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Modelling the Effects of Soil-Climate Interactions on Bioindicator Crop (Cayenne Pepper) Development in Bayelsa State, Nigeria: Challenges and Prospects

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ABSTRACT

This study modelled the effects of soil-climate interactions on the growth and development of cayenne pepper (Capsicum annuum), used as a bioindicator crop, under screenhouse conditions in Ogbia Local Government Area of Bayelsa State, Nigeria. The research focused on how soil temperature, indoor atmospheric temperature, and key soil health indices (pH, electrical conductivity, and salinity) influence plant performance, with plant height serving as the main growth indicator. Results showed that soil temperature had a moderate positive correlation with soil pH ($R = 0.4436$; $R^2 = 0.1969$) and a stronger positive correlation with soil electrical conductivity ($R = 0.6328$; $R^2 = 0.4005$). However, its relationship with soil salinity was weak ($R = 0.2555$; $R^2 = 0.0653$). Among the soil factors, soil pH had the strongest positive influence on plant height ($R = 0.7896$; $R^2 = 0.6253$), confirming its vital role in nutrient availability and plant growth. In contrast, soil temperature showed a moderate negative correlation with plant height ($R = -0.5274$; $R^2 = 0.2782$), while indoor screenhouse temperature had a very strong negative effect ($R = -0.8983$; $R^2 = 0.8071$). This indicated that excessive heat inside the screenhouse significantly suppressed crop development through physiological stress. The findings highlighted the strong impact of soil-climate interactions on crop performance in the Niger Delta. They underscored the need for a climate-smart, bioresource-based soil stabilization and fertility enhancement approach to improve cayenne pepper growth and support sustainable agriculture in coastal regions of Bayelsa State.

Keywords: Cayenne pepper, Soil-climate interactions, Screenhouse, Soil health, Plant growth, Bayelsa State, Niger Delta.

INTRODUCTION

Cayenne pepper (*Capsicum annuum*) is an economical important bioresource crop grown in Nigeria. It derives its benefits not just from its pungent flavor gotten from its alkaloid capsaicin content but also from its rich content of tannins, vitamins A and C, saponins and flavonoids that provides significant nutritional and medicinal benefits (Chime & Ogunoye, 2025). This particular bioindicator crop has drawn great research attention. Recently, the National Horticultural Research Institute (NIHORT) released improved varieties such as HORTIPEP1 and HORTIPEP2, which are known for high yield potential, medium maturity, and strong pungency (News Agency of Nigeria, 2025). Research work across Nigeria have shown that pepper growth and yield are significantly influenced by agronomic practices and soil management strategies. Akinfasoye (2020) reported that application of organic fertilizers, particularly Tithonia compost, significantly improved the growth, yield, and nutritional quality of long cayenne pepper in Ibadan and Ogbomoso, while Madina *et al*. (2023) found that poultry manure produced superior growth and yield characteristics in pepper varieties grown in Makurdi, Benue State. Despite these advances, Bayelsa State has unique agroecological challenges, including sporadic rainfall, high humidity, and predominantly acidic soils derived from coastal alluvial deposits (Dickson *et al*., 2024; Omokaro, 2025).

Studies by Ohanmu *et al*., (2018) and Raimi & Ezugwu (2017) had shown that these soil condition challenges are compounded by environmental degradation due to crude oil pollution, which increases soil acidity, reduces total nitrogen and available phosphorus levels, and creates competitive interactions between heavy metals and essential nutrients (Ohanmu *et al.,* 2018). According to Liu *et al*. (2024), Capsicum species in particular grow well within the temperature range of 25°C–30°C. Any deviation from this affects the physiological processes, reproductive development and the quality of fruits. For effective adaptation strategies development, it is important that the interactive effects of soil properties and climatic conditions on crop performance be established. Soil-climate modelling makes possible for a quantitative identification of critical factors affecting the growth and productivity of cayenne pepper, and evaluation of management interventions easy. According to Singh (2023) climate-crop models provide indispensable tools that support climate-resilient agriculture in data-sparse regions like sub-Saharan Africa. The works of Adekunle & Udoh (2025) indicated that rising temperatures and declining soil quality could significantly reduce cayenne pepper growth performance unless adaptive soil and crop management strategies are implemented.

