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Contribution of Geospatial Technologies and Multicriteria Analyses for Estimating the Yield Potential of an Oil Palm Plantation : Case of the Niamtam Palm Plantation in the Nkam Department, Littoral Region, Cameroon

AYANGMA Joseph Désiré [1], LIMALEBA Roger Blaise [2], BIKIE Gerald Anicet [3]

Email: Josephayangma8@gmail.com

1. National Advanced School of Publics Works, Cameroon.
2. School of Urban Planning and Tourism Sciences (ESSUT) / Department of Urban Development, Cameroon.

Abstract

The low productivity of oil palm in Cameroon constitutes a major constraint to the development of the sector. This situation is explained by aging plantations, empirical management of inputs, and limited control of intra-plot variability. This thesis aims to contribute to production optimization through the use of geospatial sciences and technologies, combined with multicriteria and multivariate analysis. The methodology employed relies on a combination of remote sensing and spatial analysis tools, integrated within ArcGIS Pro and PhilCarto. Climatic parameters (temperature, precipitation, sunlight) and pedological variables (clay, sand, silt, organic matter, nitrogen, CEC, and water-holding capacity) were utilized. Principal Component Analysis (PCA) identified the most influential variables on soil productivity, distinguishing four main components : (i) a textural and physico-chemical soil gradient, (ii) hydric dynamics and organic fertility, (iii) solar radiation and soil structure, and (iv) secondary climatic variability. The map resulting from the multicriteria analysis revealed five classes of yield potential : very low, low, medium, good, and optimal. Out of a total area of 230 ha, 6.96 % of plots have very low yield, 18.26 % low yield, 31.30 % medium yield, 26.96 % good yield, and 16.52 % optimal yield. The integration of pedological and climatic data, supported by literature, allowed defining a yield range between 12 and 25 t/ha/year, from very low to optimal zones, and refined the estimates for Ferralsols and Acrisols. The current total production of the plantation is estimated at 4,432 t of fresh fruit bunches per year. An improvement scenario, in which less productive soils reach optimal yield, shows a potential gain of 1,318 t/year, representing a 29.73 % increase and nearly 1.98 billion FCFA/year at the official price of palm oil in Cameroon (1,500 FCFA/L). These results highlight the importance of targeted management of less productive soils through organic amendments, rational fertilizer application, improved drainage, and regular agronomic monitoring. The integration of smart sensors for real-time monitoring of soil pH, temperature, and chemical composition is also proposed as an innovative solution to enhance precision in agricultural management. Globalisation and digitalisation have had a profound impact on public discourse and modern communication within contemporary institutions. In Morocco, these developments have resulted in an ongoing attempt to reconcile the tensions inherited from deeply rooted cultures with the contemporary demands of institutionalisation, namely efficiency and transparency. Based on Hofstede's intercultural model and the work of

Bourdieu, Giddens, Morin, and Habermas, this article takes a systemic approach to culture and communicational interactions in public organisations in Morocco. Drawing on an analysis of national administrative culture and theories of structuration and communicational rationality, the author shows the impact of societal values, hierarchical distance, collectivism, and cohesion on inter-state relations and public institutions. Far from being reduced to the circulation of information, public communication, in its modern function, is articulated around a field of tension and power relations where modernity, tradition, and the space for co-civism are negotiated.

Keywords : Oil palm, Agricultural productivity, Multicriteria analysis.

1. Introduction

Agriculture, essential for food security and economic development, is at the heart of global concerns (FAO, 2021). The sustainable management of agricultural resources and the optimization of perennial crop productivity are major challenges of the 21st. The oil palm (Elaeis guineensis Jacq.), considered one of the most profitable crops worldwide, occupies a central place in this debate (Corley & Tinker, 2016). Its production helps meet the growing demand for vegetable oil, both for domestic consumption and for the agro-food, pharmaceutical, and energy industries. Yet, many producing countries struggle to fully exploit its potential due to environmental, technical, and socio-economic constraints (Woittiez et al., 2017).

Cameroon, with its favorable agro-ecological conditions, is among the main African oil palm-producing countries (Ngando et al., 2013). However, national production remains insufficient to meet domestic demand. In 2024, crude palm oil production was estimated at 446,984 tons (MINADER, 2024), while the structural deficit exceeds 500,000 tons per year (Business in Cameroon, 2024). Between 2017 and 2023, this deficit led to the importation of nearly 409,000 tons of palm oil, valued at 280.4 billion FCFA (BEAC, 2023). This external dependence reflects a mismatch between production potential and current performance, largely attributable to the low productivity of existing plantations.

This low productivity results from several factors : aging plantations, empirical management of inputs, limited control of intra-plot variability, and a lack of knowledge of local climatic factors. Differences in soil structure, texture, and fertility, as well as climatic variations, strongly influence oil palm yield. Recent studies have shown that yield ranges from 12 to 25 t FFB$\cdot ha^{-1} \cdot yr^{-1}$ (Kogge & Tabi, 2020), from very low potential zones to optimal zones. These disparities highlight the need to integrate both soil heterogeneity and climatic factors into agronomic planning.

