madaoua, Tahoua, Niger. Case of temperature and rainfall.

Impacts de la variation des paramètres climatiques sur le rendement du mil dans le département de Madaoua, Tahoua, Niger. Cas de la température et des précipitations.

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KEY WORDS
Climate variability, Crop yield, Agricultural sustainability, Climate change adaptation, Temperature trends, Madaoua.

Abstract This article focuses on the impact of climate change on millet production in the Madaoua department, Niger. Niger is a country vulnerable to the effects of climate change due to its high climatic variability and its dependence on rain-fed agriculture. Millet is a crucial cereal grown in the region, accounting for a significant share of the country's cultivated area and cereal production. The objective of this study is to assess the impact of climatic parameters, such as temperature and rainfall, on millet yield. Production data and meteorological data were used to analyze rainfall trends and anomalies, as well as the variation in maximum temperature over a 30-year period (1992-2022). The results show a slight upward trend in mean annual rainfall, although year-to-year variability is high. Dry and wet years do not necessarily follow a linear trend. Dry years are associated with below-average precipitation, while wet years have above-average precipitation. The maximum temperature showed a steady increase over the years, with some fluctuations. In 2021, the average maximum temperature was 36.5°C. This increase in temperature may have a negative impact on millet production and food security in the region. The study also uses regression analysis to examine the relationship between millet yield and climatic parameters. The results of this analysis can help to better understand the effects of climate change on agriculture and to formulate recommendations for effective adaptation in order to maintain agricultural productivity and sustainability in the department of Madaoua.

MOTS CLES
Variabilité climatique, rendement des cultures, durabilité agricole, adaptation au changement climatique, tendances de température, Madaoua.

Résumé Cet article porte sur l'impact du changement climatique sur la production de mil dans le département de Madaoua, au Niger. Le Niger est un pays vulnérable aux effets du changement climatique en raison de sa grande variabilité climatique et de sa dépendance à l'agriculture pluviale. Le mil est une céréale cruciale cultivée dans la région, représentant une part importante de la superficie cultivée et de la production céréalière du pays. L'objectif de cette étude est d'évaluer l'impact des paramètres climatiques, tels que la température

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et les précipitations, sur le rendement du mil. Les données de production et les données météorologiques ont été utilisées pour analyser les tendances et les anomalies des précipitations, ainsi que la variation des températures maximales sur une période de 30 ans (1992-2022). Les résultats montrent une légère tendance à la hausse des précipitations annuelles moyennes, bien que la variabilité d'une année à l'autre soit élevée. Les années sèches et humides ne suivent pas nécessairement une tendance linéaire. Les années sèches sont associées à des précipitations inférieures à la moyenne, tandis que les années humides ont des précipitations supérieures à la moyenne. La température maximale a montré une augmentation constante au fil des ans, avec quelques fluctuations. En 2021, la température maximale moyenne était de 36,5 °C. Cette augmentation de la température pourrait avoir un impact négatif sur la production de mil et la sécurité alimentaire dans la région. L'étude utilise également l'analyse de régression pour examiner la relation entre le rendement en mil et les paramètres climatiques. Les résultats de cette analyse peuvent aider à mieux comprendre les effets du changement climatique sur l'agriculture et à formuler des recommandations pour une adaptation efficace afin de maintenir la productivité agricole et la durabilité dans le département de Madaoua.

1. Introduction

Niger is a country located in West Africa, in the Sahelian region, and landlocked, covering an area of 1,267,000 km ^{2}. With more than 23 million inhabitants, Niger has an annual population growth rate of 3.8%, which is currently the highest in Africa [1]. Like other countries in sub-Saharan Africa, Niger is highly vulnerable to climate change due to various factors, including high climate variability, increased dependence on rain-fed agriculture, and limited economic and institutional capacity to cope and adapt to climate variability and change [2]–[4].

In Niger, the agricultural sector plays a crucial role in the national economy, accounting for nearly 39.2% of GDP. Most crops are grown on a small scale and are vital to local livelihoods [5]. However, agricultural production is threatened by increasing temperatures and rainfall variability, which endangers food security [5].

