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CACCI FIELD NOTES

Exploring Methane Concentration Dynamics above Senegalese Croplands

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About the CACCI Field Notes

AKADEMIYA2063 CACCI Field Notes are publications by AKADEMIYA2063 scientists and collaborators based on research conducted under the Comprehensive Action for Climate Change Initiative (CACCI) project. CACCI strives to help accelerate the implementation of Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs) by meeting the needs for data and analytics and supporting institutional and coordination capacities. In Africa, CACCI works closely with the African Union Commission, AKADEMIYA2063, the African Network of Agricultural Policy Research Institutes (ANAPRI), and climate stakeholders in selected countries to inform climate planning and strengthen capacities for evidence-based policymaking to advance progress toward climate goals.

Published on the AKADEMIYA2063 website (open-access), CACCI Field Notes provide broad and timely access to significant insights and evidence from our ongoing research activities in the areas of climate adaptation and mitigation. The data made available through this publication series will provide evidence-based insights to practitioners and policymakers driving climate action in countries where the CACCI project is being implemented.

AKADEMIYA2063's work under the CACCI project contributes to the provision of technical expertise to strengthen national, regional, and continental capacity for the implementation of NDCs and NAPs.

AKADEMIYA2063 is committed to supporting African countries in their efforts against climate change through provision of data and analytics using the latest available technologies. In this Field Note, AKADEMIYA2063 scientists examine the dynamics of methane concentration above croplands in Senegal for the period from November 2021 to April 2023 using TROPOMI datasets.

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About AKADEMIYA2063

AKADEMIYA2063 is a pan-African non-profit research organization with headquarters in Kigali, Rwanda and a regional office in Dakar, Senegal. Inspired by the ambitions of the African Union's Agenda 2063 and grounded in the recognition of the central importance of strong knowledge and evidence-based systems, the vision of AKADEMIYA2063 is an Africa with the expertise we need for the Africa we want. This expertise must be responsive to the continent's needs for data and analysis to ensure high-quality policy design and execution. Inclusive, evidence-informed policymaking is key to meeting the continent's development aspirations, creating wealth, and improving livelihoods.

AKADEMIYA2063's overall mission is to create, across Africa and led from its headquarters in Rwanda, state-of-the-art technical capacities to support the efforts by the Member States of the African Union to achieve the key goals of Agenda 2063 of transforming national economies to boost economic growth and prosperity.

Following from its vision and mission, the main goal of AKADEMIYA2063 is to help meet Africa's needs at the continental, regional and national levels in terms of data, analytics, and mutual learning for the effective implementation of Agenda 2063 and the realization of its outcomes by a critical mass of countries. AKADEMIYA2063 strives to meet its goals through programs organized under five strategic areas—policy innovation, knowledge systems, capacity creation and deployment, operational support, and data management, digital products, and technology—as well as innovative partnerships and outreach activities. **For more information**, visit www.akademiya2063.org.

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1. Introduction

The issue of methane (CH4) emissions has garnered growing attention due to its substantial role in augmenting global greenhouse gas levels, intensifying the imperative to tackle climate change (Saunois et al. 2020). Fossil fuel extraction and livestock have long been recognized as sources of methane emissions, while current research also emphasizes the significant contribution of agricultural operations, particularly in croplands, to the release of methane (Smith et al. 2021; Nisbet et al. 2019).

Methane emissions within the framework of croplands are a substantial and ever-changing element of the worldwide budget for greenhouse gases. The emissions originate from a multifaceted interaction between agricultural methods, soil microbial processes, and environmental conditions. Flooded soils play a significant role in methane production, where the anaerobic conditions promote the production of methane by methanogenic microorganisms. Rice fields contribute a considerable portion of agricultural methane emissions, as rice plants provide both factors that enhance and limit methane production (Rajendran et al. 2023). Furthermore, the application of nitrogen (N) fertilizer to increase crop yields has a significant influence on soil methane (CH_4) and nitrous oxide (N_2O) emission/uptake (Binfeng et al. 2016). Various factors, including irrigation systems, soil conditions, and crop varieties, exert an influence on the magnitude of methane emissions originating from croplands.

The assessment of methane dynamics is of paramount importance in comprehending its intricate function within the Earth's climate system and in devising efficacious approaches to tackling global environmental issues. Methane has a substantial radiative forcing effect on the climate, ranking second only to carbon dioxide (Myhre et al. 2013). The acquisition of precise and thorough data regarding methane concentrations is crucial in enhancing our comprehension of its behavior and interactions within the atmosphere. This knowledge facilitates the enhancement of climate models and the accuracy of predictions (Saunois et al. 2016). In addition, these data offer significant insights into the efficacy of policies intended to mitigate methane emissions, thereby assisting in the development of focused interventions for reducing methane's impact on global warming (Nisbet et al. 2019). Our understanding of methane dynamics could be advanced through the use of robust measuring methodologies. Such progress would, in turn, have the potential to bolster our capacity to effectively tackle climate change, preserve ecosystems, and provide a sustainable environment for future generations.

Methane concentrations are commonly assessed through the integration of ground-based monitoring networks and satellite-based remote sensing methodologies. Ground-based measurements encompass the use of specialized instruments, such as Fourier transform infrared (FTIR) spectrometers and gas chromatographs, positioned at different sites to directly collect, and examine methane concentrations in the atmosphere (Peterson et al. 2010). These measurements offer precise and accurate data for particular locations, aiding in the validation and calibration of satellite observations. In contrast, satellite-based studies employ advanced instrumentation installed on satellites to detect the absorption of methane in sunlight or the thermal radiation emitted by the Earth's surface (Bergamaschi et al. 2007). The use of modern technologies, such as the Tropospheric Monitoring Instrument (TROPOMI) and the Greenhouse Gases Observing Satellite (GOSAT), has greatly enhanced our capacity to spatially map and continuously monitor global methane levels from a satellite-based perspective (Kuze et al. 2009; Palmer et al. 2021). The amalgamation of terrestrial and satellite observations facilitates a holistic comprehension of methane's dispersion, fluctuation, and patterns throughout diverse spatial extents, yielding significant insights into its origins and potential ecological ramifications.

This field note aims to study the dynamics of methane emissions above croplands in Senegal for the period from November 2021 to April 2023 using TROPOMI datasets. Croplands are important in ensuring food security and economic stability in Senegal, a nation heavily reliant on agriculture (FAO 2021). This assessment will foster a better understanding of methane concentration dynamics in Senegal's croplands and support the design of effective mitigation strategies and targeted interventions to reduce emissions, enhance soil health, and contribute to global emission reduction goals.

This study does not allocate methane concentrations to their sources. Rather, it explores the methane concentrations dynamics above croplands. However, the measurements principle makes the data sensitive to the lower levels of the dry air column measurements meaning the emissions from the ground will greatly contribute to the concentration levels. Furthermore, the calibration of TROPOMI measurements with ground stations allows their use as a potential proxy for emission levels. Therefore, the use of the term emission in lieu of concentration will be done several times throughout the document based on the justification above.