In spite of the economic benefits of cayenne pepper and growing research on its agronomic requirements, there still exist significant knowledge gaps as regards the specific soil-climate interactions that govern its growth performance in Bayelsa State. The farmers in this region still lack systematic, empirical guidance on how soil properties like pH, salinity, electrical conductivity and temperature interact with climatic conditions to affect pepper growth. This study therefore seeks to model the effects of soil-climate interactions on cayenne pepper growth in Bayelsa State using 45 screenhouse observations which will be analyzed through Pearson correlation. The findings will provide evidence-based recommendations for soil and climate management to enhance cayenne pepper growth and productivity, and support sustainable bioresource development in Bayelsa State and similar agroecological zones in the Niger Delta.

MATERIALS AND METHODS

This study was carried out at the Golden Food Research Project Site (Cayenne Pepper Hub) of the Federal University Otuoke (FUO), in Ogbia Local Government Area of Bayelsa State, Nigeria. This research facility provides both controlled (screenhouse) and natural (open-field) settings that suits the assessment of the interactions between climate change, soil health, and crop growth and productivity. Normal agronomic practices which include land clearance, bed formation, and the arrangement of experimental plots were utilized to establish the research site.

Experimental Design and Field Operations

Quality-tested cayenne pepper (*Capsicum annuum*) seeds were first germinated in the nursery for about four weeks before they were transplanted to the prepared beds. The seedlings were watered immediately after being transplanted in order to reduce transplant shock, and the watering was consistent throughout the growth cycle. Soil samples were collected using a hand trowel at the depth of 0–30 cm and stored in polythene bags for laboratory analysis.

Tools and Materials for Measurement

Field measurements were conducted using a digital infrared thermometer (Model JXB-178), a treaded rope, a measuring rule, and a field notebook. A multimeter (Model EZ-9910) for measuring soil EC, pH, and salinity.

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Temperature Monitoring Procedures

Both soil and atmospheric temperatures were captured in the morning, afternoon, and evening for five weeks. In accordance with WMO, (2021-2025) recommendations, the atmospheric temperature was captured at 150cm above the ground while the soil temperature at a depth of about 5cm.

Assessment of Crop Growth Performance

To assess crop growth performance, the plant height was measured weekly. Cayenne pepper was chosen as the bioindicator crop because of its sensitivity to changes in temperature and soil conditions. A meter rule was used to measure height from the soil surface to the apical meristem which serves as common indices for assessing how crops react to environmental fluctuations.

Soil Health Assessment

Soil samples were transferred into beakers, and 50cl of distilled water was added. The mixture was stirred thoroughly for some minutes. After allowing it to settle for about 20 minutes, it was filtered into receiving glass wares. The multimeter (Model EZ-9910) which had been standardized by appropriate standard (using buffersolution) was inserted into the filtrates and readings on soil pH, soil salinity and soil electrical conductivity were taken.

Statistical Analysis

Pearson correlation analysis using SPSS version 25 was used to determine the relationships between (i) screenhouse soil temperature and soil health indices (ii) soil health indices and bioresource growth (iii) screenhouse temperature and bioresource growth. This statistical method made it possible to thoroughly assess the linear relationships between soil conditions, climate variables and cayenne pepper growth performance.

RESULTS

The statistical observations from correlation and regression analyses conducted on 45 field data of soil parameters (soil temperature, pH, electrical conductivity, salinity), climatic variables (indoor and outdoor air temperature), and cayenne pepper plant height as a measure of bioresource growth performance are presented in this section.

Correlation between Screenhouse Soil Temperature and Soil Health Indices

Fig. 1 showed a moderate positive correlation ($R = 0.4436$; $R^2 = 0.1969$) between soil temperature and soil pH with a regression model ($y = 0.2898x - 4.4136$) which indicated slight increase in soil pH as soil temperature rises. Also, the model showed that soil temperature explained only about 19.69% of the variability in soil pH which implied that other environmental factors also contribute significantly. Soil temperature and soil EC gave a stronger positive correlation ($R = 0.6328$; $R^2 = 0.4005$) and regression model ($y = 0.8348x + 562.2$), which indicated that increase in soil temperature are associated with higher EC levels, (Fig. 2). This may be as a result of enhanced ion mobility and salt dissolution within the soil solution; soil temperature measured approximately 40.05% of the variation in soil EC. Conversely, Fig. 3 showed a relatively weak correlation between soil temperature and soil salinity ($R = 0.2555$; $R^2 = 0.0653$) with the regression model ($y = 32.966x - 513.88$), indicating that soil temperature contributes minimally to changes in soil salinity, which explained only 6.53% of its variability. This result suggested that other environmental factors such as groundwater interactions, soil moisture dynamics, and tidal influences common in coastal agroecosystems have strong effect on salinity.