In response to this challenge, the use of geospatial sciences and advanced statistical analysis methods appears to be a promising solution (Goodchild, 2009). Unlike traditional approaches, often limited to local observations, remote sensing and Geographic Information Systems (GIS) enable large-scale mapping of biophysical variables (Malczewski, 2006 ; Eastman, 2012). Multicriteria analysis (MCA) allows the combination and weighting of pedological, climatic, and vegetative factors, while multivariate analysis, notably Principal Component Analysis (PCA), identifies the most significant variables and reduces data complexity (Jolliffe & Cadima, 2016). These tools thus provide a finer understanding of spatial variability and pave the way for targeted and optimized plantation management (Thenkabail et al., 2013).

The central question of this research is therefore : how can geospatial sciences and multicriteria and multivariate analysis methods be leveraged to assess the yield potential of oil palm, considering both soil variability and climatic factors, and guide soil improvement and climate management strategies in the Niamtam plantation (Littoral Region, Cameroon) ?

The main objective of this study is to identify and map high-yield potential zones of oil palm using geospatial and statistical data. Specifically, it aims to :

- ❖ Analyze the biophysical factors (soil, climate) influencing yield;
- ❖ Prioritize these factors using PCA and MCA;
- ❖ Produce suitability maps for oil palm cultivation.
- ❖ Estimate potential production gains under a scenario of soil improvement for very low, low, medium, and high-yield zones.

1.1. Description of the Study Area

The study focuses on the Niamtam oil palm plantation, located in the Littoral Region of Cameroon, about 18 km from Yabassi (4°29’49’’ N, 10°08’26’’ E). The area features flat to gently undulating terrain with an average altitude of 140 m, favorable for mechanized agriculture and effective natural drainage. Hydrologically, it lies within a well-drained basin fed by small streams flowing into the Dibamba and Wouri Rivers, ensuring good soil moisture and groundwater recharge.

Niamtam experiences an equatorial climate with two rainy and two short dry seasons. Annual rainfall varies from 35 mm in the driest to 325 mm in the wettest months, while temperatures range from 23.7 °C to 27 °C. High humidity (78–91 %) supports continuous oil palm growth, though heavy rains can occasionally hinder fieldwork.

Ecologically, the area lies in the humid forest zone, where dense evergreen forests have been gradually replaced by secondary vegetation and agricultural land dominated by oil palm, alongside food crops like cassava, maize, and plantain. This land-use mosaic reflects agricultural intensification while maintaining agroforestry elements.

Soils are mainly ferralitic (Ferralsols), deeply weathered and rich in iron and aluminum oxides. Though naturally low in nutrients, they are well-suited for perennial crops such as oil palm when managed with organic amendments, crop rotation, and erosion control.

Figure 1. Geographical location of the plantation

2. Methodology

2.1. Data

The study utilized high-resolution pedological and climatic data from reliable global sources. Soil information was derived from the SoilGrids (ISRIC) database at 250 m resolution, using AI-based geostatistical modeling. Key parameters included soil texture, cation exchange capacity (CEC), organic matter, total nitrogen, and water-holding capacity, all critical for assessing soil fertility and oil palm growth.

Climatic variables were obtained from Landsat 8/9, SMAP, and the SRTM DEM, focusing on land surface temperature, precipitation (from NDVI–SMAP coupling), and simulated sunlight exposure (hillshade). Together, these datasets supported the analysis of pedoclimatic interactions influencing oil palm productivity.

2.2. Data Processing

2.2.1. Resampling of Spatial Data

To ensure spatial consistency among the different raster layers, resampling was performed. The bilinear interpolation method was used, as it calculates a weighted average of the four nearest pixels. This technique is particularly suitable for continuous variables such as temperature, precipitation, or sunlight, thereby ensuring spatial continuity and improved accuracy in the analysis.

2.2.2. Normalization of Variables

Data from multiple sources have different units and value ranges. To make them comparable, a Min–Max linear normalization was applied using the following formula :

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \qquad (2.1)$$

This transformation scales all values to the range [0, 1] while preserving the original distribution. It thus facilitates the combination of different data layers in the calculation of the overall potential.

2.2.3. Calculation of Agronomic Yield Potential

The overall agronomic potential of oil palm was obtained by a weighted combination of biophysical and climatic criteria using the following formula :

$$P = \sum_{i=1}^{n} W_i \times C_i \qquad (2.2)$$

- ❖ Wi : weight of criterion i, obtained from PCA,
- ❖ Ci : raster map representing criterion i,
- ❖ N : total number of criteria considered.

This approach allows the generation of a composite map illustrating the agronomic yield potential in the study area.

2.2.4. Calculation of Agronomic Yield Potential

2.2.4.1. Evaluation of Variable Contributions to Variance

The Principal Component Analysis (PCA) method is used to identify and assess the contribution of each variable to the explanation of the total variance in the data. PCA is particularly useful for understanding which variables have the greatest impact on the agronomic yield of oil palm, highlighting those that are most influential among the different criteria.