Disclaimer

This document uses publicly available satellite remote sensing data. Data content clipped to Senegalese national borders might be added for illustration purposes. The national borders are defined by shapefiles derived from the Database of Global Administrative Areas (GADM) at https://gadm.org/download_country.html. AKADEMIYA2063 uses the country shapefiles mentioned above solely for limiting the data map to the country's geographical extent. Therefore, the boundaries, names, and designations shown on maps do not imply official endorsement or acceptance by AKADEMIYA2063.

2. Methodology

2.1. Methane Satellite Measurements

For methane density measurements, we used the TROPOspheric Monitoring Instrument (TROPOMI), which is the unique payload of the Sentinel 5 Precursor (S5P) mission of the European Space Agency (ESA). The instrument is a nadir-viewing shortwave spectrometer. It uses a passive remote sensing technique to measure radiations reflected by and radiated from the Earth at the top of the atmosphere. The instrument collects information in the UV-Visible, Near Infrared (NIR), and Shortwave Infrared (SWIR) wavelengths through a two-detector sensor. The TROPOMI has a swath width of seven kilometers for the duration of a second and in the flight direction. The collected data for each swath is divided into two parts: the first embeds the position of the information in the swath, and the second its spectral information. The TROPOMI entered its operational phase in April 2018 and is scheduled to end its mission in 2023.

2.2. Measurement principles

The methane concentration provided by the TROPOMI is a column-averaged dry air mixing ratio. The methane concentration is measured as a fraction of its abundance in an atmospheric column vis-à-vis the corresponding amount of dry air. The computation was done by computing the concentration in each atmospheric sub-layer within the column and then summed up. The formula is shown below.

$$X_{CH_4} = \sum_{i=1}^{n} \frac{x_i}{V_{air,dry}}$$

In the equation above, is the column-averaged dry air mixing ratio of methane, is the methane concentration for each sub-layer of the atmosphere within the column and, is the volume of dry air in the column. The European Centre for Medium-Range Weather Forecasts (ECMWF) provided the latter and was retrieved from the full physics (RemoTeC) algorithm. The formulation above also means the methane concentration from TROPOMI should not be taken as an earth surface methane concentration but as its concentration in an atmospheric column. Its use here is justified by three factors: (i) the capability it provides to cover large areas of interest, (ii) its temporal and spatial resolution, and (iii) its sensitivity to surface methane concentration which can be used as a proxy for methane emissions on the ground. In addition, the methane concentration was computed to have a high sensitivity to its concentration in the layer closer to Earth. For more information about the data validation process, please refer to a previous field note available at (Ly et al. 2023).

2.3. The region of interest: Senegal

Located on the westernmost periphery of the African continent, Senegal exhibits a wide array of topographical, agroecological, and meteorological characteristics that profoundly influence its agricultural topography. Senegal encompasses a landmass of approximately 196,712 square kilometers and displays significant heterogeneity in its agroecological zones. These zones can be generically classified as Sahelian, Sudano-Sahelian, and Sudanian areas. The zones mentioned above exhibit a continuum of aridity levels, wherein the northern region, known as the Sahelian zone, is characterized by semi-arid conditions. In contrast, the southern part, referred to as the Sudanian zone, has a higher humidity level, facilitating a more comprehensive range of crop cultivation.

The nation's climate is characterized by a clearly defined arid period spanning from November to May, followed by a wet period from June to October. Senegal exhibits a distinct precipitation gradient from north to south, characterized by a notable disparity in the quantity and predictability of rainfall. The country's northern region receives comparatively smaller amounts of rain, which also tend to be less reliable in timing and occurrence, in contrast to the southern part of Senegal. These climatic variables have noteworthy ramifications for agricultural activities, exerting influence over decisions regarding crop selection, water resource management, and livestock-rearing methods.

The agricultural landscape of Senegalese croplands is characterized by its diversity and substantial contributions to the country's economy and livelihoods. According to the most recent data, the agricultural sector in Senegal currently sustains roughly 70 percent of the population and contributes to approximately 16 percent of the country's Gross Domestic Product (GDP) (World Bank 2021). The croplands under consideration encompass a variety of agroecological zones, ranging from semi-arid Sahelian areas to more productive regions located in the southern parts. The primary agricultural commodities grown in Senegal include millet, sorghum, maize, groundnuts, and rice. Notably, rice cultivation contributes to around 35 percent of Senegal's overall cereal production (FAO 2021; World Bank 2021). Croplands continue to play a crucial role in ensuring food security and sustaining livelihoods. However, croplands are also subjected to significant obstacles associated with the impacts of climate change and the degradation of soil quality. It is imperative to tackle these difficulties by implementing sustainable agricultural practices, enhancing water management techniques, and adopting novel technologies in order to safeguard the ongoing production and resilience of croplands in Senegal.

2.4. Data analysis

In this study we used the TROPOMI's methane column concentrations for Senegal from November 2021 and April 2023. For each observation date – at a weekly temporal frequency – a map of CH4 column concentration was available for the entire country. Subsequently, to target Senegalese croplands, the discrete Copernicus Global Land Service land cover map (CGLS-LC100m V3.0 Level 1) was used as a cropland mask at a spatial resolution of 100 x 100 meters. By cropping each TROPOMI methane observation to the cropland mask, a map of CH4 column emission was obtained for Senegal at cropland locations.

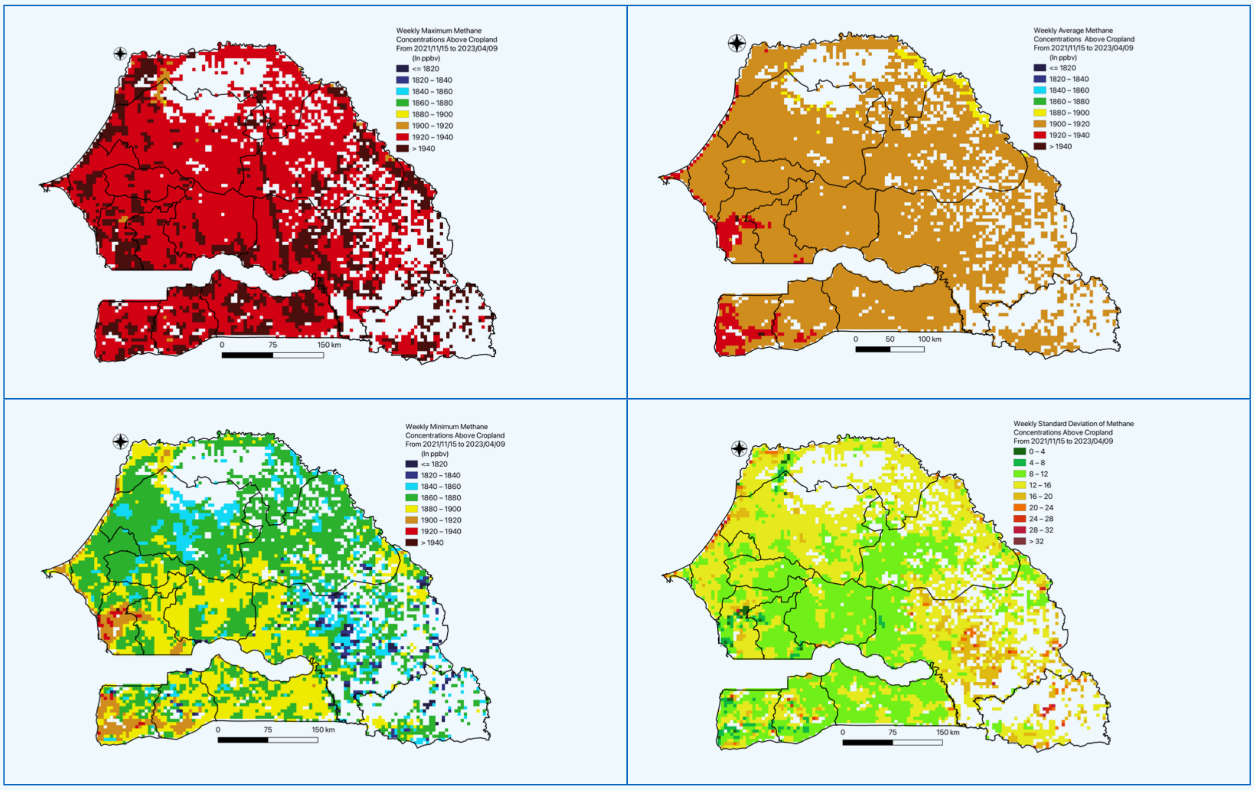
Two computations were hence conducted. First, the computations of descriptive statistics of methane above croplands for the period of study: mean, maximum, minimum, and standard deviation for methane emissions above croplands and at the national level. Second, the aggregation of methane emissions above croplands to the 14 administrative regions in Senegal and the plot of their fluctuations through time and against the sowing, growing, and harvesting of major crops such as rice, maize, millet, and groundnut.

