American Journal of Climate Change, 2024, 13, 477-498
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

Irrigated Agriculture Facing the Challenge of Climate Change: Adaptation Strategies for Farmers in the Irrigated Perimeters of Môle Saint-Nicolas, Haiti

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How to cite this paper: Mial, F., Bissonnette, J.-F., Bourgault, M.-A., & Qacami, M. (2024). Irrigated Agriculture Facing the Challenge of Climate Change: Adaptation Strategies for Farmers in the Irrigated Perimeters of Môle Saint-Nicolas, Haiti. *American Journal of Climate Change, 13*, 477-498.
https://doi.org/10.4236/ajcc.2024.133022

Received: April 6, 2024
Accepted: August 11, 2024
Published: August 14, 2024

Abstract

Môle Saint-Nicolas, like all other communes in the Republic of Haiti, faces increasing climate variability, impacting agricultural production and water resources. Consequently, there is a pressing need for adaptation to these climatic changes. This research aims to showcase the adaptation strategies deployed by farmers to cope with the increasing climate variability. Surveys were conducted through group and individual discussions with a randomly selected cohort of 150 farmers. Two types of analysis were performed: quantitative and qualitative. The quantitative data analysis was conducted using Statistical Package for the Social Sciences (SPSS) software. The findings reveal that farmers have perceived changes in rainfall patterns, temperature, wind, and their environment. These changes manifest as irregular rainfall, higher temperatures, prolonged drought periods, violent winds accompanied by rain, premature cessation of rains, and reduced flow from water sources. In response, the most common adaptation strategies adopted include selecting new cultivars, early-maturing varieties, crop rotation and diversification, canal dredging, new soil preparation methods, upstream water source protection, and micro-watershed management. The significance of this research lies in its contribution to enhancing farmers' adaptive capacities by alerting stakeholders in the irrigated perimeters about the consequences of climate change, thereby incorporating the real needs of farmers in future projects.

Keywords

Climate Change, Perception, Adaptation, Agriculture, Irrigated Perimeter

1. Introduction

The latest World Bank (2020) report identifies Haiti as the poorest country in the Western Hemisphere and ranks it among the top 10 countries most affected by climate change. The report also estimates that damages related to climate change could reach $3 billion USD by 2025 without effective intervention. Thus, climate change poses a significant threat to Haiti, which contributes minimally to the greenhouse gas emissions phenomenon. Like other Latin American and Caribbean countries, Haiti has been experiencing the adverse effects of global changes for years, including disruptions in rainfall patterns and prolonged drought periods (Saint-Louis et al., 2019). Generally, the poorest countries and individuals are the most vulnerable to the impacts of climate change, disproportionately affecting those with fewer resources (Guivarch & Taconet, 2010). These impacts are already threatening development progress, especially in poor rural communities and in the agricultural sector, which sustains the economies of many low-income countries (Ryan & Damassa, 2018). Additionally, agriculture has seen a decline in productivity along with an accelerated process of capital depletion among farming households (Beaucejour, 2016).

In 2012, the agricultural sector was hit by several extreme weather events, including droughts causing an estimated $80 million USD in damages to agriculture, and Hurricane Sandy, which resulted in agricultural losses of about $52 million USD (CNSA, 2013)[1]. According to the United Nations Food and Agriculture Organization (FAO, 2022), rural Haitian communities facing high risks of crop losses lack the necessary resources to cope with climate variability. Warmer temperatures will harm plant crops, irrigation canals will receive less water, and pests like giant ants will appear in the Central Plateau and the Northwest, where the irrigated perimeters[2] are located. Consequently, irrigated agriculture has emerged as a means of adaptation in response to climate change. It has developed through the construction of large dams, particularly in developing countries, where the number of dams in 2000 accounted for two thirds of the global total (Tapsoba et al., 2018). Improving water management for more resilient agriculture allows producers to adapt to climatic constraints, enabling them to diversify their crops in the irrigated perimeters and promote better crop

[1]National Coordination of Food Security (CNSA), which aims to influence public policies designed to sustainably improve the food security conditions of the Haitian population under the supervision of the Ministry of Agriculture, Natural Resources and Rural Development (MARNDR).

[2]Ramons Claude Jean-Philippe, climate change: the need to manage the inevitable, master in environmental economics and natural resources.

rotation (Azar, 2017).

Irrigated agriculture can provide the necessary water quantities for crops through various artificial irrigation methods. Irrigated agriculture, in the face of climate change, must adapt by optimizing water use through efficient irrigation techniques such as drip irrigation and high-efficiency sprinkler irrigation, while using sensors and weather forecasts for accurate water management. Rainwater harvesting and storage, as well as the reuse of treated wastewater, are essential to increasing water availability. Conservation practices, such as topsoil techniques and reduced tillage, preserve soil moisture, while selecting drought-tolerant crops and adjusting planting schedules help reduce water demand. Furthermore, water management policies, including pricing and regulation, as well as integrated water resources management plans, are necessary to ensure sustainable and equitable use of water resources. This type of agriculture requires capital investment and infrastructure for water transport, such as irrigation canals, sprinklers, and water reservoirs, necessitating advanced technical developments in turn[3]. In Haiti, the development of the irrigation sector is a significant asset for the agricultural sector to address the impacts caused by the January 12, 2010 earthquake, serving as a crucial determinant in improving agricultural productivity and income, and job creation (MARNDR, 2012). It is noteworthy that the Republic of Haiti has about 250 irrigation systems, covering an estimated 135,000 to 150,000 hectares of land, which constitute areas with high agricultural potential (MARNDR, 2012)[4]. The practice of irrigation in Haiti is longstanding. At the end of the colonial period, the irrigated areas accounted for some 58,000 hectares. After a period of collapse due to the degradation of facilities and their operating conditions, the development of irrigated areas resumed at the beginning of the century[5]. The Ministry of Agriculture is making efforts to improve irrigation systems; however, there is no policy aimed at adapting agriculture and irrigation canal management to climate change (Singh & Cohen, 2014). Climate change poses considerable challenges that Haitian farmers must urgently adapt to. The challenge is to identify this threat, assess it, and develop targeted adaptation measures[6]. The adoption of adaptation measures by a farmer depends on their perception of climate change and its causes, its negative impacts on the environment, and the means available to provide solutions (Kabore et al., 2009). Moreover, the capacity to adapt, or the ability of a system to adjust to climate change, allows for coping with the potential

[3]Irrigated land: definition, explanations, Aqua Portail.