Millet (*Pennisetum glaucum (L.) R. Br.*), a cereal native to Africa and domesticated more than 4000 years ago [6], [7] is mainly grown in arid and semi-arid regions of Africa and India for human food, as well as for other uses such as fodder and construction [8]. In Niger, millet is one of the most cultivated cereals over an area of 5.30 million hectares. This crop accounts for more than 65% of the cultivated area and around 75% of the country's total cereal production [9], [10].

However, climatic changes, such as the increase in temperature and the variability of rainfall, have a negative impact on agricultural productivity, in particular on the cultivation of millet, one of the main food crops in the country [11]. The department of Madaoua, in the region of Tahoua, is one of the regions most affected by these climate changes, which has led to a decline in millet production over the years [12].

The objective of this study is to evaluate the impact of the variation of climatic parameters, such as temperature and rainfall, on the yield of millet in the department of Madaoua. Based on production data and meteorological data, this study will provide a better understanding of the effects of climate change on agriculture and provide recommendations for effective adaptation to climate change in order to maintain productivity and sustainability of agriculture in the region.

2. Material and methods

2.1. Presentation of the study area

The department of Madaoua is located in the region of Tahoua, in the center-west of Niger. More specifically, it is located between latitudes 14° 00' and 15° 15' north and longitudes 5° 30' and 7° 00' east [13].

The department of Madaoua is an administrative subdivision of the Tahoua region located in the center-west of Niger. It is bounded to the north by the department of Tchintabaraden, to the east by the

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department of Mayahi, to the south by the department of Tessaoua, and to the west by the department of Bouza . According to the 2012 census, its population was estimated at around 323,000 [14].

The relief of Madaoua is characterized by plains and hills. The region is located largely within the Niger River Basin, with tributaries such as the Goulbi of Maradi and the Dargol. The climate is of the Sahelian type, with a dry season from November to May and a rainy season from June to October. The average annual precipitation is about 400 mm. The city of Madaoua, which is the capital of the department, is located approximately 163 km northwest of the city of Tahoua, the regional capital [15], [16].

Economically, the department of Madaoua is mainly agricultural. The main crops are millet, sorghum, maize, cowpea, sesame, groundnuts and cotton. Livestock is also important, with the raising of cattle, goats and sheep [17].

Madaoua has experienced several episodes of drought over the past decades, which has had a negative impact on the livelihoods of local populations. In addition, the region has also been affected by attacks by non-state armed groups, which has had an impact on the security of the population and on access to natural resources [16].

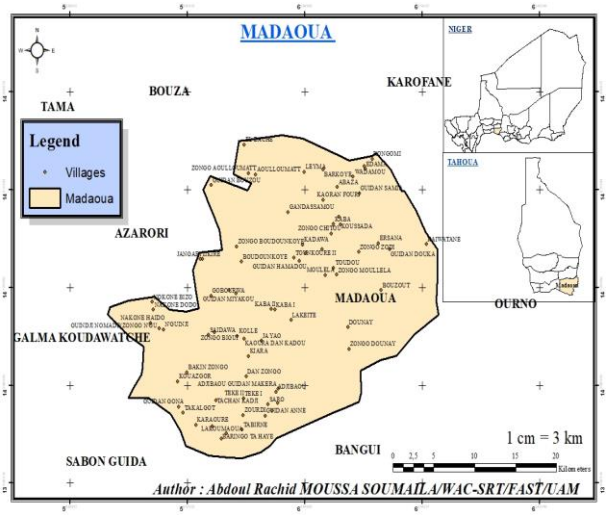

Fig. 1: Location map of Madaoua department
Source: Authors

2.2. Research methodology

2.1.1. Data

2.1.1.1. Meteorological data

Temperature (maximum and minimum from 1992 to 2022) and rainfall (1992 to 2022) of the department of Madaoua. These data were obtained from the Direction of Meteorology Nations (DMN) of Niger.

2.1.1.2. Millet production data

Millet production data from the department of Madaoua from 1992 to 2022. These data were obtained from the Directorate of Agricultural Statistics (DSA) of Niger.