The data processing and mapping were performed using the Anaconda Python distribution (version 4.12.0) and Q-GIS (version 3.36.0), respectively.

3. Findings and analysis

3.1. Overview of methane emissions above Senegalese croplands

Figure 1: Methane concentration above cropland from November 2021 to April 2023



Data processing and mapping: Authors.

In Senegal, methane concentrations (Figure 1) observed above cropland areas from November 2021 to April 2023 reveal a comprehensive spectrum of values that reflect the interplay of various factors over this period. The dataset encompasses a range of methane concentrations, with the maximum levels extending from 1920 to 1940 parts per billion by volume (ppbv) and occasionally surpassing this threshold. These upper limits signify instances where localized influences and changing agricultural practices coincide to produce heightened emissions.

Conversely, the minimum methane concentrations recorded fall within the range of 1860 to 1900 ppbv. These lower measurements represent the baseline methane emissions inherent to the region and serve as a reference point for assessing fluctuations caused by external factors.

When considering the average methane concentration across Senegal's cropland areas during this timeframe, the calculated mean falls within the range of 1900 to 1920 ppbv. This average offers a representative overview of methane emissions arising from agricultural activities, considering the evolving practices and conditions over the study period.

Notably, the standard deviation of the methane concentrations remains consistently below 16 ppbv, indicating a relatively stable and predictable pattern of emissions. This low standard deviation implies a degree of coherence in methane release across the cropland areas, despite potential variations in agricultural techniques, land use, and meteorological factors.

The temporal scope of the data collection, spanning from November 2021 to April 2023, provides valuable insights into the seasonal and yearly trends of methane concentrations above Senegal's croplands. By encompassing multiple growing seasons and meteorological cycles, this dataset aids in understanding the intricate relationship between agricultural practices and methane emissions. The observed variations underscore the importance of continued monitoring and analysis to inform sustainable agricultural approaches and emission reduction strategies, contributing to a more environmentally responsible future for Senegal and the global community.

3.2. Overview per agroecological zone

Figure 2: Methane concentrations dynamics in agro-ecological zones of Senegal

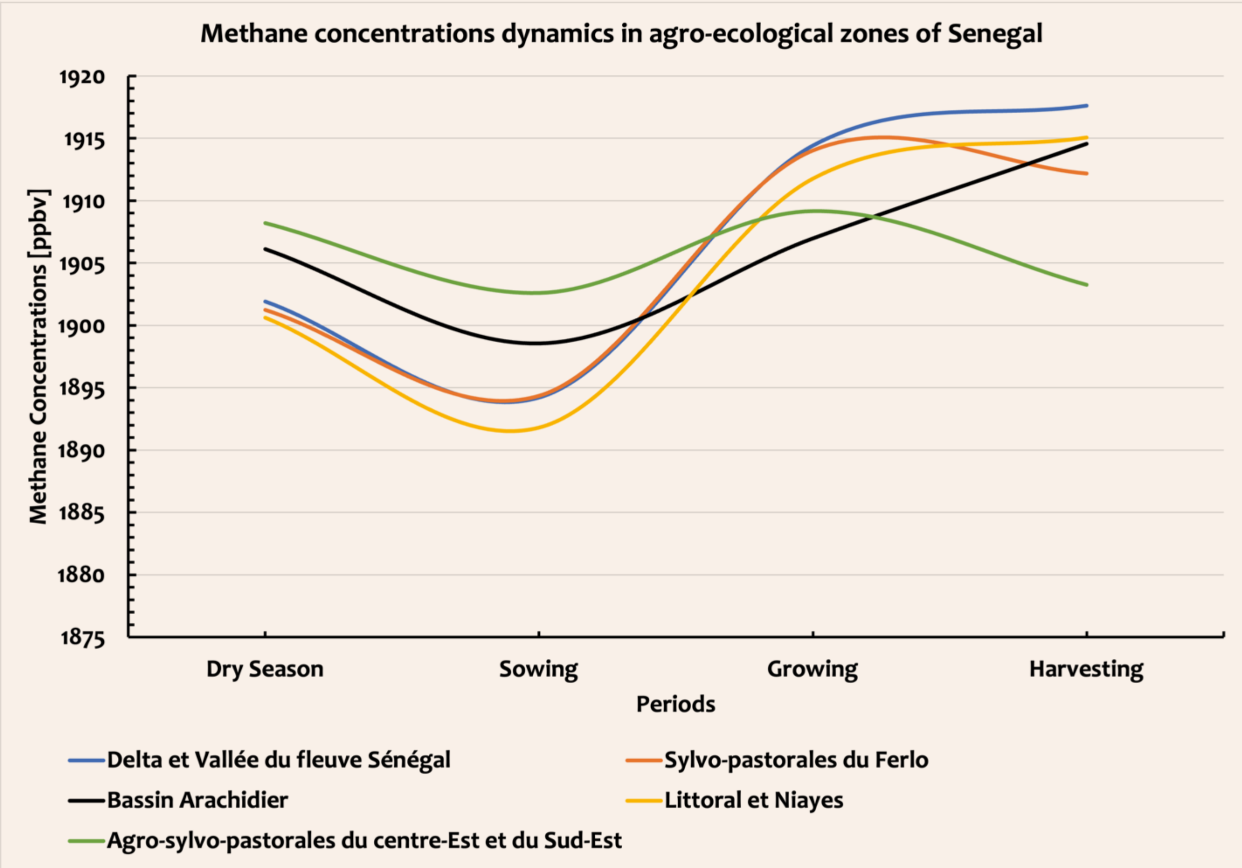


Figure 2 illustrates the variations in atmospheric methane concentrations across different seasons in various agro-ecological zones of Senegal. This data sheds light on the complex interactions between natural processes and human activities that contribute to the levels of methane in the atmosphere.