Standardization of Variables

$$Z_{ij} = \frac{X_{ij} - \bar{X}_j}{\sigma_j} \qquad (2.3)$$

Where X_{ij} is the value of variable j for observation i , $\bar{X}_j$ is the mean, and σ_j is the standard deviation of variable j.

Computation of Principal Components

$$Z_{ij} = a_{1k}Z_1 + a_{2k}Z_2 + \cdots + a_{nk}Z_n \qquad (2.4)$$

Where a_{ik} are the contribution coefficients of each variable to component k. The first principal components explain the maximum variance, and their interpretation allows the identification of the variables most influential on yield.

Variable Weighting and Significance

$$\text{Contrib}_{ik} = \frac{a_{ik}^2}{\lambda_k} * 100 \qquad (2.5)$$

Where :

- a_{ik} : correlation coefficient (or loading) of variable i on component k,
- λ_k : eigenvalue (explained variance) associated with component k.

Overall Weighting

$$\text{W}_i = \sum_{k=i}^{m} (\text{Contrib}_{ik} * \frac{\lambda_k}{\sum_{k=1}^{m} \lambda_k}) \qquad (2.6)$$

Where :

- Wi : overall weight of variable i,
- $\frac{\lambda_k}{\sum \lambda_k}$: proportion of variance explained by component k.

Thus, variables with the highest Wi values are those that best explain the total variability of the data. These weights are then used to weight the factors during the spatial aggregation and mapping of yield potential.

2.2.4.2. Hierarchical Multicriteria Formulation and Development of the Various Criteria

The Analytic Hierarchy Process (AHP), developed by Saaty (1980), structures decision problems hierarchically to compare criteria by relative importance. In this study, it was used to evaluate the agronomic potential of oil palm based on selected biophysical (texture, organic matter, CEC, water content) and climatic (temperature, precipitation, sunlight) factors identified from previous tropical studies as key determinants of growth and yield (table 1).

Table 1. The Different Criteria

Criteria	Agronomic Role
Mean Temperature	Promotes photosynthesis and flowering.
Annual Precipitation	Ensures adequate water supply.
Sunlight	Stimulates photosynthesis and production.
Clay Content	Improves water and nutrient retention.
Sand Content	Enhances soil aeration and drainage.
Silt Content	Contributes to soil stability and texture.
Cation Exchange Capacity (CEC)	Indicates soil chemical fertility.
Water-Holding Capacity	Maintains moisture favorable for growth.
Organic Matter	Improves soil structure and fertility.
Nitrogen Content	Supports vegetative growth.

2.2.4.3. Categorization and Normalization of Criteria

In a multicriteria approach, it is recognized that not all factors have the same importance in determining yield potential. It is therefore necessary to assign them relative weights that reflect their actual contribution to the overall variability of the phenomenon under study.

2.2.4.4. Weighting of Criteria

The weighting of criteria is based on the results of Principal Component Analysis (PCA), which allowed the assessment of each variable's contribution to the total variance. The most influential variables identified by PCA are therefore assigned the highest weights within the framework of the Analytic Hierarchy Process (AHP). This integrated PCA–AHP approach ensures an objective weighting, based both on statistical relationships and expert judgment. Pairwise comparison of the criteria, following Saaty's (1980) scale, was then used to refine the relative weights assigned to each factor. Once the degrees of importance have been assigned, the weight of each criterion is determined using formula (2.7).

$$Criteria\ weight = \frac{Line\ sum}{Number\ of\ criteria} \qquad (2.7)$$

2.2.4.5. Consistency Check

The Consistency Index (CI) measures the reliability of judgments in the comparison matrix. A low CI indicates consistent evaluations, while a high CI reflects inconsistency. To assess this reliability, Saaty (1980) introduced a control method using specific consistency equations.

$$\alpha_{avg} = \sum \left(\sum ci.wi \right) \qquad (2.8)$$

$$IC = \frac{\alpha_{avg} - n}{n - 1} \qquad (2.9)$$

$$RC = \frac{IC}{CA} \qquad (2.10)$$

Where:

- α_{avg} : average eigenvalue,
- ci : values of each column,
- wi : weight associated with each criterion,
- n: total number of elements,
- IC: consistency index
- RC: consistency ratio, obtained using the random index (RI).

The consistency ratio (CR) thus measures the degree of internal logic in the pairwise comparisons of the criteria. A CR below 0.1 (or 10%) indicates that the comparison matrix is consistent and that the judgments are acceptable. Conversely, CR above this threshold reflects inconsistency in the evaluations, requiring a revision of the judgments to improve the reliability of the weighting model.