2.1.2. Data analysis

2.1.2.1. Trend of climatic parameters

Trends in climatic parameters (temperature and rainfall) have been studied from meteorological data, the method consists in analyzing the evolution of the maximum temperature, minimum temperature and rainfall from 1992 to 2022 thanks to the free office 7 software.

2.1.2.2. Millet Yield Trend

The millet yield trend has been studied from production data, the method consists in analyzing the evolution of the yield from 1992 to 2022 in the department of Madaoua thanks to the free software office 7.

2.1.2.3. Study of the rainfall anomaly

The method of calculating the rainfall anomaly with Excel 2019 consists of comparing the observed rainfall values to the average rainfall data from 1992 to 2022. Years with a negative rainfall anomaly are considered dry years, while years with a positive rainfall anomaly are called wet years.

2.1.2.4. Impact study

The regression analysis model (multiple linear regression) was used to determine the relationship between millet yield and climatic parameters such as temperature and rainfall. Historical data of millet production and climatic conditions are used to adjust this model which predicted yield based on current climatic conditions. R software was used for this analysis.

3. Results and Discussion

3.1. Rainfall variation

Analysis of the Fig.2 shows a slight upward trend in average annual rainfall in the department of Madaoua between 1992 and 2022, although this trend is not significant (as evidenced by the low coefficient of determination of 0.04). The trend line equation (Y= 2.71X – 4933.41) indicates that for each additional year the rainfall increases by an average of 2.71 mm.

However, looking at the descriptive statistics, we see that the annual rainfall is very variable from one year to another, with a minimum of 284.7 mm and a maximum of 738.8 mm. The median of 500.6 mm indicates that half of the years recorded a rainfall above this value and the other half a lower value.

Finally, by analyzing the dry and wet years, we see that most of the wet years occurred between 1994 and 2007, with a slight recovery in 2012 and 2019, while the dry

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years are more dispersed in time. The driest year was recorded in 2000, while the wettest years were 2014, 2015 and 2016.

Although the trend line suggests a slight upward trend in average annual rainfall in the department of Madaoua, rainfall is highly variable from year to year and dry and wet years do not necessarily follow a linear trend. It is therefore important to continue monitoring annual rainfall to better understand the factors that influence rainfall variability in this region.

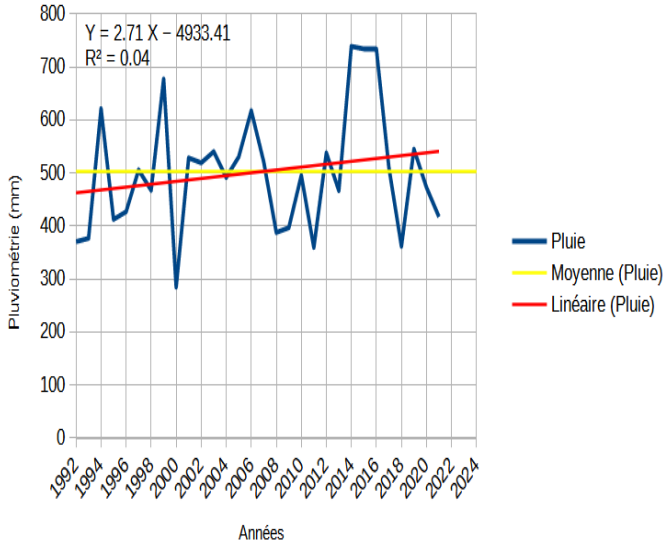

Fig. 2: Evolution of rainfall
Source: Authors

3.2. Rainfall anomalies

The average rainfall anomaly over the period from 1992 to 2022 is about -13.67 mm. This means that the region has experienced below normal rainfall on average over the past 30 years.

Dry years are those for which the rainfall anomaly is negative (below average). The driest years are: 1992, 1993, 1995, 1996, 1998, 2000, 2004, 2008, 2009, 2010, 2011, 2013, 2018, 2020 and 2021. The driest year is 2000, with a rainfall anomaly of - 216.93mm.