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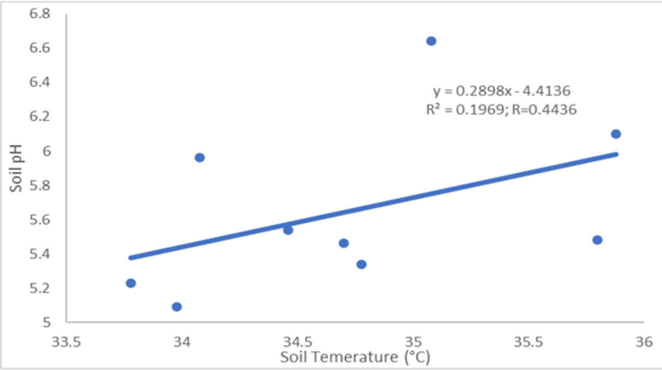

Fig. 1: Correlation between Soil pH and Soil Temperature

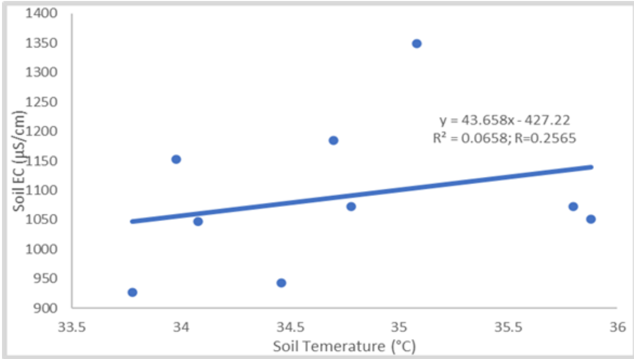

Fig. 2: Correlation between Soil EC and Soil Temperature

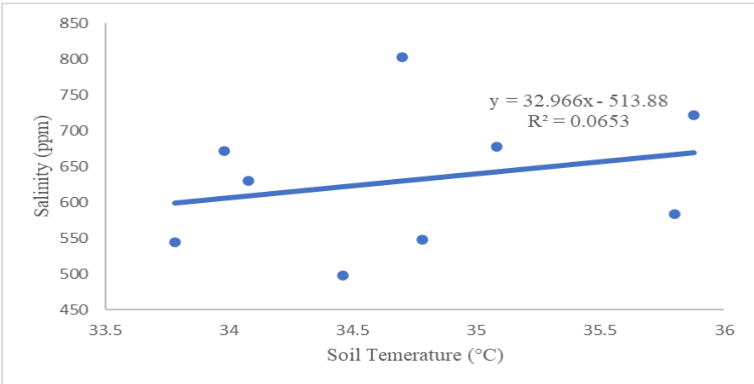

Fig. 3: Correlation between Soil Salinity and Soil Temperature

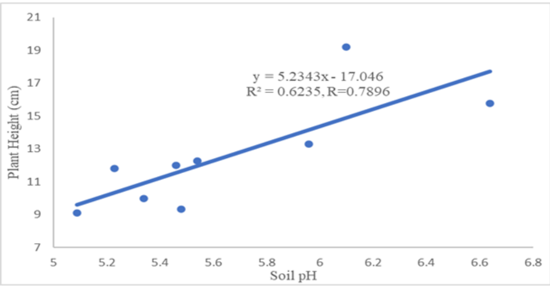

Fig. 4: Correlation between Plant Height and Soil pH

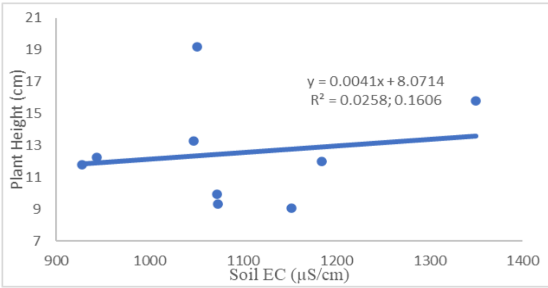

Fig. 5: Correlation between Plant Height and Soil EC

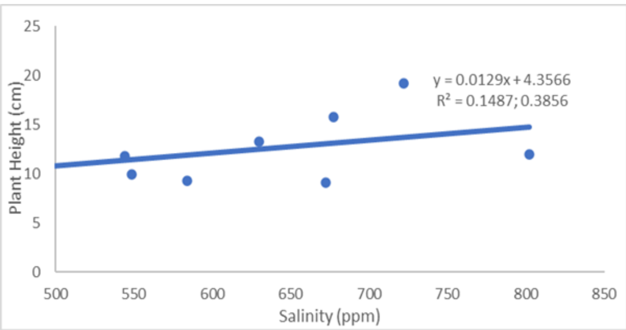

Fig. 6: Correlation between Plant Height and Soil Salinity

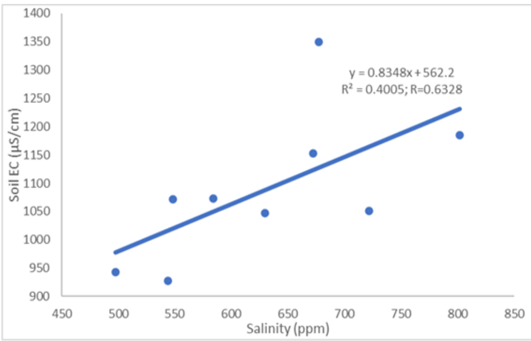

Fig. 7: Correlation between Soil EC and Soil Salinity

Correlation between Soil Health Indices and Bioresource Growth

The regression analysis (Fig. 4 - 6) showed that soil pH had a strong positive correlation with plant height (R = 0.7896; R^2 = 0.6235) whereas, soil electrical conductivity (EC) and salinity had positive weak correlations ($R = 0.1606$; $R^2 = 0.0258$) and ($R = 0.3856$; $R^2 = 0.1487$). On the other hand, Fig. 7 presented a moderately strongly correlation between soil EC and salinity ($R = 0.6328$; $R^2 = 0.4005$). In general, it can be clear here that soil pH is the most influential factor that affects plant height while EC affects plant growth indirectly through its relationship with salinity. These observations are in line with the findings of Brady & Weil, (2016); Munns & Tester, (2008) that nutrient availability and plant physiological performance are regulated by soil pH, while EC and salinity affect plant growth through ionic imbalance and osmotic stress.

Correlation between Screenhouse Temperature versus Crop Growth

Plant height and soil temperature showed a moderately negative correlation (($y = -2.2831x + 91.808$; $R = -0.5274$), which indicated that plant height tends to decrease as soil temperature increased (Fig. 8). The determination coefficient ($R^2 = 0.2782$) suggested that about 27.82% of the variation in plant height was explained by soil temperature. This finding indicated that soil temperature had a noticeable but not dominant influence on plant growth. On the other hand, Fig. 9 presented a very strong negative correlation between plant height and indoor atmospheric temperature ($y = -7.3721x + 269.87$; $R^2 = 0.8071, R = -0.8983$).

In general, soil temperature showed a moderate inhibitory effect on plant height**,** while indoor atmospheric temperature appeared to have a very strong correlation with plant height. This is in agreement with existing knowledge by (DeWit *et al.*, 2025; Fischer, 2025) that Capsicum species experience impaired growth and reduced productivity when soil temperatures exceed 30°C.