2.2.4.6. Aggregation Criteria

Once the criteria have been established and weighted, they are aggregated through a weighted linear combination based on the formula shown in the equation below :

$$\sum_{i} wi.xi \times \prod_{j} cj \qquad (2.11)$$

3. Results

This study adopts a mixed methodological approach, combining documentary analysis and geospatial data processing to evaluate the agronomic potential of oil palm cultivation in Niamtam, Cameroon. Pedological data were obtained from the SoilGrids platform (ISRIC), while climatic data were generated and processed using Google Earth Engine. These datasets were analyzed through Principal Component Analysis (PCA) and the Analytic Hierarchy Process (AHP) to identify and weight the most influential soil and climatic factors affecting oil palm productivity.

3.1. Mapping of Environmental and Pedological Criteria

The climate analysis of the study area focused on the main parameters influencing oil palm growth and yield, namely temperature, precipitation, and sunlight. These variables were processed and normalized within a GIS environment to produce thematic maps illustrating their spatial distribution. The mapping highlights a strong spatial variability in climatic conditions, with warmer and more humid zones in the central and southern parts of the area, favorable for oil palm development, whereas areas with higher temperatures and lower rainfall show more limited production potential. These maps form the basis for the subsequent weighted combination used to estimate the overall agronomic potential of the crop.

Figure 2. Mean Temperature

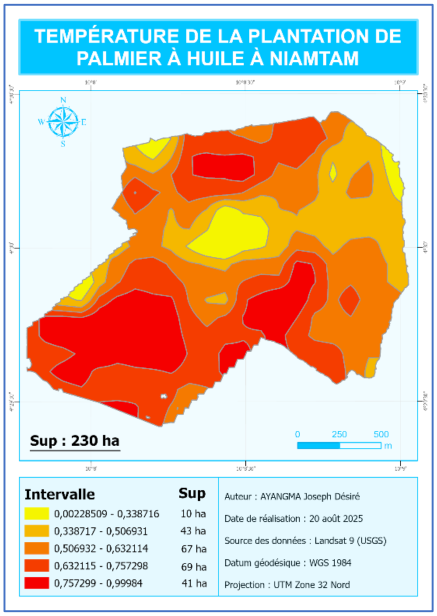


Figure 3. Annual Precipitation

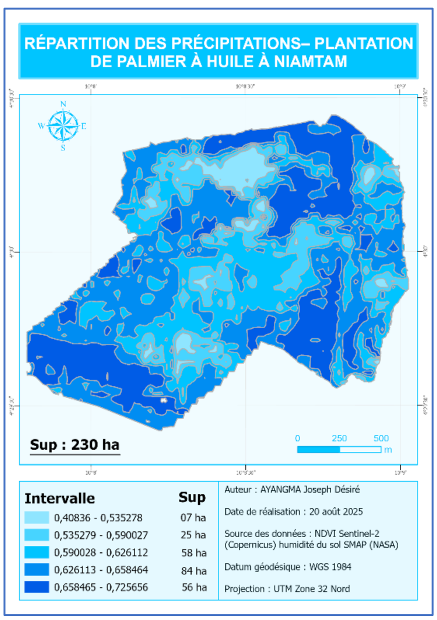
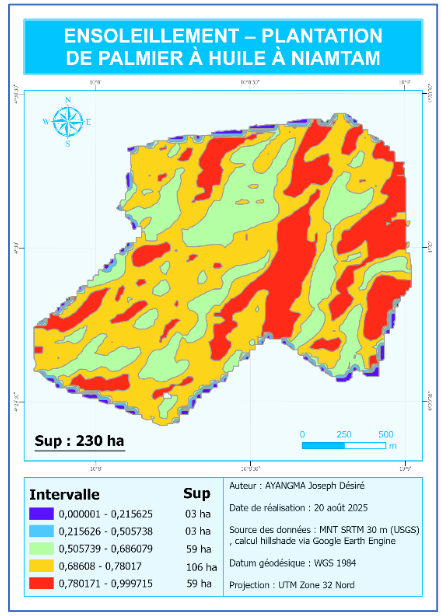


Figure 4. Sunlight



The physical analysis focused on soil texture, defined by the proportions of clay, silt, and sand. These factors influence soil structure, water retention, and root penetration of the oil palm. The textural map reveals a predominance of clay–silt soils in the central areas, favorable for cultivation, whereas sandy soils at the margins, with low water-holding capacity, present an increased risk of leaching .