Wet years are those for which the rainfall anomaly is positive, (above average). The humid years are: 1994, 1997, 1999, 2001, 2002, 2003, 2005, 2006, 2007, 2012, 2014, 2014, 2015, 2016, 2017 and 2019. The most humid years are 2014, 2015 and 2016, with anomalies rainfall greater than 200 mm.

The rainfall anomaly curve of the department of Madaoua shows significant variations from one year to another. Dry years had below average precipitation while wet years had above average precipitation. It is important to carefully monitor rainfall fluctuations in this region and to put in place adaptation strategies to deal with dry years.

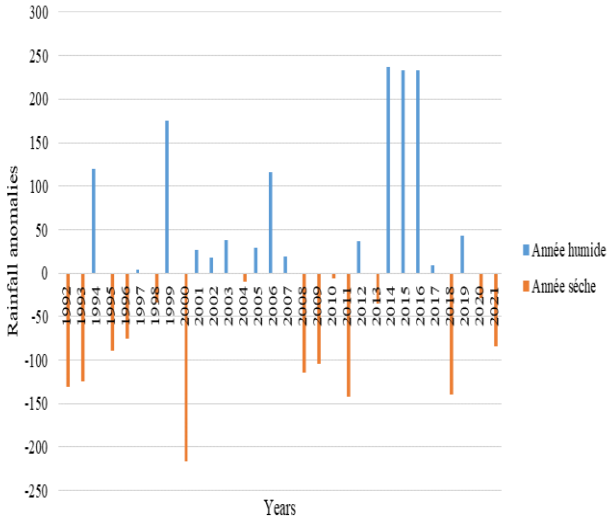

Fig. 3: rainfall anomalies
Source: Authors

3.3. Temperature variation

The maximum temperature variation curve (Fig. 4) shows a steady increase over the years, with some fluctuations, reaching an average of 36.5°C in 2021. Maximum temperatures fluctuated between 34.9°C in 1992 and 37.5°C in 2009, 2010 and 2021. This indicates an increasing temperature trend in this region.

The minimum temperature variation curve (Fig. 5) also shows a slight upward trend, but with larger fluctuations than for Tmax. Minimum temperatures fluctuated between 21.8°C in 1992 and 23.7°C in 2016, but also experienced a significant drop in 2008, with a minimum temperature of 22.0°C. The average of minimum temperature is 22.7°C, which is higher than the average of the lower quartile, the median and the upper quartile.

In general, the department of Madaoua is experiencing an increasing temperature trend, with maximum temperatures constantly increasing and minimum temperatures experiencing significant fluctuations, but also remaining on an increasing trend. This increase in temperature can have significant effects on the environment, human health and economic activities in the region.

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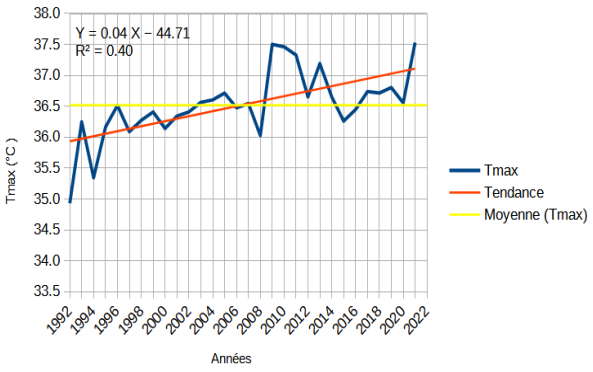

Fig. 4 : Evolution of maximum temperatures
Source: Authors

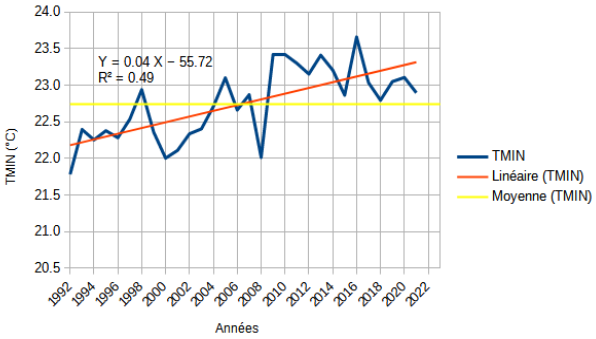

Fig. 5: Evolution of minimum temperatures
Source: Authors

3.4. Evolution of millet yield according to rainfall

Analysis of rainfall and yield data in Madaoua department from 1992 to 2022 (Fig. 6) reveals some interesting trends. However, there is no clear and consistent correlation between rainfall and crop yield. Years with high rainfall do not necessarily guarantee high yield, and vice versa.