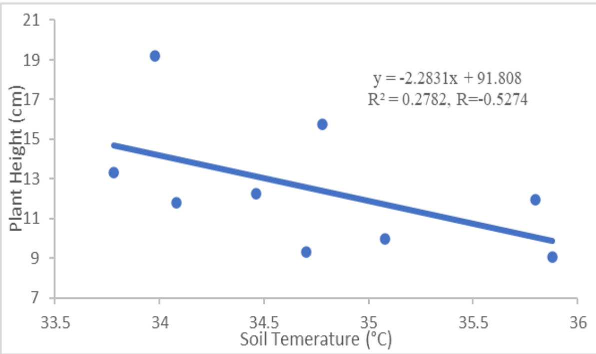

Fig. 8: Correlation between Plant Height and Soil Temperature

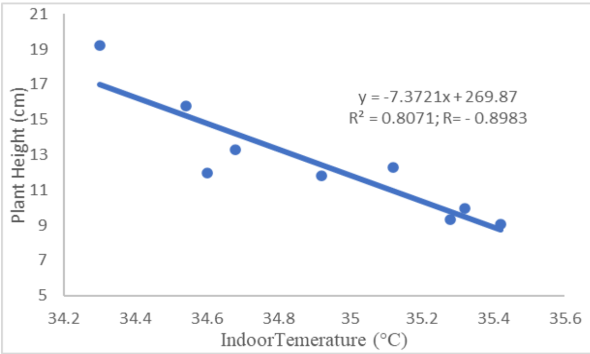

Fig. 9: Correlation between Plant Height and Indoor Atmospheric Temperature

DISCUSSION

In this study, we looked at how the temperature inside the screenhouse, the health of the soil, and the growth of cayenne pepper are connected. The pepper was grown under controlled conditions in Ogbia Local Government Area of Bayelsa State. Our results showed that soil temperature does affect the chemical properties of the soil and how well the crop grows. However, the strength of this relationship differs depending on the soil parameter we examined. We found a moderate positive correlation between soil temperature and soil pH ($R = 0.4436$; $R^2 = 0.1969$). This showed that rising soil temperature resulted ina slight elevation of soil pH. But the R^2 value of just 19% indicated that other factors, such as soil organic matter and irrigation, might also play an important role in changing the soil pH. A stronger positive relationship was observed between soil temperature and soil electrical conductivity ($R = 0.6328$; $R^2 = 0.4005$). This suggested that higher temperatures help ions to move more freely and allow salts to dissolve better in the soil. On the other hand, the correlation between soil temperature and soil salinity was quite

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weak (R = 0.2555; R^2 = 0.0653). This indicated that salinity in the soil is mostly controlled by water-related factors like soil moisture and groundwater movement.

When we examined the relationship with plant height, soil pH showed a very strong positive correlation (R = 0.7896; R^2 = 0.6235). This confirmed that soil pH plays a very important role in making nutrients available to the plant and supporting good growth. Soil electrical conductivity and salinity had only weak positive correlations with plant height. As expected, electrical conductivity and salinity were strongly related to each other. Interestingly, soil temperature had a moderate negative correlation with plant height (R = −0.5274; R^2 = 0.2782). This means that very high soil temperatures can slow down plant growth. Even more striking was the very strong negative correlation between the indoor screenhouse temperature and plant height (R = −0.8983; R^2 = 0.8071) which clearly showed that too much heat in the air inside the screenhouse put serious stress on the plants, reduced their ability to photosynthesize properly, and greatly affected their growth.

Overall, while soil pH turned out to be the most important soil factor affecting plant growth, the atmospheric temperature inside the screenhouse had the strongest negative effect on the performance of the cayenne pepper.

CONCLUSION

This study examined the relationships between soil temperature, soil health indicators, and the growth of cayenne pepper (*Capsicum annuum*) grown in a screenhouse in Bayelsa State, Nigeria. The results showed that soil temperature has a moderate effect on soil pH and a strong effect on soil electrical conductivity, but only a weak relationship with soil salinity. Among all the soil factors we studied, soil pH had the greatest influence on plant height. This confirmed how important it is to keep the right chemical balance in the soil for nutrients to be available and for the plant to grow well.

The study also revealed that while rising soil temperature moderately reduced plant height, the temperature of the air inside the screenhouse had a very strong negative impact on crop growth. Too much heat in the screenhouse could have seriously limited the plants development and productivity. If we manage these factors properly, we can improve cayenne pepper production and support sustainable farming in the coastal areas of the Niger Delta.

RECOMMENDATION

Based on the findings in this study, the use of climate-smart, bioresource-based soil stabilization and fertility enhancement approach is recommended.

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