[4]The Ministry of Agriculture, Natural Resources and Rural Development (MARNDR) addresses the issue of irrigation in Haiti through the Directorate of Agricultural Infrastructure (DIA).

[5]Haiti, National Plan for Agricultural Investment - Development of Rural Infrastructures, Annex 2 of MARNDR: The majority of irrigation systems in Haiti are gravity systems, fed from spring and river waters (diversion capture). They are generally small in size.

[6]Adaptation to climate change: a challenge for family farming, news flash N˚2, authors: Markus Giger, Udo Hoeggel, Centre for Development and Environment (CDE), 2011.

consequences of climate change damages (IPCC, 2007; Bissonnette et al., 2017)[7]. According to Madisson (2007), perceiving climate change is a prerequisite for adaptation; one must perceive before adapting. According to this author, adaptation is the combined result of populations' perceptions of climate evolution and their demographic and socio-economic characteristics.

The commune of Môle Saint-Nicolas is one of the 146 communes in the country's most vulnerable to climate change. It is primarily an agricultural commune, but its crops have been subject to drought and scarce rainfall for many years. According to Rainer Schmidt (2011), the northwest bottom of Haiti is an arid region where access to water is difficult. This poses challenges for agriculture and the daily life of the inhabitants, especially for irrigated areas where water is essential for culture. More than 180,000 people suffer from food insecurity and try to increase their income by cutting wood to make charcoal since agriculture, with insufficient yields, cannot meet families' needs.

This research aims to show the adaptation strategies deployed by farmers in the irrigated perimeters of Môle Saint-Nicolas to face meteorological variability and extreme weather events. The interest of this study is to contribute to strengthening farmers' adaptive capacities by alerting stakeholders in the irrigated perimeters to take into account the real needs of farmers in future projects. The central question addressed in this research is as follows: What are the adaptation strategies deployed by farmers in the irrigation perimeters of Môle Saint-Nicolas to face the increase in variability and extreme climatic events? To achieve this objective, the methodological approach used was both qualitative and quantitative. SPSS[8] software was used for processing quantitative data. In this article, we analyze how farmers perceive the decline in agricultural production and water resources in the rehabilitated irrigated perimeters in a context of climate change. Then, we present and discuss the main results in terms of farmers' perceptions of climate variability, deployed adaptation strategies, and the vulnerability of farmers to climate change.

2. Theoretical Framework

In the context of combating climate change[9], adaptation encompasses a category of thought and action. It brings together all practices aimed at acknowledging and addressing the consequences of climate change (Garcia, 2015). The classical concept of adaptation is the idea that there exists a pre-existing problem that an organism resolves by adapting to it (Godard, 2010). Adaptation is defined as all

[7]The Intergovernmental Panel on Climate Change was established in 1988 to provide detailed assessments of the state of scientific, technical, and socio-economic knowledge on climate change, its causes, potential impacts, and response strategies.

[8]Statistical Package for the Social Sciences (SPSS), it is software used for statistical analysis.

[9]The United Nations Framework Convention on Climate Change defines climate change as changes in climate that are attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that are in addition to the natural variability of the climate observed over comparable periods.

the organizational, locational, and technical evolutions that societies must undertake to limit the negative impacts of these changes and maximize their beneficial effects (Hallegatte et al., 2010). The most commonly used definition of adaptation is that of the IPCC, which is an adjustment process to current or expected climate and its effects, to mitigate harmful effects and exploit beneficial opportunities (IPCC, 2018). Thus, adaptation to climate change refers to all strategies, initiatives, and measures specifically aimed at dealing with the evolving climate and its consequences. Adaptation actions are generally intended to address the major risks induced by climate change but can also stimulate innovation (Walthall et al., 2013; Janowiak et al., 2016; Pepin, 2020). It is fundamentally local, as the direct impacts of climate change are and will be felt locally (Van Gameren et al., 2014).

However, several factors influence the adaptation capacity of producers, such as their socio-economic, environmental conditions, and access to information and technology[10] (IPCC, 2007; Fabre, 2010). Adaptation seeks to limit vulnerabilities to reduce the impact of climate change. Farmers already have numerous technical adaptation options for marginal changes in existing systems. These autonomous adaptations are part of strategies to manage climate risk, which still require research efforts, especially in developing countries (Soussana, 2013). Indeed, agriculture is linked to climate change in three ways according to Bouramdane (2023). First of all, agriculture and land use contribute to global warming because they emit 18.4% of global greenhouse gases. They emit methane (CH4) coming for example from livestock, the flatulence of ruminants, and certain crops such as rice, nitrous oxide (N20) mainly coming from the application of nitrogen fertilizers, and carbon dioxide carbon (CO_2) via the use of fuels for machines and certain practices such as savannah fires. Second, agriculture is suffering the negative consequences of climate change. Indeed, the increase in droughts and floods contributes, with the use of pesticides, to weakening the soil, which accelerates erosion. As a result, soils lose part of the carbon necessary for their fertility, this is desertification. Surface areas are threatened by this phenomenon and are therefore less productive. Third, increasing temperatures modify the geographic distribution of plant and animal species. It also promotes the development of diseases so quickly that crops do not have time to adapt, leading to reduced yields. Agricultural activities, whether at the level of agroecosystems or farm infrastructure (building, storage of agricultural products or effluents, agricultural engines) intervene very directly in these interactions between air pollution and climate change. They are today clearly identified as contributing, in the same way as other anthropogenic activities, to climate change and air population (Cellier & Génermont, 2016). Climate change can impact agriculture in various ways. Beyond certain temperature thresholds, agricultural yields can decrease, because the acceleration of the growth process results in less grain production (Cline, 2008). In addition, increasing temperature changes the