Figure 5. soil texture

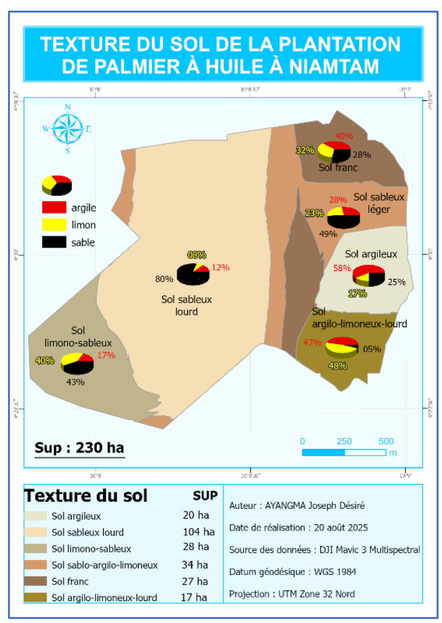
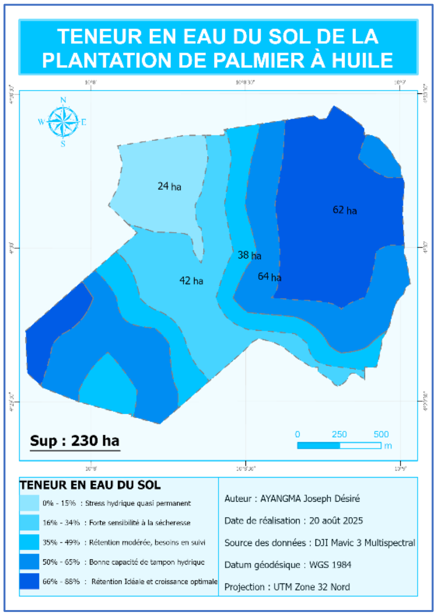


Figure 6. Water-Holding Capacity



The chemical analysis evaluated organic matter, nitrogen, CEC, and water content, which are key indicators of soil fertility. Areas with high CEC and rich in organic matter offer higher agronomic potential due to better nutrient availability, whereas zones with low CEC and limited nitrogen require improvement through organic or mineral amendments.

Figure 7. Nitrogen Content

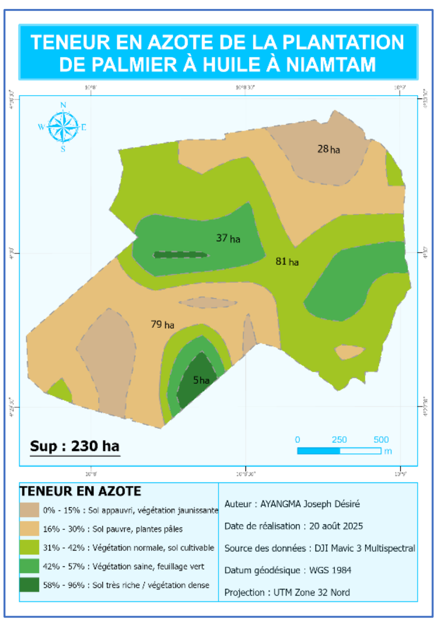


Figure 8. Organic Matter

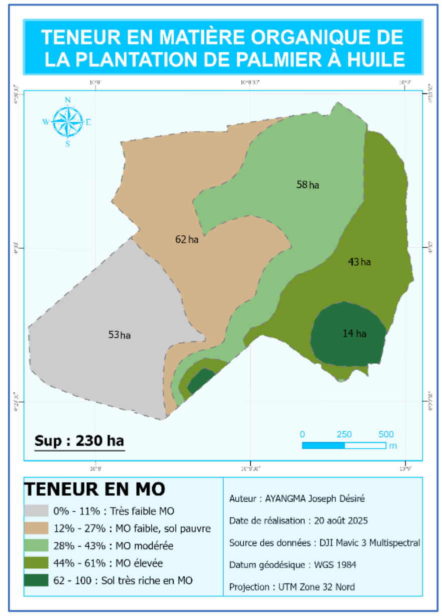
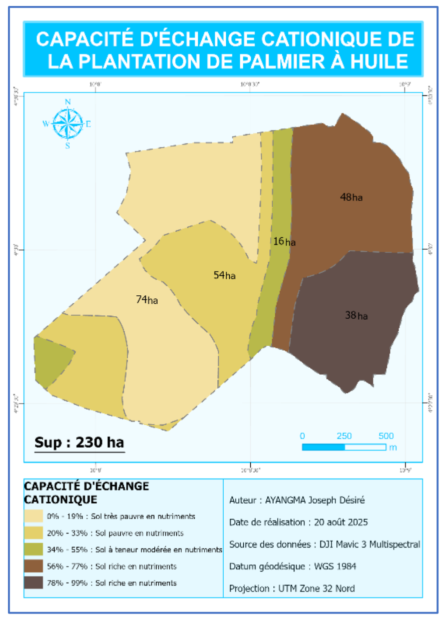


Figure 9. Cation Exchange Capacity (CEC)



3.2. Yield

3.2.1. Weighting of Criteria

Principal Component Analysis (PCA) was then performed to reduce variable redundancy and identify the main axes of variation (Table 2).