During the years 1994 to 1999, rainfall was generally higher, but yield was variable, indicating that other factors influence crop yield. The years 2000 to 2003 had relatively low rainfall, but the yield remained stable.

An increase in rainfall during the years 2004 to 2010 was generally associated with an increase in yield. However, the years 2011 to 2014 showed a decrease in rainfall, but the yield remained variable.

The years 2015 to 2022 saw high rainfall, but the yield remained relatively stable. It is important to note that other factors, such as farming practices, crop diseases and cultivation methods, can also have a significant impact on crop yield.Although rainfall is an important factor in agricultural production, it cannot be considered in isolation to predict crop yield. A comprehensive approach taking into account several variables is necessary to fully understand the factors that influence crop yield in the department of Madaoua.

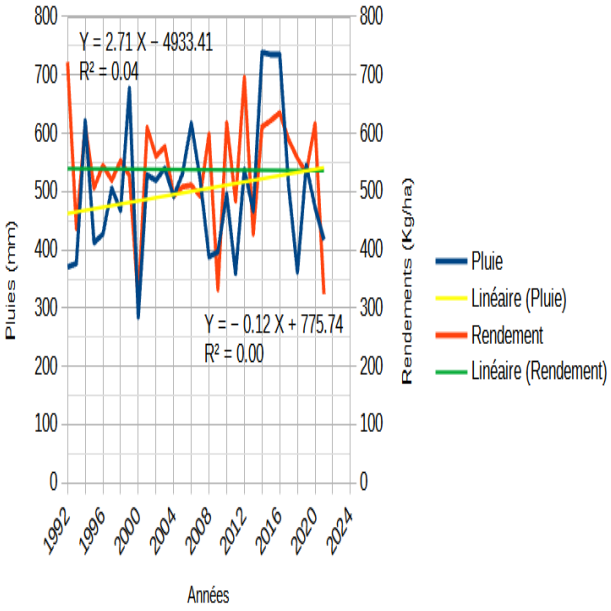

Fig. 6: Evolution of millet yield according to rainfall
Source: Authors

3.5. Evolution of millet yield according to maximum temperatures

Analysis of yield data as a function of maximum and minimum temperatures in Madaoua department from 1992 to 2022 (Fig. 7) reveals that there is no clear and consistent correlation between temperatures and crop yield. Years with high temperatures do not necessarily guarantee high yield, and vice versa.

During the period studied, the maximum and minimum temperatures (Fig. 8) experienced slight variations, but there was no significant overall trend. Similarly, crop yield fluctuated from year to year without following any specific trend in relation to temperatures.

These observations suggest that other factors, such as rainfall, farming practices, crop diseases and other environmental variables, may play a greater role in crop yield than temperatures alone. It is crucial to consider these other factors to fully understand crop yield variations in Madaoua department.

It should be noted that this analysis is based on climate data only and that other factors and variables not included in the dataset may also influence crop yield. A comprehensive and holistic approach is needed to assess and understand all the factors that affect agricultural production in the department of Madaoua.