During the dry season, which spans a significant portion of the year in Senegal, atmospheric methane concentrations display a relatively consistent pattern, fluctuating within a narrow range of 1900 to 1910 parts per billion by volume (ppbv). This consistency might be attributed to a balance between methane emission sources and sinks during this period.

As the country transitions towards the sowing period, a noteworthy trend emerges. Methane concentrations across the entire region start to decline. This reduction is likely influenced by factors such as decreased microbial activity in wetlands and soils due to drier conditions, which limit methane production. Additionally, the diminished decomposition of organic matter under these conditions could contribute to the decline.

However, a shift occurs between the sowing and growing periods. Atmospheric methane concentrations begin to rise again. This increase might be linked to various anthropogenic activities across Senegal's diverse agro-ecological zones. The distinct contributions of different regions to methane emissions become evident during this phase.

In the agricultural zone, which encompasses areas such as the Delta and Valley of the Senegal River, methane emissions are largely associated with specific farming practices. Rice cultivation in these regions is known to produce methane due to the anaerobic conditions in flooded rice paddies. Similarly, the cultivation of groundnuts in the Bassin Arachidier and the cultivation of various food and vegetable crops in the Littoral and Niayes zones contribute to methane emissions from agricultural activities.

In contrast, the Sylvo-pastoral zones of Ferlo and the Agro-sylvo-pastoral zones of the center-east and southeast focus on cattle breeding. Methane is released during digestion in ruminants through a process called enteric fermentation. This leads to ongoing methane emissions in these regions, which continue to influence atmospheric concentrations.

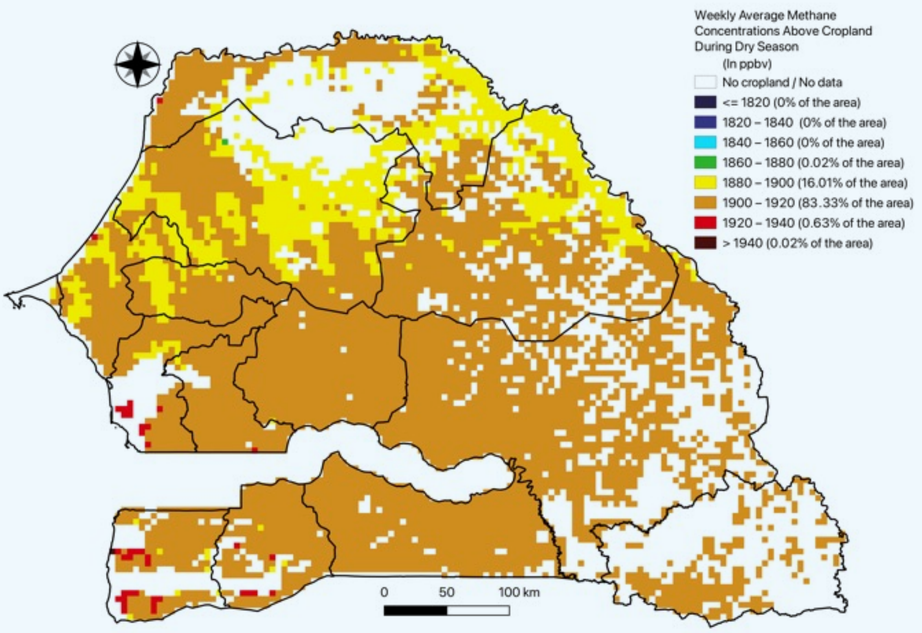
As the harvesting period arrives, methane emissions from agricultural zones continue to rise, likely due to increased agricultural activity and the release of stored gases in soils and wetlands. However, a counterintuitive trend is observed in the sylvo-pastoral zones. Despite ongoing methane emissions from livestock grazing, the reduction in agricultural activities during the harvesting period, attributed to forestry practices, leads to decreased methane production. This emphasizes the role of land-use changes in influencing methane dynamics.

In conclusion, the intricate interplay between natural processes and human activities shapes the dynamics of atmospheric methane concentrations in Senegal's diverse agro-ecological zones. Understanding these patterns is crucial for effective climate change mitigation and sustainable land-use planning.

3.3. Spatial distribution of emissions

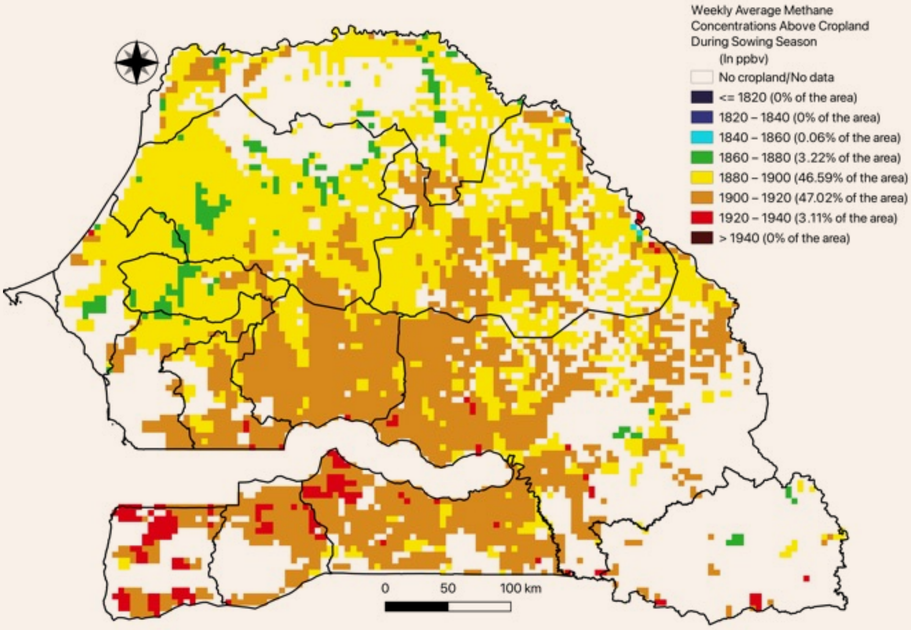
Figure 3: Methane concentration above cropland during cropping season in Senegal.

Figure 3.1. Weekly average Methane Concentrations above croplands in Senegal during the Dry season.