[10]https://www.ipcc.ch/site/assets/uploads/sites/2/2019/10/SR15_Glossary_french.pdf.

ability of plants to retain and use humidity. Soil evaporation accelerates and plant leaves lose more moisture, a double effect called evapotranspiration (Cline, 2008).

In these theoretical considerations, Fishbein and Ajzen (1975) propose the basic hypothesis that producers' adaptation to stimuli such as climate change is coherent only in light of their conception and, therefore, their perception. According to these authors, since the perception of climate change is the interpretation of the observed stimulus, the producers' decision to adapt would be a reasoned process. For the agricultural sector, adaptation to climate change translates into an adjustment of activities and practices to mitigate the harmful effects of climate change and to seize new opportunities that may arise from climate evolution (FAO, 2011; Ouranos, 2015; Pepin, 2020). Moreover, irrigation is a key adaptation strategy to boost agricultural production where water is available (CNEDD, 2020). It has become necessary to ensure continuous growth and guarantee product quality[11]. According to Renoux (2011), at the farm level, irrigation allows for the diversification of crops, balance between winter and summer crops, thus providing security against climatic hazards. It also aims to increase and stabilize agricultural yields, especially in the face of droughts expected to intensify due to global warming (Ducharne et al., 2010).

At this level, the primary goal is to mobilize broad agronomic expertise to adapt to altered climatic conditions. This begins with the use of appropriate genetic material better suited to higher temperatures and more effectively utilizing increased photosynthesis and water efficiency, while minimizing the effect of shortened growth cycles (Seguin, 2003). Documented studies on adaptation strategies indicate that the use of drought-resistant seeds, adjusting sowing and irrigation dates (Ofuoku, 2011; Abid et al. 2015; Sarr et al., 2015), efficient water and fertilizer management (Bagula et al. 2013), and crop diversification are among the most favored adaptation methods in agriculture worldwide (Bele et al., 2014; Makate et al. 2016; Torquebiau, 2017).

3. Materials and Methods

3.1. Study Area and Justification for Site Selection

This study was conducted in five irrigated perimeters located in the commune of Môle Saint-Nicolas, Haiti. The selection of this commune was based on its agricultural potential in the past. Môle Saint-Nicolas, through its irrigated perimeters, has historically contributed to supplying local and regional markets with agricultural products. It was known as one of the communes in the lower Northwest with significant agricultural potential due to its irrigated perimeters, and the non-irrigated areas were also known for producing peanuts, roots, and tubers, as well as for ruminant livestock. From the 1960s, farmers from other regions of the country came to find an irrigated plot, which at that time were difficult to find.

Observing the decline in agricultural production since 2000, local authorities

[11]Irrigation, a Response to Climate Change by Pierre Sauriol, Horticultural Consultant Agronomist.

have lobbied national authorities and international NGOs to address this situation. According to testimonies from some local actors, local and international NGOs, in concert with the Haitian state, have implemented projects to strengthen agricultural sectors in the irrigated zones of the commune. These NGOs have invested thousands of dollars through humanitarian projects to rehabilitate the irrigated perimeters with the goal of reviving agricultural production, yet the socio-economic situation of the farmers remains unchanged and even deteriorated. During natural disasters, agricultural plots are completely destroyed, and livestock, which represent a guaranteed source of income, especially ruminants, die and disappear. Given the agricultural potential of this commune from the 1960s and its decline since 2000, scientific interests have led us to choose this theme to conduct this research and demonstrate the causes of the deterioration of agricultural production in the rehabilitated irrigated perimeters to make better decisions.

3.2. Presentation of the Commune of Môle Saint-Nicolas

Môle Saint-Nicolas is a commune in Haiti located at the extreme western tip of the peninsula, in the north of the country. The commune covers an area of 227 km^2 with a population of 30,795 inhabitants in 2009 according to the latest IHSI[12] census. It is one of the coastal communes of the Northwest department. The distribution across the territory is very uneven, with two main urban centers: the town of Môle Saint-Nicolas, located in the first section, and the agglomeration of Mare-Rouge, at the center of the 2nd section. The latter often claims the status of a commune, with a geographical and economic environment very different from that of the town of Môle Saint-Nicolas. The eastern part, covered by the first section and overlooking the Windward Passage, is almost uninhabited due to a challenging environment, while habitats are found along the main roads first leaving Mare-Rouge towards Côtes-de-Fer. The rainfall in Môle Saint-Nicolas varies between 1000 and 1200 mm of rain on average per year, and the average annual temperature is 26.9˚C (CNIGS, 2014)[13]. This commune has two rainy seasons: one starts in April to May, and the other from September to December. It has two rivers: the La Gorge River, which originates in the commune of Bombardopolis and flows into the vicinity of the town of Môle Saint-Nicolas, where it supplies the town's drinking water network, and also the Lema River (CNIGS, 2014) (**Figure 1**).