Table 2. Eigenvalues and Variance Explained by the Principal Components

Component	Eigenvalue	Explained Variance (%)	Cumulative (%)
PC1	4.37	43.71	43.71
PC2	1.96	19.64	63.35
PC3	1.24	12.39	75.74
PC4	1.19	11.85	87.59

Table 3. Contributions of Variables to the Principal Components (×1000)

Variable	PC1	PC2	PC3	PC4
Temperature	3	102	128	414
Precipitation	14	132	174	234
Sunlight	8	21	428	225
Clay	213	8	0	14
Sand	220	1	11	0
Silt	100	102	77	51
Organic Matter	177	61	2	39
Nitrogen	8	378	75	1
CEC	215	2	3	4
Water	43	193	102	16

Overall, the first two components (PC1 and PC2) group the soil physico-chemical factors, while PC3 and PC4 reflect the climatic factors, allowing a clear interpretation of the environmental interactions.

According to Table 3, the variables sand, clay, organic matter, and silt dominate PC1, representing soil fertility and texture, while nitrogen and water influence PC2, related to nutrient and water availability. Climatic factors (precipitation, temperature, sunlight) mainly contribute to PC3 and PC4, reflecting the climatic gradient.

Thus, the order of importance, from most to least influential, is as follows:

Sand → Clay → CEC → Organic Matter → Silt → Nitrogen → Water → Precipitation → Temperature → Sunlight

Table 4. Comparison Matrix

Criterion	Temp	Prec	Sun	Clay	San d	Silt	OM	Nitrogen	CEC	Water
Temp	1	3	1/3	7	7	5	5	3	7	3
Preci	1/3	1	1/3	7	7	5	5	3	7	3
Sun	3	3	1	7	7	5	5	3	7	3
Clay	1/7	1/7	1/7	1	3	1/3	1/3	1/3	2	1/3
Sand	1/7	1/7	1/7	1/3	1	1/3	1/3	1/3	1/3	1/3
Silt	1/5	1/5	1/5	3	3	1	2	1/2	3	1/2
Organic Matter	1/5	1/5	1/5	3	3	1/2	1	1/2	3	1/2
Nitrogen	1/3	1/3	1/3	3	3	2	2	1	3	1/2
CEC	1/7	1/7	1/7	1/2	3	1/3	1/3	1/3	1	3
Water	1/3	1/3	1/3	3	3	2	2	2	1/3	1
Sum	5.81	8.48	3.14	34.83	40	21.49	22.99	13.99	33.66	15.16

The normalized matrix is presented in Table 5.

Table 5. *Normalized matrix*

Criterion	Temp	Prec	Sun	Clay	Sand	Silt	OM	Nitrogen	CEC	Water
Temp	0.172	0.354	0.105	0.201	0.175	0.233	0.217	0.214	0.208	0.198
Prec	0.057	0.118	0.105	0.201	0.175	0.233	0.217	0.214	0.208	0.198
Sun	0.516	0.354	0.318	0.201	0.175	0.233	0.217	0.214	0.208	0.198
Clay	0.024	0.017	0.045	0.029	0.075	0.015	0.014	0.024	0.059	0.022
Sand	0.024	0.017	0.045	0.009	0.025	0.015	0.014	0.024	0.010	0.022
Silt	0.034	0.024	0.064	0.086	0.075	0.047	0.087	0.036	0.089	0.033
Organic Matter	0.034	0.024	0.064	0.086	0.075	0.023	0.043	0.036	0.089	0.033
Nitrogen	0.057	0.039	0.105	0.086	0.075	0.093	0.087	0.071	0.089	0.033
CEC	0.024	0.017	0.045	0.014	0.075	0.015	0.014	0.024	0.030	0.198
Water	0.057	0.039	0.105	0.086	0.075	0.093	0.087	0.143	0.010	0.066
Sum	0.999	1.003	1.001	0.999	1.000	1.000	0.997	1.000	1.000	1.001

Formula (2.7) yields the results presented in Table 6.

Table 6. Criteria Weights

Criterion	Weight
Temperature	0.208
Precipitation	0.173
Sunlight	0.263
Clay	0.032
Sand	0.021
Silt	0.058
Organic Matter	0.051
Nitrogen	0.074
CEC	0.046
Water	0.076
Sum	1.002

Consistency is evaluated by first multiplying each column of the unnormalized comparison matrix by the weight of the associated criterion. The results of this operation are presented in Table 7.

Table 7. Consistency Assessment

Criterion	Temp	Prec	Sun	Clay	Sand	Silt	OM	Nitrogen	CEC	Water	Sum
Temp	0.208	0.519	0.087	0.224	0.147	0.290	0.255	0.222	0.322	2.274	4.548
Prec	0.069	0.173	0.087	0.224	0.147	0.290	0.255	0.222	0.322	1.789	3.578
Sun	0.624	0.519	0.263	0.224	0.147	0.290	0.255	0.222	0.322	2.866	5.732
Clay	0.029	0.024	0.037	0.032	0.063	0.019	0.017	0.024	0.092	0.337	0.674
Sand	0.029	0.024	0.037	0.011	0.021	0.019	0.017	0.024	0.015	0.197	0.394
Silt	0.042	0.035	0.053	0.096	0.063	0.058	0.102	0.037	0.138	0.624	1.248
Organic Matter	0.042	0.035	0.053	0.096	0.063	0.029	0.051	0.037	0.138	0.544	1.088
Nitrogen	0.069	0.057	0.087	0.096	0.063	0.116	0.102	0.074	0.138	0.802	1.604
CEC	0.029	0.024	0.037	0.016	0.063	0.019	0.017	0.024	0.046	0.275	0.550
Water	0.069	0.057	0.087	0.096	0.063	0.116	0.102	0.148	0.015	0.753	1.506
Sum	1.210	1.467	0.828	1.115	0.840	1.246	1.173	1.034	1.548	10.461	20.922

Next, the sum of each row is divided by the weight of the corresponding criterion. The results are presented in Table 8.