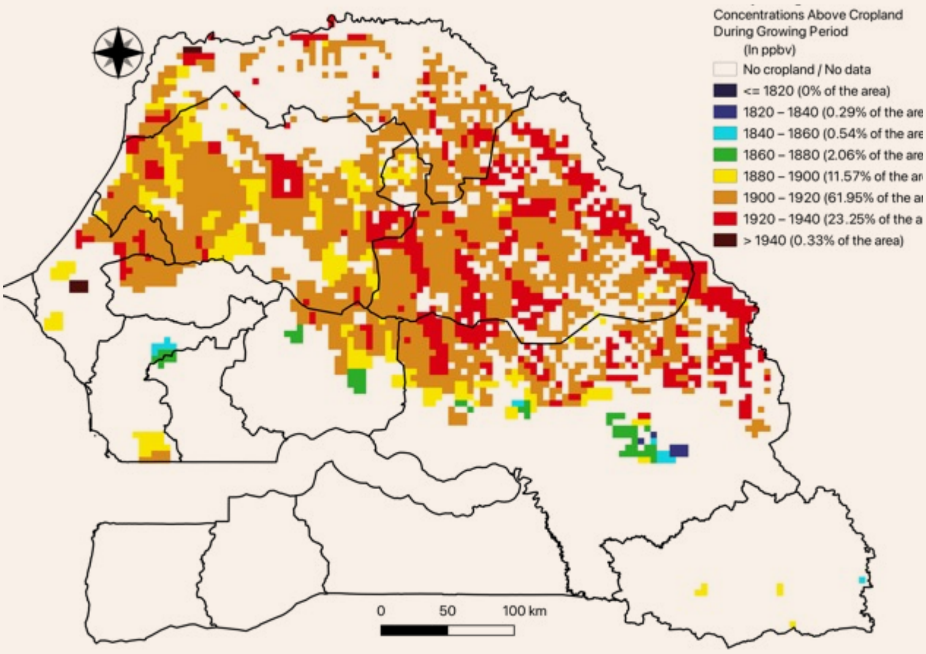
Data source: Copernicus Sentinel-5P (processed by ESA), 2021, TROPOMI Level 2 Methane Total Column products. Version 02. European Space Agency. https://doi.org/10.5270/S5P-3lcdqiv; Data processing and mapping: Authors.

Figure 3.2. Weekly average Methane Concentrations above croplands in Senegal during the Sowing season.



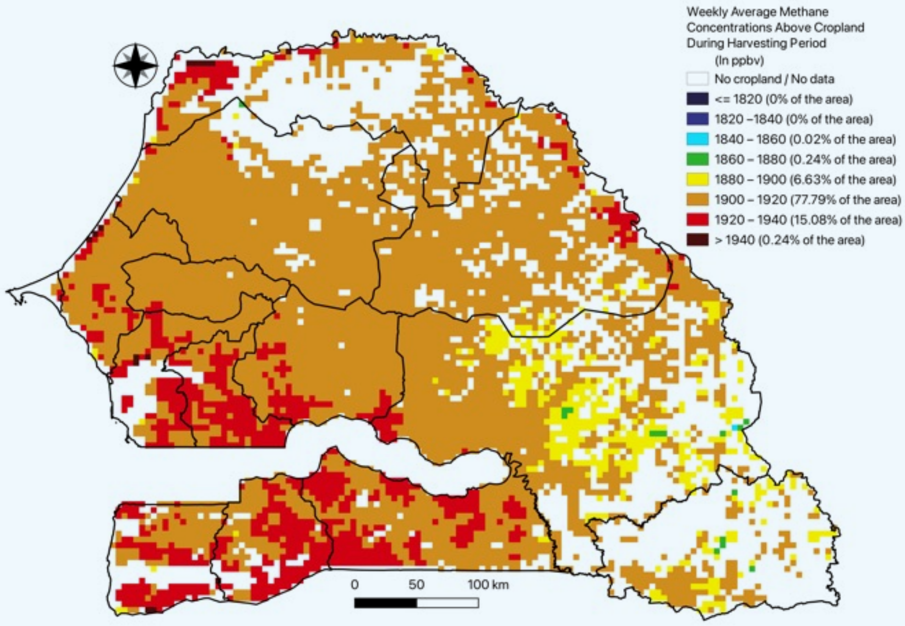
Data source: Copernicus Sentinel-5P (processed by ESA), 2021, TROPOMI Level 2 Methane Total Column products. Version 02. European Space Agency. https://doi.org/10.5270/S5P-3lcdqiv; Data processing and mapping: Authors.

Figure 3.3. Weekly average Methane Concentrations above croplands in Senegal during the Growing period.



Data source: Copernicus Sentinel-5P (processed by ESA), 2021, TROPOMI Level 2 Methane Total Column products. Version 02. European Space Agency. https://doi.org/10.5270/S5P-3lcdqiv; Data processing and mapping: Authors.

Figure 3.4. Weekly average Methane Concentrations above croplands in Senegal during the Harvesting period.



Data source: Copernicus Sentinel-5P (processed by ESA), 2021, TROPOMI Level 2 Methane Total Column products. Version 02. European Space Agency. https://doi.org/10.5270/S5P-3lcdqiv; Data processing and mapping: Authors.

The figures 3.1, 3.2, 3.3, and 3.4, show that Senegal's cropland areas reveal different variations in methane concentration as they traverse distinct phases of the dry season and cropping season: sowing, growing, and harvesting. These fluctuations in methane levels yield valuable insights into the intricate interplay between agricultural practices and the dynamic atmospheric methane emissions.

Dry season to sowing season

Transitioning from the dry season to the sowing season, we observe a significant decrease in methane concentration. This notable diminution can be attributed to a combination of factors, including shifts in weather patterns and agricultural practices. For example, by transitioning away from stubble burning and adopting alternative residue management techniques such as plowing, mulching, or incorporating crop residues into the soil, methane emissions can be curtailed. Stubble burning releases methane due to incomplete combustion in oxygen-limited conditions, creating a direct link between this practice and elevated methane levels. Also, the transition to the sowing season brings about more favorable conditions for plant growth which suggest increased soil moisture and moderate temperatures. Rafalska et al. (2023) showed that methane uptake in grassland soils can change from -57.7 percent to +6.1 percent by increased precipitation, from -37.3 percent to +85.3 percent by elevated temperatures, and from +0.87 percent to +92.4 percent by decreased precipitation.

Geographically, significant shifts in methane concentration colors are evident across distinct regions. The yellow color, indicative of medium methane concentration, expands notably by 30 percent, extending from its initial 16 percent coverage centered around the Louga region to now encompass Louga, Saint-Louis, Matam, and Thies. This expansion predominantly encompasses the arid northern part of the country.

Conversely, the brown color, indicating high methane concentration, undergoes a substantial reduction. It diminishes from its prior coverage of 83 percent, which spanned nearly the entire cropland area, to 47 percent. This shift is now concentrated in the southern regions, where the rainy season commences earlier than in other parts of the country. This transformation suggests a decline in areas emitting elevated methane levels, potentially attributed to evolving agricultural practices. Meanwhile, the red color consistently remains negligible at 0.6 percent, signifying minimal methane emissions during both periods. These geographical variations offer valuable insights into the shifting methane emission landscape, correlated with changing regional agricultural dynamics.