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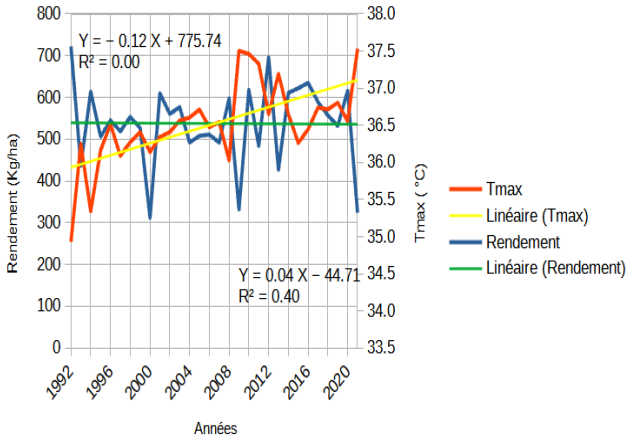

Fig. 7: Evolution of millet yield according to maximum temperatures
Source: Authors

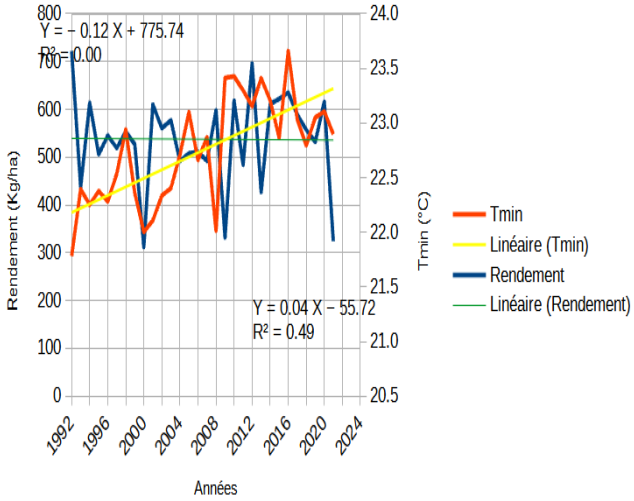

Fig. 8: Evolution of millet yield according to minimum temperatures
Source: Authors

3.6. Impact of variation of rainfall and temperatures on yield

The analysis of the multiple linear regression between yield, rainfall, maximum temperature and minimum temperature from 1992 to 2022 (Tab. 1) in the department of Madaoua reveals interesting results. The regression equation obtained from the results of the multiple linear regression is: Yield = -115.221 * Tmax + 64.775 * Tmin + 0.263 * Rain + 3139.269. This equation represents the estimated relationship between crop yield and the independent variables: maximum temperature (Tmax), minimum temperature (Tmin) and rainfall (Rain). The coefficients in the equation indicate how each variable affects performance. A negative value for the maximum temperature coefficient (-115.221) suggests that higher temperatures may cause a decrease in crop yield. On the other hand, a positive value for the minimum temperature coefficient (64.775) indicates that an increase in the minimum temperature can be associated with an increase in yield. The rainfall coefficient (0.263) suggests that higher rainfall may have a positive, although not significant, influence on crop yield. Analysis of the multiple linear regression between yield, rainfall, maximum temperature and minimum temperature in the department of Madaoua from 1992 to 2022 also reveals several important conclusions:

Intercept (Constant): The intercept represents the expected yield when all other variables (rainfall, maximum and minimum temperature) are zero. In this case, the intercept is significant, indicating that there are other factors, not included in the model, that influence crop yield.

Maximum Temperature (Tmax): The maximum temperature has a significant effect on crop yield. A decrease in maximum temperature is associated with an increase in efficiency. This suggests that crops in the department of Madaoua may be sensitive to high temperatures, which can reduce their yield.

Minimum temperature (Tmin): In this analysis, minimum temperature did not show a significant influence on crop yield. However, it is important to note that further studies or additional analyzes may be required to fully assess the impact of minimum temperature on crop yield in the department of Madaoua.

Rainfall: Although rainfall showed some tendency to have a potential influence on yield, it did not reach a level of statistical significance in this analysis. This suggests that other factors, such as farming practices or other climatic variables, may have a greater impact on crop yield than rainfall alone.

In summary, this multiple linear regression analysis suggests that maximum temperature has a significant influence on crop yield in Madaoua department, while minimum temperature and rainfall did not show a statistically significant influence. It is important to emphasize that this analysis is based on climate data and that other factors or variables not included in the model may also play a role in crop yield. Therefore, further studies and a holistic approach are needed to better

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understand the different factors that influence agricultural production in Madaoua department.