Table 8. Criteria Weights

Criterion	Weight
Temperature	10.933
Precipitation	10.341
Sunlight	10.897
Clay	10.531
Sand	9.381
Silt	10.759
Organic Matter	10.667
Nitrogen	10.838
CEC	5.978
Water	9.908
Sum	100.233
α_{avg}	10.0233

By applying formulas (2.9) and (2.10), the following values are obtained :
Consistency Index (CI) : 0.002588
Consistency Ratio (CR) : 0.001738
Since CR ≪ 0.1, the arbitrarily chosen comparison matrix is considered acceptable.

3.2.2. Map of Agronomic Yield Potential

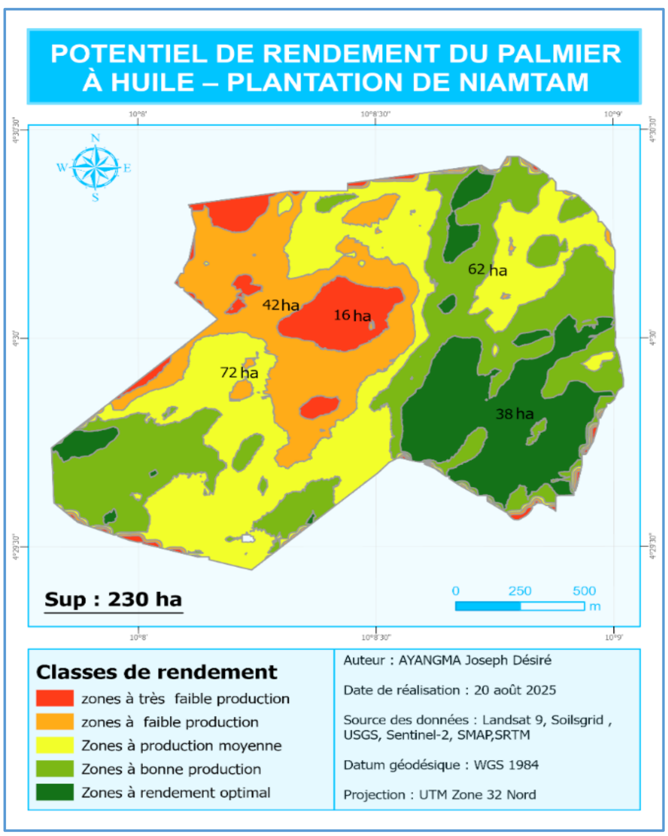


Figure 10. Map of Agronomic Yield Potential

The percentage of each zone can be calculated and the results are presented in Table 10.

Table 10. zones Percentage of Area of Different Zones

Category	Area (ha)	Percentage (%)
Very low production potential	16	6.96
Low production potential	42	18.26
Medium production potential	72	31.30
High production potential	62	26.96
Optimal production potential	38	16.52
Total	230	100

3.2.3. Estimation and Valorization of Production Potential

The assessment of production potential in terms of Fresh Fruit Bunches (FFB) per hectare allowed the classification of plots into five yield levels, ranging from "very low" to "optimal." The two identified soil types, Ferralsols and Acrisols, are evenly distributed (115 ha each), with a predominance of medium (72 ha) and high (62 ha) classes, indicating an overall favorable potential. The current total production of the plantation is estimated at 4,432 t FFB/year, calculated based on the average yields per productivity class.

A potential improvement scenario was then simulated, assuming that the low-yield plots reach the productivity of the optimal zones 25 t FFB·ha^{-1}·year^{-1}. This scenario results in a potential production of 5,750 t FFB/year, representing a gain of 1,318 t/year, corresponding to a 29.73% increase in total production.

Economically, this gain corresponds to approximately 1,318,000 L of crude palm oil, valued at 1,500 FCFA/L, yielding an additional estimated income of 1.98 billion FCFA/year. These results are presented in Table 11.