Sowing season to growing season

The transition from the sowing season to the growing season reveals subtle changes in color percentages, providing valuable insights into shifting methane emission patterns. Agricultural activities play a pivotal role in shaping methane emissions, influenced by factors such as soil preparation methods, fertilizer choices, water management, and crop types. Fertilizers, essential for modern farming, have a complex impact on methane release. The choice between nitrogen-based and organic fertilizers significantly affects methane emissions by altering soil conditions and microbial dynamics. Nitrogen-based fertilizers, vital for productivity, modify soil conditions, promoting methane-producing microorganisms and thus increasing emissions (Pittelkow et al. 2013). Water management strategies, such as flooding rice fields, create optimal conditions for methane-producing microbes to thrive (Xu et al. 2022).

The yellow color undergoes a substantial 35 percent decrease, diminishing from its previous coverage of 46 percent, mostly located in the northern part of the country, to 11 percent of the covered area. This reduction suggests a decline in regions emitting medium methane concentrations, possibly attributable to an increase in initial growth-related emissions.

In contrast, the brown color experiences a noteworthy increase, growing from 47 percent to 61 percent of the covered area. This shift signifies a transition in the cropland landscape towards regions characterized by higher methane emissions, as indicated by the brown color. This rise highlights a pronounced shift towards areas with elevated methane concentrations, reflecting agricultural processes contributing to intensified emissions. Notably, the methane concentration demonstrates an increase between the sowing and growing seasons. Similarly, the red color undergoes a significant leap, surging from 3 percent to 23 percent. This shift towards reddish emissions predominates in the northeast of the country, where rice fields are prevalent and contribute significantly to methane emissions. It signifies a transition from low to very high methane concentration areas, potentially influenced by the intricate interplay between photosynthesis, nutrient uptake, and biomass development.

Growing season to harvesting season

The transition from the growing season to the harvesting season continues to reveal intricate changes in color percentages, shedding light on the evolving methane emission landscape. The period of harvest and post-harvest activities represents a pivotal phase within agricultural cycles, exerting a substantial influence on methane emissions. As the growing season concludes, a shift in agricultural practices occurs, engendering alterations in the patterns of methane release. The act of harvest entails the removal of mature crops from fields, potentially disrupting soil structure and creating pockets of oxygen-deprived environments. Changes in soil temperature, often linked to reduced shading, have been shown to impact methane release (Zerva and Mencuccini 2005). Soil bulk density can play a role in emissions, a consequence of soil disturbance and compaction, particularly as a result of mechanized harvesting equipment (Yashiro et al. 2008; Mojeremane et al. 2012). These conditions foster anaerobic microbial activities, consequently giving rise to methane production.

Moreover, the disturbance of crop residues during harvesting exposes them to microbial degradation, thereby contributing to additional methane emissions. Post-harvest practices, spanning residue management, transportation, and storage, also play a role in influencing methane release dynamics. Ineffective residue management approaches, such as burning or leaving residues uncovered, can accelerate methane emissions. Similarly, the transportation and storage of harvested crops in anaerobic settings may lead to methane emissions stemming from the decomposition of organic matter.

The spatial distribution of the yellow color gradually decreases by 5 percentage points, contracting from 11 percent to 6 percent of the covered area, now primarily located in the southeast part of the country, specifically in the Tambacounda region. This diminishment hints at a further reduction in areas emitting low methane concentrations, likely due to decreased photosynthesis and reduced crop activity. Methane concentration remains relatively stable or experiences a slight increase between the growing and harvesting seasons.

Concurrently, the brown color maintains its dominance, experiencing a significant increase from 61 percent to 77 percent, now covering almost the entire cropland area. This expansion signifies a shift towards regions characterized by high methane concentrations, potentially attributed to post-harvest practices and crop removal. In contrast, the red color, representing very high methane concentrations, decreases from 23 percent to 15 percent. These high methane concentration areas are now primarily located in the "Bassin arachidier" and the northwest part of the country, which are the main cropland areas of Senegal. This change illuminates a transition from very high to medium methane concentration areas, reflecting the culmination of the crop's lifecycle and the influence of specific agricultural interventions.

Harvesting season to dry season

The transition from the post-harvest phase to the dry season brings about changes in methane emissions dynamics. Post-harvest activities, such as residue management and field clearing, can influence methane release patterns. With the onset of the dry season, characterized by reduced rainfall and shifts in soil moisture levels, conditions for methane production and emission may evolve. The decreased soil moisture during this period can potentially limit the availability of anaerobic environments required for methane-producing microbial activity (Conrad 1996; Segers 1998). As a result, methane emissions during the dry season may show a decline compared to the post-harvest phase.

A geographical shift becomes evident when comparing the harvesting season to the dry season, revealing a distinct pattern that signifies changes in methane concentration dynamics. The yellow color, symbolizing low methane concentration, demonstrates a consistent increase of 5 percent. This transition involves a shift from the southeastern to the northern part of the country, implying a reduction in emissions during this shift.

Conversely, the brown color, dominant at 77 percent during the harvesting season, experiences a marginal increase to 83 percent in the dry season. Meanwhile, the red color, representative of high methane concentration and concentrated primarily in the northwest region of the country, undergoes a significant decrease from 15 percent in the harvesting season to a mere 0.6 percent in the dry season. This observed geographical shift in methane concentration across seasons offers valuable insights into evolving emission dynamics, shedding light on their connection to specific agricultural and environmental factors.

3.4. *Seasonal variations of emissions*

Above croplands, methane is in general produced during the microbial decomposition of organic matter under anaerobic (oxygen-deprived) conditions (Conrad 2020). This process, known as methanogenesis, happens very often in wetlands where flooded soils are deprived of dioxygen. It produces anthropogenic methane that escape into the atmosphere from the anaerobic environment and thus contributes to total atmospheric methane concentrations.

Figure 4: Methane concentration above cropland during maize, millet, and sorghum season.