3.3. Data Collection and Analysis

Data collection was carried out in the five irrigated perimeters of Môle

[12]The Haitian Institute of Statistics and Informatics (IHSI) is the institution responsible for collecting quantitative information on the social, economic, and demographic aspects in Haiti. It was established by the law of September 4, 1951. About four decades later, a new decree, dated July 1, 2020, came to renovate and reorganize the Haitian Institute of Statistics and Informatics.

[13]The National Center for Geo-Spatial Information is a public reference organization for the production, exploitation, archiving, and dissemination of specialized data on the Haitian territory using modern geo-scientific methods and tools.

Saint-Nicolas, namely the Nan Trou, Polvo, Digotrie, Lavaltière and La Gorge irrigated perimeters. In each irrigated area, 30 farmers were selected at random in consultation with the executive committee of each irrigator's association, according to previously defined criteria. The selection of 30 farmers at random among irrigating associations in each irrigated perimeter is a random process insofar as each farmer has an equal chance to be selected.

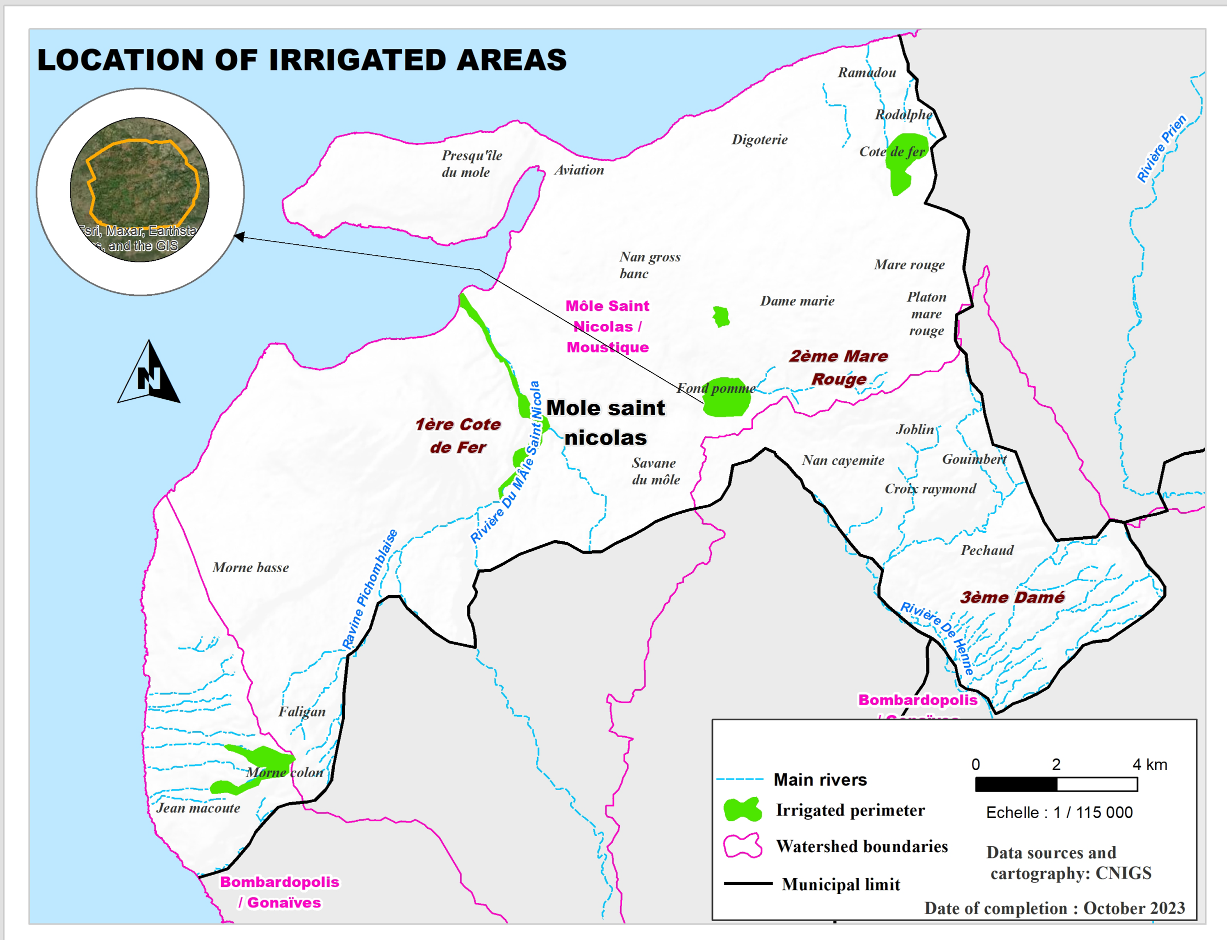

Figure 1. Geographic map of the commune of Môle Saint-Nicolas.

The choice of farmers was made in consultation with the executive committee of each irrigators' association, according to previously defined criteria. These farmers must have at least ten years' experience as users of irrigated perimeters and own an irrigated agricultural plot. In addition, the farmers considered in this study must be at least 18 years old. Overall, 150 farmers participated in an individual survey, while some responded to a collective questionnaire containing both closed and open-ended questions.

The focus groups varied from 8 to 12 participants and included both male and female users of irrigated perimeters. This number was chosen in accordance with Baribeau (2009), specifying that the average number of people in a focus group is between 8 and 10. In addition, observation visits were carried out in conjunction with perimeter stakeholders, in order to observe the state of the physical infrastructure of the irrigated perimeters, water sources, micro-watersheds and agricultural plots. The objective is to collect accurate data on the state of infrastructure and resources in these irrigated areas, which can be crucial for the planning, management and improvement of irrigation systems and agricultural practices in these regions. The main data collected from farmers in the irrigated agricultural perimeters were based on the following themes: socio-economic characteristics, the various environmental changes observed, perception of climate change, adaptation strategies adopted and local knowledge. However, the questions put to farmers during data collection focused much more on their perception of and strategies for adapting to climate change.