Tab. 1 : multiple linear regression

	Estimate	Standard. Error	t-value	Pr (>|t|)
(Intercept)	3139.269	968.655	3.241	0.00326 **
Tmax	-115.221	41.997	-2.744	0.01086 *
T min	64.775	50.957	1.271	0.21493
Rain	0.263	0.148	1.777	0.08725

Yield = -115.221Tamx + 64.775Tmin + 0.263Rain +3139.269

Source: Authors

4. Conclusion

This study assesses the impact of climatic parameters on the yield of millet in the department of Madaoua, in Niger. The results highlighted the challenges facing Nigerien agriculture due to climate change, particularly in arid and semi-arid regions.

Rainfall analysis showed a slight upward trend in average annual rainfall, although this trend was not significant. However, rainfall is highly variable from year to year, with dry and wet years scattered over time. These variations make it difficult to accurately forecast rainfall and highlight the need to continue to carefully monitor rainfall to better understand the factors that influence its variability.

Furthermore, the analysis of rainfall anomalies revealed that the Madaoua region has experienced on average below normal rainfall over the past 30 years. Dry years had below-average precipitation, while wet years had above-average precipitation. These year-to-year variations represent a challenge for local agriculture, which largely depends on rainfall for the production of crops such as millet.

Regarding temperatures, a steady increase in maximum temperature has been observed over the years. This increase in temperature can have adverse consequences on agricultural productivity, in particular for the cultivation of millet. High temperatures can reduce plant growth time, increase water loss through evaporation, and promote the spread of diseases and pests, jeopardizing food security and the livelihoods of local farmers.

Faced with these challenges, it is essential to implement adaptation strategies to maintain the productivity and sustainability of agriculture in the Madaoua region. This could include adopting climate-resilient agricultural practices, such as breeding heat- and drought-tolerant millet varieties, improving water management, and promoting soil conservation techniques. Additionally, investments in agricultural infrastructure, farmer training and access to reliable weather information are also needed to build the resilience of farming communities.

Contribution of the authors

The authors of this study made significant contributions to the realization of this research, focusing on the impacts of climate parameters, particularly temperature and rainfall, on millet yield in the department of Madaoua, Tahoua, Niger. Two key contributors played pivotal roles in this endeavor:

Abdoul Rachid MOUSSA SOUMAILA, serving as the lead author, assumed a central role in this study. He meticulously conducted data analysis, probing deeply into the datasets acquired, and provided invaluable insights into result interpretation. His expertise in this domain was instrumental in deriving meaningful conclusions from the amassed data, shedding light on the intricate relationship between climatic variables and millet production in the region.

The second author, Nazirou MAHAMANE LAWALI ANDILLO, undertook the vital task of sourcing meteorological data critical to this research. Additionally, he gathered and organized data related to millet production, ensuring its accuracy and relevance to the study. His diligence in the acquisition and management of these datasets significantly bolstered the empirical foundation of our work.

The collaborative synergy between these two authors proved instrumental in the successful execution of this research, ultimately providing substantial insights and a profound understanding of the dynamics between temperature, rainfall, and millet yield in the department of Madaoua, Tahoua, Niger.

Acknowledgement

The successful completion of this research would not have been possible without the generous support and cooperation of several organizations and individuals. We wish to express our heartfelt gratitude to the following institutions:

The National Meteorological Directorate (DMN): We extend our sincere appreciation for their collaboration in

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providing us with crucial climatic data, which formed the cornerstone of our study.

The Directorate of Agricultural Statistics of Niger (DSA): are thankful for their assistance in furnishing us with vital agricultural production data, essential for our research.

We also want to acknowledge the significant contributions of our Lectures at the West African Center for Sustainable Rural Transformation (WAC-SRT), Abdou Moumouni University, Niamey, Niger and the Faculty of Agronomy, Abdou Moumouni University, Niamey, Niger. Their guidance and mentorship have been instrumental in our academic journey.

Our gratitude extends to all the dedicated lectures who have imparted their invaluable knowledge, shaping our understanding of the subject matter. Their unwavering commitment to our education has greatly influenced the quality of this study.

The collective efforts and support of these organizations and individuals have played a pivotal role in advancing our research and enhancing our knowledge.

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