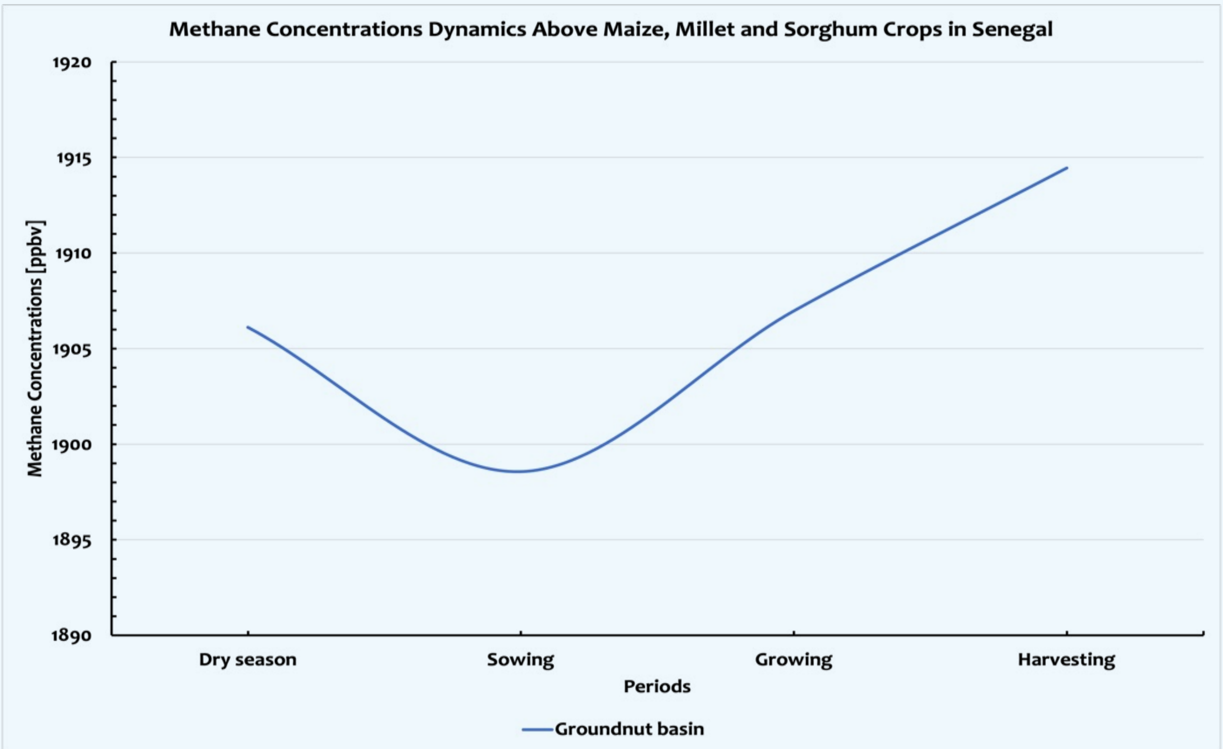


Figure 4 shows a comprehensive analysis, unraveling intricate methane concentration patterns intrinsic to the cyclical phases of maize, millet, and sorghum cultivation. This empirical exposition, driven by meticulous data analysis, encapsulates distinct stages and regions, culminating in a narrative of significant insights.

The seasonal patterns of atmospheric methane concentrations in regions where maize, millet, and sorghum are cultivated exhibit distinct characteristics compared to crops like rice that are cultivated in flooded conditions. While methane emissions tend to be lower for these cereal crops, they are still influenced by a range of factors, including climate, soil conditions, and agricultural practices.

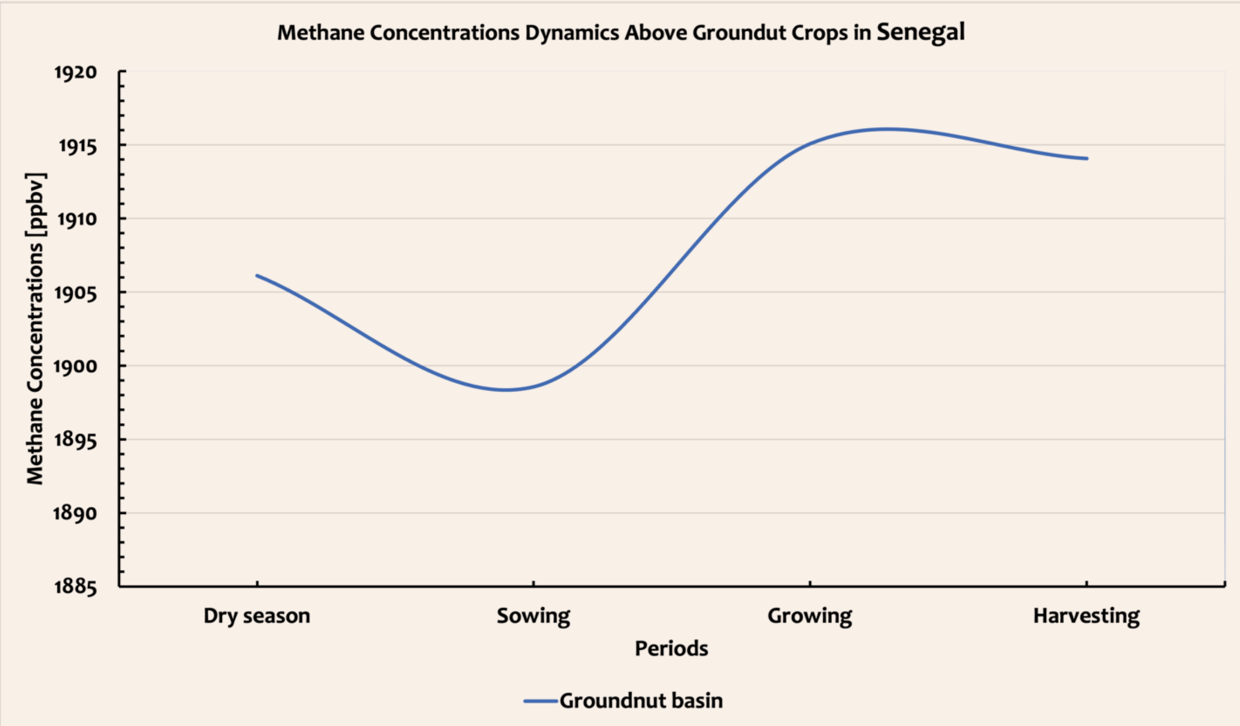
During the dry season, methane emissions generally remain at a low level. The reduced rainfall leads to decreased soil moisture, resulting in more aerobic (oxygen-rich) soil conditions. As drier soils are less conducive to methane production, the mean atmospheric methane concentration during this period is measured at approximately 1906.12 ppbv.

As the sowing season commences and maize, millet, and sorghum are planted, methane emissions continue to remain low. The act of sowing itself does not usually release significant amounts of methane into the atmosphere. Consequently, the mean atmospheric methane concentration decreases slightly to around 1898.56 ppbv during this phase.

During the growing period of these crops, the soil's moisture content typically increases due to natural rainfall or irrigation. As a result, methane concentrations experience a moderate increase, reaching approximately 1906.97 ppbv. This increase is in line with the enhanced microbial activity that can occur with higher moisture levels.

Interestingly, the harvesting of maize, millet, and sorghum is not associated with significant methane emissions. These crops typically do not create anaerobic conditions during the harvesting process. Despite this, the mean methane concentration in the atmosphere continues to rise, reaching around 1914.45 ppbv.

Figure 5: Methane concentration above cropland during groundnut season.



The seasonal patterns of atmospheric methane concentrations above groundnut cultivation areas exhibit distinct characteristics in comparison to zones where rice is cultivated. Groundnut, being cultivated in non-flooded lands, tends to produce fewer methane emissions. The concentration of methane in the atmosphere within groundnut cultivation areas follows patterns influenced by seasonal climate variations and agricultural practices.

During the dry season, when the soil tends to be drier and more aerobic, methane emissions are generally low. This is because dry soils are less conducive to methane production. In the groundnut basin, the mean atmospheric methane concentration is recorded at 1906.12 ppbv during the dry season, reflecting the minimal emissions under these conditions.

As the sowing season begins and groundnuts are planted, methane concentrations remain low, similar to the dry season, with a mean atmospheric methane concentration decreasing to 1898.56 ppbv. The act of sowing itself does not typically release significant amounts of methane into the atmosphere, contributing to the consistent low emissions during this phase.