Relevant questions on perception and adaptation revolved around climatic variables: rainfall, temperature and wind. The data were collected in May 2023. The perception questions are as follows: How long have you been farming on the irrigated perimeter? What changes have you observed on the irrigated perimeter? What is your perception of the rainy season in the irrigated perimeter areas? Have you noticed the appearance or disappearance of new plant or animal species? How long is the dry season on the irrigated perimeter? Has the temperature increased or decreased on the irrigated perimeter? How often does it rain with strong winds?

After collecting data on perception, farmers were asked questions on adaptation in order to understand the strategies deployed to cope with extreme weather events. The questions were as follows: Have you adopted new cultivars in irrigated agricultural plots? Have you changed your cropping calendar? What were your previous soil preparation and sowing practices? Are you adopting new soil preparation and sowing practices? Are you adopting crop rotation practices? What is the frequency of community work to combat depletion of water resources? Do you usually decrease or increase the number of agricultural plots per season? These questions are part of the questionnaire designed to collect valuable information from farmers about their experiences and adaptation strategies in response to changing environmental conditions.

The data collected was processed and analyzed according to the objectives set for this research. Nevertheless, two (2) types of analysis were carried out. These were quantitative and qualitative. Quantitative data were analyzed using SPSS software for descriptive analyses (frequency and percentage). As for qualitative data, processing was based on narrative documents from irrigator associations and NGOs involved in irrigated perimeters. In addition, qualitative data refer to farmers' perceptions of weather events and the various local strategies developed to combat climate change.

As with historical studies of climates and floods, research into low water levels, the beginnings of water sources and water scarcity suffers from a lack of available data and documentation. Thus, the discontinuity and irregularity of low-water and climatic data explains the lower scientific investment in these areas (Kabo et al., 2023). Only studies on watershed management plans, civil engineering studies and diagnoses of irrigated perimeters have been carried out. In the commune of Môle Saint-Nicolas, no in-depth studies have been carried out on the impact of climatic variability, low-water levels and the flow rates of irrigation water sources over long periods, either by national universities or by government research centers. Stakeholders' decisions about water use and management are best understood through post-positivism, defined as a paradigm that sees knowledge of a given phenomenon as linked to the exploration of empirical data. Within post-positivism lies the constructivist paradigm, which considers the object of inquiry to be socially constructed. The constructivist paradigm considers the subjective, lived experience of individuals to contribute to the construction of reality (Kabo et al., 2023). His paradigm seeks to produce knowledge based on the confrontation of subjective knowledge (ideas, perceptions, representations) brought together by the social experience of two or more individuals interacting together. Moreover, the research approaches used in this paradigm consist mainly of qualitative methods (Kabo et al., 2023) to determine the perception and adaptation strategy of farmers in irrigated agricultural perimeters in the face of climate variability. **Table 1** presents data on different irrigated areas, including developed areas, number of farmers, sample size, and sampling rate. This information provides insight into the distribution of agricultural resources in each area, as well as how samples were selected for surveys or observations.

Table 1. Presentation of the irrigated perimeters.

Irrigated perimeter	*Number of developed hectares*	*Number of farmers*	*Sample size*	*Sampling rate*
Polvo	78	129	30	23.25%
Nan Trou	54	197	30	15.22%
Digotrie	68	225	30	13.33%
Lavaltière	75	215	30	13.95%
La Gorge	80	286	30	10.48%

Source: Author's survey, 2023.

4. Results

4.1. Socio-Economic Characteristics of Farmers

The study of the socio-economic characteristics of farmers in the irrigated perimeters was based on a sample of 150 farmers presented in **Table 2**. Among the 150 surveyed farmers, 33 of them, or 22%, are women, and 117, or 78%, are men. The average age of the farmers is about 50 years, with the youngest farmer being 23 years old and the oldest 76 years old. Younger individuals are more engaged in non-agricultural activities and have migrated to urban areas within the country or abroad in search of a better life (Dameus, 2022). The educational level of the farmers is generally low. There are 22 farmers, or 14.7% of those surveyed, who are illiterate. The majority of the farmers have primary level education, accounting for 52.7% of the surveyed population. Only two individuals have a university-level education, representing 1.3% of the total sample. The land tenure modes in the irrigated perimeters include purchase, leasing, and inheritance from grandparents. The leasing term for lands varies between 2 and 5 years across the perimeters, and access to this land, upon the owner's approval, confers full rights of exploitation throughout the leasing period. In fact, agriculture is the main activity for 100% of the surveyed farmers. These farmers supplement their agricultural production with non-agricultural activities to support their families' survival. Through their agricultural activities and the establishment of social and solidarity economy structures, they have been able to save a portion of their income, which is then transformed into credit among the members.

Table 2. Number of interviewed farmers.

Characteristics	*Number (150)*	*Percentage %*
Sex		
Female	33	22%
Male	117	78%
Age group		
18 to 29 years	10	6.7%
30 to 39 years	18	12%
40 to 49 years	55	29.3%
50 years and over	77	51.3%
Education level		
Illiteracy	22	14.7%
Primary	79	52.7%
Secondary	47	31.3%

Source: Author's survey, 2023.

4.2. Farmers' Perception of Climate Change

An irrigator's ability to adapt to water scarcity depends on their perception of observed climatic phenomena, such as rainfall, temperature, and wind speed (Mahdhi et al., 2019). These parameters are crucial to determine how farmers perceive climate change in irrigated areas. Table 3 lists the indicators of climatic variables perceived by farmers. Knowledge of these variables at the regional scale makes it possible to prevent risks and optimize agricultural operations (Gommes, 2011). The 150 farmers interviewed all perceive changes in precipitation, as directly impacting irrigated agricultural production. They note a reduction and irregularity of precipitation, longer dry seasons, a high intensity of rains often accompanied by violent winds, and a reduction in the flow rates of water sources supplying the irrigated areas.

Table 3. Indicators of climatic parameters perceived by farmers in the irrigated perimeters.

Climatic parameters	Indicators of changes
Rainfall	Decrease in rainfall patterns; Delayed onset and early cessation of rains; Lengthening of drought periods; High intensity of cyclonic rains; Reduction in water source flow; Irregular rainfall patterns.
Temperature	Increased temperatures; Very strong heatwaves; Increase in the number of hot days.
Wind	Stronger winds; Rain accompanied by violent winds.
Environmental changes	Emergence of pest insects; Appearance of diseases in crops; Reduction and disappearance of certain plant.

Source: Author's survey, 2023.

All 150 farmers surveyed expressed their perception of the changes observed in the irrigated perimeter areas. They all responded that extreme weather events are increasing on irrigated perimeters, especially on water resources. Faced with increasing variations in extreme weather events, farmers are increasingly vulnerable to the changes noted in Table 3. Thus, the climatic data collected on farmers' perceptions make it possible to validate their perceptions and note the strategies they have developed to cope with the changes observed. They perceive great variability in rainfall water resources, rising temperatures and strong winds that accelerate plant evapotranspiration associated with high temperatures.

Thus, 44.7% of farmers interviewed stated that the dry season varies between 3 and 7 months in the areas and zones surrounding the irrigated perimeters. After the dry period, 55.3% of farmers say that rain always comes in the form of cyclones and floods, which destroy the physical infrastructure of the perimeters and the agricultural plots. In fact, irregular rainfall has the effect of totally reducing the plots worked, and also challenges farmers' local knowledge of their environment. For the most part, rain is always accompanied by violent, harsh winds for several days on the irrigated perimeter. During interviews, a total of 132 farmers (88% of those surveyed) stated that the rainy season always starts late and ends early. Very often, this early cessation on irrigated perimeters comes at the vegetative development phase, and the plants can't find the water they need. This often leads to a drop in crop yields.

As for the temperature, 139 farmers, or 93%, perceive an increase in temperature with very strong heat waves. According to them, the days and nights are getting hotter and hotter, and this increase in temperature causes evapotranspiration. It's essential to acknowledge the observations of farmers and their direct experience in the field. While I haven't personally conducted measurements, scientific data often confirm the trends perceived by farmers. Phenomena such as temperature rise and heat waves are well-documented in climate research. Therefore, farmers' observations can be a valuable indication of ongoing environmental changes. As a result, the flow of springs and the drying up of certain water points are the consequences of this extreme temperature. In addition to the temperature, strong winds contribute to the drop in agricultural production, causing the destruction of crops, young fruit trees and the drying out of soils after rain. The farmers interviewed were unanimous in declaring that there has been an environmental change in the irrigated perimeters. Insect pests are destroying irrigated crops. In addition, certain plants such as citrus trees, coconut palms and taro mazombèle are disappearing from their environment. The results of this research also corroborate those of Madisson (2007), Mertz et al. (2009), Gnanglè et al. (2012), Paraïso et al. (2012), who note that populations are aware of climate variability, identifying wind, lack and excess of rainfall and rising temperature as the most perceptible factors of climate change (Yegbemey et al. 2014).

4.3. Adaptation Strategies of Farmers in the Irrigated Agricultural Perimeters

In response to the increasing climate variability, farmers in the irrigated perimeters of Môle Saint-Nicolas have adopted new strategies to combat climate change. They have introduced short-cycle cultivars adapted to drought periods. The introduction of crops in the areas of the irrigated perimeters completely alters the traditional agricultural calendar by prioritizing new technical pathways adapted to climate variability. Through their experience and observed changes, they make specific choices and varieties for each season. They have given up (89%) certain water-intensive and high-maintenance crops in favor of others that can withstand water stress, and they also practice crop rotation. Thus, from September to November, 84.6% of farmers produce onions, leeks, and carrots in sufficient quantities due to water availability. However, they unanimously cultivate shallots throughout the year due to their drought resistance and yield potential. After harvesting these crops, they replace them with cereal and leguminous crops. Moreover, farmers diversify their agricultural production to minimize the risks of total yield loss by practicing polycultures in the irrigated perimeters.

According to Balasha and his allies (Balasha et al., 2021), diversification and choosing less maintenance-intensive crops are strategies used to reduce the risk of crop losses due to climatic uncertainties. In the spring season, when water resources in the irrigated perimeters start to diminish, off-season irrigation is applied by about 72% of farmers by carrying out small-scale productions, i.e., reducing the cultivated area. They divide their production plots into two, one part for vegetable production and the other for cereals and legumes. During drought periods, some farmers use water storage containers for manual watering of vegetable crops. This practice is more widespread in the Nan Trou irrigated perimeter because, during this period, the water source flows significantly decreases. Farmers organize community activities after floods to dredge irrigation canals and repair some damaged infrastructure.

Facing soil fertility loss due to water erosion, farmers develop soil and water conservation methods following techniques taught by NGOs and Haitian state officials. Furthermore, the maintenance of irrigation canals, the protection of the upstream water sources that feed the agricultural perimeters, and the establishment of anti-erosion structures in the micro-watersheds are adaptation means implemented by farmers to combat water scarcity in the face of climate variability. The main types of structures built in the plots are thresholds, stone bunds, and living and non-living ramps. These anti-erosion structures contribute to adapting to rainfall variability by reducing water erosion and increasing water infiltration into the soil to recharge aquifers, which helps reduce crop water stress during drought periods.