As the groundnut plants grow and the soil moisture content increases due to natural rainfall or irrigation, methane concentrations experience a slight increase. The mean atmospheric methane concentration rises to approximately 1915.08 ppbv, reflecting the influence of moisture on microbial activity and methane production.

Interestingly, the harvesting of groundnuts itself is not associated with significant methane emissions. Similar to the other stages, mean methane concentrations found in the atmosphere actually decrease during the harvesting period, reaching around 1914.08 ppbv.

In summary, the seasonal variations in atmospheric methane concentrations above groundnut cultivation areas are influenced by the absence of flooded conditions and the unique nature of groundnut cultivation practices. This demonstrates the intricate interplay between agricultural practices, soil conditions, and methane emissions in these regions.

Figure 6 : Methane concentration above cropland during rice season

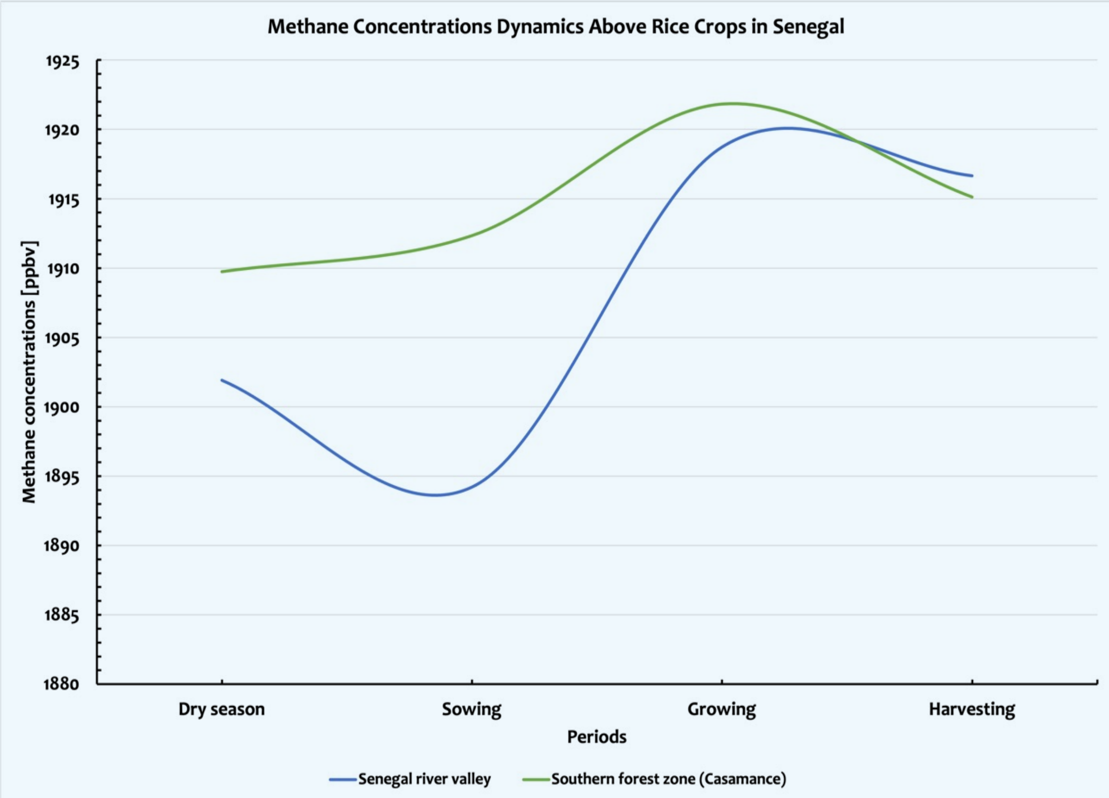


Figure 6 provides an all-encompassing portrayal of methane concentration levels noted during the rice cropping seasons across a diverse range of regions.

The atmospheric concentration of methane exhibits intriguing seasonal patterns that correspond to the different stages of rice cultivation. These fluctuations are particularly pronounced within the rice cultivation areas. As the cycle progresses, the concentration of methane in the atmosphere undergoes notable changes, highlighting the dynamic relationship between rice growth and methane emissions.

During the dry season, characterized by unflooded rice fields and fallow land, methane emissions remain relatively low. This can be observed with methane concentrations measuring around 1901.92 ppbv in the Senegal river valley and 1909.73 ppbv in the Southern forest zone (Casamance). The absence of standing water limits the anaerobic conditions required for methane-producing microbes to thrive, resulting in minimal methane emissions during this period.

With the onset of the sowing season, a shift occurs as rice fields are initially flooded. The introduction of anaerobic conditions in the soil can trigger the production of methane. However, in the early stages of flooding, methane emissions remain moderate, increasing to approximately 1912.33 ppbv in the Southern forest zone (Casamance) and decreasing slightly to 1894.22 ppbv in the Senegal river valley.

As rice plants continue to grow and fields stay flooded, methane concentrations experience a gradual increase. This trend is attributed to the ongoing decomposition of organic matter in the waterlogged soil, including plant roots and residues. These elements serve as a consistent source of carbon for methane-producing microbes, fostering methane production. The culmination of these factors results in peak atmospheric methane concentrations, reaching around 1921.82 ppbv in the Southern forest zone (Casamance) and 1918.73 ppbv in the Senegal river valley.

Interestingly, the process of harvesting rice itself does not significantly contribute to methane emissions. However, the subsequent field management practices that follow harvesting play a role in emissions. Often, fields are drained or dried post-harvest, introducing more aerobic conditions and consequently reducing methane emissions. In the Southern forest zone (Casamance), atmospheric methane concentrations decrease to approximately 1915.12 ppbv, and in the Senegal river valley, they decrease to about 1916.66 ppbv.

4. Discussion on mitigation options

The implementation of mitigation methods aimed at reducing methane emissions in the agricultural sector of Senegal necessitates a collaborative endeavor to incorporate enhanced farming techniques and sustainable water management practices. By adopting agroecological methods, such as conservation tillage, agroforestry, and crop rotation, it is possible to improve soil health and mitigate methane emissions through the modification of microbial activity in agricultural areas.

The adoption of drought-resistant and climate-resilient crop types can effectively reduce the reliance on irrigation methods that consume significant amounts of water. This, in turn, helps to minimize the release of methane from waterlogged soils, while simultaneously enhancing crop yield.

The use of effective irrigation methods, such as drip or sprinkler systems, and the adoption of water-conserving strategies such alternating wetting and drying, have the potential to reduce methane emissions from irrigated croplands while simultaneously addressing the issue of water shortages. Additionally, the promotion of community-driven water management initiatives and the provision of assistance for the restoration of degraded lands have the potential to improve the capacity of soil to retain moisture. This, in turn, can help mitigate the necessity for excessive irrigation practices and therefore reduce the release of methane gas.

Through the strategic integration of enhanced agricultural practices and sustainable water management methods, Senegal has the potential to navigate towards a trajectory characterized by a heightened capacity to withstand climate-related challenges and a greater commitment to environmental stewardship within its agricultural sector.

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