Some farmers build rectangular ridges with furrows inside. This method not only allows for better water management but also facilitates weeding in the plots. During soil preparation, farmers use organic matter composed of domestic animal manure to increase soil fertility. Very few farmers practice fallowing. They exploit the irrigated agricultural plots throughout the year. Ruminant farming is a very profitable activity for farmers in the irrigated perimeters. In case of agricultural season losses, they rely on cattle and goat farming. Grazing is the first and last activity undertaken by farmers in a day before working on the irrigated perimeters. Moreover, they organize themselves through social and solidarity economy structures, named AVEC (Village Savings and Loan Association) and Mutual Solidarity. According to them, these structures allow them access to credits adapted to their socio-economic reality to improve their living conditions. Table 4 below shows the different local strategies adopted by farmers in the irrigated perimeters to face climate variability.

Table 4. Farmers' adaptation strategies to climate variability.

Adaptation strategies	Effective	Percentage (%)
New technical pathways	144	96
Selection of new cultivars	150	100
Crop diversification	145	96.6
Crop rotation	140	93.3
Abandonment of certain crops	133	88.7
Off-season irrigation	108	72
Reduction of plots in the spring	101	67.3
Anti-erosion structures in plots	146	97.3
Fallow practices	61	40.7
Membership in savings and credit groups	150	100
Storage and manual watering of crops	32	21.3

Source: Author's survey, 2023.

4.4. Impacts of Climate Variability on Irrigated Perimeters

Due to climate change, farmers in the five irrigated perimeters of Môle Saint-Nicolas are increasingly vulnerable. Faced with this vulnerability, they have developed adaptation means based on their socio-economic capacity. However, extreme weather events continue to create uncertainties among them despite their efforts. These extreme events manifest as prolonged drought periods ranging from 3 to 6 months, rains accompanied by violent winds that destroy irrigated crops, and increased temperatures causing rapid evapotranspiration. During drought episodes, water source flows decrease significantly, and farmers are forced to turn to other income-generating activities. Furthermore, not only are farmers unable to meet their families' basic needs, but their children under five also suffer from malnutrition related to food insecurity, predominantly experiencing acute and moderate malnutrition. Over the past two decades, water resources have become increasingly limited and scarce during certain times of the year (from January through April and from May to September), leading to conflicts among users. Moreover, conflicts related to water resources in the irrigated perimeters are likely to increase due to the high demand for irrigation water by farmers. Additionally, climate variability causes forced displacement of farmers seeking other economic activities. They migrate to other cities in the country in search of a better life because the yield from irrigated agricultural production is not profitable.

4.5. Farmers' Vulnerability to Climate Change

The irrigated perimeter of Môle Saint-Nicolas remains vulnerable to the consequences of climate change. Hazards such as drought episodes, changes in rainfall patterns, cyclones, and floods negatively impact farmers' livelihoods. The level of vulnerability of farmers to climate shocks is high on several fronts. Socio-economically, access to certain basic services and their economic means to cope with extreme events are limited. Agriculturally, the productivity of the irrigated perimeters decreases, and farmers experience yield losses due to a lack of water resources. Consequently, the loss of agricultural yields has become a normal and acceptable fact across the five irrigated perimeters. In fact, the study of farmers' vulnerability was conducted based on the exposure of the four elements mentioned in the table below (Table 5) to climate risks. Vulnerability factors and their levels were identified and analyzed during group interviews with farmers who were part of the study sample.

Table 5. Consequences of climate change on water resources and production.

Vulnerability	Vulnerability factors	Level
Water Resources	• Major drought episodes; • Extreme temperature; • Degradation of micro watersheds and exploitation of trees upstream of water sources; • Poorly fed aquifers and increased runoff; • Surface water evaporation; • Increased water demand.	High

Continued

Agricultural Production	• Variations in rainfall patterns; • Violent winds with rain; • Shifting sowing seasons; • Rapid/accelerated evapotranspiration; • Soil erosion and loss of arable layers; • Emergence of pest insects and diseases in crops; • Abandonment of certain crops; • Inability to find quality and suitable seeds during sowing; • Decrease in yields.	High
Socioeconomic	• Decapitalization of farmers; • High production costs; • High prices of agricultural inputs during sowing and lowered during harvests; • Exclusion from the conventional banking system and limited access to credit; • Migration of labor to other income-generating activities; • Limited access to basic needs: education for their children, quality healthcare, quality food; • Food insecurity (acute malnutrition in children under five); • Seasonal parasitic diseases; • Aging of farmers.	High

Source: Author's survey, 2023.

4.6. Discussion

The findings of this research indicate that farmers in the irrigated perimeters perceive climate change a phenomena contributing to the reduction of farmer income. Climate change induces extreme weather events that negatively impact the irrigated agricultural production of Môle Saint-Nicolas. Furthermore, climatic variables such as decreased rainfall, extended dry seasons, increased temperature, and violent winds are perceptions confirmed by farmers across the five irrigated perimeters. This perception by the farmers is due to the direct influence of these climatic variables on agricultural production, which can determine a good or bad agricultural season (Sanou et al. 2018). During dry periods, the water sources feeding the irrigated perimeters are unable to meet the water needs of vegetable crops, which are highly water-demanding and sensitive.

Bationon (2009), in his research thesis presented at the University of Ouagadougou, mentions that vegetable crops, unlike rainfed crops, have specific water and temperature requirements. When these requirements are not met, either the plants do not reproduce, or the production is of poor quality. Farmers in the irrigated perimeters often record a decrease or total loss of yields due to a sudden cessation of rains during the vegetative growth phase of crops. When the rains are insufficient, the consequences are reflected in the crops through poor development, wilting of leaves, crop burn due to increased temperature, lack of water for domestic needs, etc., similar to peasant perceptions identified in surveys conducted in the cotton zone of Northern Benin (Guilbert et al., 2010; Bambara et al., 2013; Sanou et al., 2018).

The irrigated perimeters of Môle Saint-Nicolas are managed by projects from non-governmental organizations (NGOs) in collaboration with the Haitian state through the Ministry of Agriculture. The construction of hydro-agricultural infrastructure was aimed at increasing water resources and agricultural sectors in the irrigated perimeters. However, this goal has not been achieved to date, and the agricultural situation is deteriorating. Mostly, these NGOs do not take into account the socio-economic reality of the farmers. During the project lifecycle, adaptation capacity is improved, i.e., more progress is recorded due to the distribution of agricultural inputs and the development of micro-basins located upstream of the perimeters. During project implementation, there are always labor-intensive activities by distributing cash to workers. Moreover, some NGOs often used "food for work" as a payment method for building dry walls and contour canals (Smucker, 2012). It was always a public works approach using mechanical structures on farmers' private lands. For these NGOs, it was a matter of mobilizing volunteer work with some encouragement, while for the farmers, the in-kind payment was a real salary that far exceeded the current price of agricultural labor (Smucker, 2012). However, once the project ends, farmers receive no support to continue facing climate shocks.

The local adaptation strategies developed by farmers in Môle Saint-Nicolas are linked firstly to their perception and secondly to their economic means. Their perception is based on the different changes observed in the areas of the irrigated perimeters related to climate variability, and their economic means allow them to anticipate and better adapt to climate change. To cope with the increase in climate variability, the implemented strategy is focused on water resources, which, according to them, are cross-cutting both to ensure the profitability of agricultural production and to carry out domestic activities. Faye and Sané (2015), in a research conducted in Senegal, mention that "in the agricultural sector, the implemented adaptation strategies consist of seeking more water-efficient cropping systems, better aligning the cropping cycle by using animal traction and choosing early-maturing varieties, and developing techniques that allow concentrating rainwater where it is most useful." Similarly, in Haiti, farmers in the irrigated perimeters often consider early-maturing varieties as a good response to delayed rains and better adaptation. Despite these efforts to cope with increased climate variability, the degradation of hydro-agricultural infrastructure in the irrigated perimeters is an obstacle for the agricultural sector. However, farmers do not have sufficient financial means to maintain the damaged canals. Their economic means merely allow for canal dredging through community activities. In this situation, the agricultural sector offers low yields due to the degradation of hydro-agricultural infrastructure, and food needs are not met, as confirmed by Abdoul-Kader and Dambo (2022) in their research in the urban commune of Konni in Niger.

In terms of capacity building on the use of climate data and understanding the challenges of climate change, farmers remain vulnerable. No stakeholder in the perimeters participates in the mobilization of knowledge on adaptation to climate change. Moreover, few scientific studies have been conducted on the irrigated perimeters of Môle Saint-Nicolas, which is why climate data remains limited for conducting scientific work. In line with the research of Mushagalusa Balasha and colleagues (Balasha, 2021) conducted in South Kivu in the eastern Democratic Republic of Congo, the results of this study can guide public authorities and agricultural development actors in defining a program to strengthen adaptation capacities to climate change by formulating new strategies based on existing indigenous knowledge. Furthermore, one of the biggest problems of the irrigated perimeters is the unavailability of labor due to the migration of some farmers. Additionally, the cost of soil preparation and plot maintenance is very high. Farmers are forced to do this work themselves over several days. Ahodode's work in Northern Benin on farmers' adaptation strategies shows the same reality as Haiti in terms of labor, stating: to mobilize labor, one must have an effective social network and sufficient financial and material resources. Even when calling for mutual aid, the mobilized workers must be fed, and one must be available to help them in return.

5. Conclusion and Perspectives

This study aimed to analyze the impact of rainfall variability on irrigated agricultural production and to assess farmers' perceptions and adaptation strategies to climate change in Môle Saint-Nicolas, Haiti. Results show that farmers perceive climate change through the increase of extreme weather events, which negatively affects their standard of living by reducing water resources for irrigation and increasing commercial exploitation of upstream tree resources. To mitigate the effects of climate variability, farmers have adopted several strategies, including introducing new cultivars, modifying agricultural calendars, diversifying and rotating crops, adopting early maturing varieties, managing soil, dredging canals, and developing micro-basins. These practices have significantly boosted irrigated agricultural yields.

However, adaptation capacity varies with socio-economic factors, particularly affecting older farmers and those with limited education, who rely solely on agriculture for income and face substantial losses during natural disasters. There is an urgent need to enhance the resilience of these farmers through regular training programs on vulnerability, natural disasters, and climate change. Additionally, establishing a national research center to gather data and develop decision-support tools would aid in managing climate challenges and improving the resilience of vulnerable communities. Current meteorological data, managed by under-trained personnel from local NGOs, is unreliable, highlighting the need to integrate local and scientific knowledge to effectively combat the impact of climate variability on Haiti's marginalized farmers.

Acknowledgements

The full production of this scientific article as part of my doctoral thesis at Laval

University, Quebec, Canada, is made possible thanks to the support of the thesis directors assigned to the geography department. A special thank you to professors Jean-François Bissonnette (thesis director) and Marc-André Bourgault (co-director) who contribute to providing the main lines to be developed in this article and the various corrections. Likewise, a big thank you to Meryem Qacami for the translation of this article and her research on the climatic data of the commune of Môle Saint-Nicolas. Finally, a big thank you also to Kossivi Fabrice Dossa for the attentive reading and their relevant advice.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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