Table 3.11. Current Production and Potential Gain by Yield Class in the Oil Palm Plantation

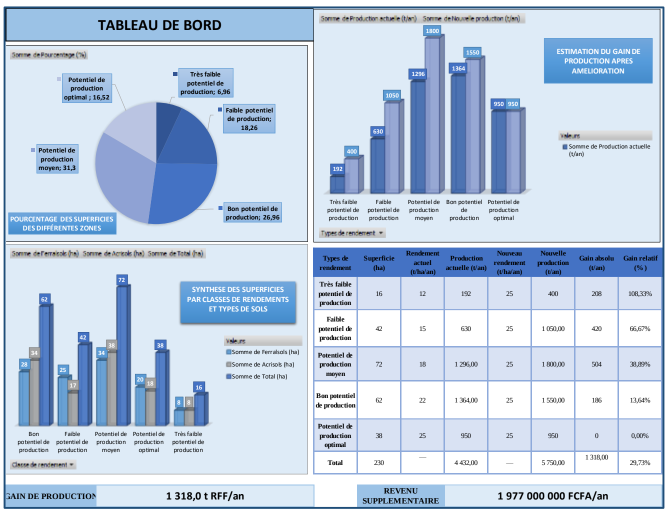
Yield Type	Area (ha)	Current Yield (t/ha/year)	Current Production (t/year)	New Yield (t/ha/year)	New Production (t/year)	Absolute Gain (t/year)	Relative Gain (%)
Very low production potential	16	12.0	192.0	25.0	400.0	+208.0	+108.33
Low production potential	42	15.0	630.0	25.0	1,050.0	+420.0	+66.67
Medium production potential	72	18.0	1,296.0	25.0	1,800.0	+504.0	+38.89
High production potential	62	22.0	1,364.0	25.0	1,550.0	+186.0	+13.64

Optimal production potential	38	25.0	950.0	25.0	950.0	0.0	0.00
Total	230	—	4,432.0	—	5,750.0	+1,318.0	+29.73

3.2.4. Overview of Current Performance and Plantation Potential

The dashboard (figure 11) provides a synthetic overview of the distribution of yield classes, comparing current yields with optimized potential yields and estimating the production gain. This offers a comprehensive and integrated view of the overall potential of the Niamtam oil palm plantation.

Figure 11. Overview of Current Performance and Plantation Potential



4. Discussion

The integrated analysis of climatic and pedological data made it possible to identify high-yield potential zones within an oil palm plantation in the locality of Niamtam.

4.1. Spatial Distribution Analysis of Yield Potential

The spatial assessment, based on AHP and PCA methods, reveals a high variability in production potential. Medium-potential (31.30%) and high-potential (26.96%) zones dominate the plantation, indicating a generally favorable environment. Low yields observed on 25% of the area are explained by sandy soil texture, low organic matter content, and reduced cation exchange capacity (CEC). Ferralsols are more productive than Acrisols, confirming the predominant role of soil structure and fertility in oil palm performance.

4.2. Interpretation of Yield Results and Production Gains

The current production is estimated at 4,432 t FFB/year, with an average yield of 19.3 t/ha/year. Under the improvement scenario, production could reach 5,750 t FFB/year, representing a gain of 1,318 t (+29.73%). The highest gains occur in areas with very low and low potential (+108% and +67%, respectively), indicating that targeted management of low-yield plots is the main lever for optimization. The estimated economic gain of 1.977 billion FCFA/year confirms the profitability of targeted improvement without expanding cultivated land.

4.3. Agronomic and Environmental Implications

Low performance is linked to chemical and hydric soil degradation. Improvement measures include organic amendments, balanced fertilization, and better drainage. This approach optimizes productivity while reducing land pressure and deforestation risks. Yield potential mapping thus serves as a decision-support tool for sustainable agriculture, combining economic efficiency with environmental preservation in line with precision agriculture principles.

4.4. Study Limitations

- The pedological data used are derived from maps, sometimes outdated, without systematic field measurements for each plot.
- The spatial resolution of raster data (soil, temperature, precipitation, sunlight) may cause overgeneralization in some areas.
- The lack of supplementary sampling campaigns limits the accuracy of organic matter, CEC, and nitrogen values.
- Biotic factors (diseases, pests) and rock types influencing yield were not considered.
- The absence of cross-validation between GIS results and actual yield measurements (via physical sampling of fruit bunches) reduces the robustness of estimates.
- The multicriteria model does not yet account for socio-economic factors (farming practices, labor, palm age).
- The lack of connected instruments (IoT sensors, local weather stations) prevents dynamic monitoring of microclimate and soil moisture.
- The improvement scenario is based on a theoretical assumption (optimal yield of 25 t/ha/year) without empirical field validation.
- The study covers only a single agricultural campaign, which does not allow assessment of result stability over time.

Conclusion

The objective of this chapter was to present the results of the study on the use of geospatial sciences and multicriteria analysis for evaluating the yield potential of oil palm in the Niamtam plantation. The analysis revealed that the study area comprises 6.96% of land with very low potential, 18.26% with low potential, 31.30% with medium potential, 26.96% with high potential, and 16.52% with optimal potential. The assessment indicated that the current total yield is 4,432 t FFB/year, with a potential additional gain of 1,318 t/year if low-, medium-, and high-yielding soils are optimized, representing an increase of 29.73% and an additional income of approximately 1.98 billion FCFA. This study demonstrates that GIS combined with multicriteria and multivariate analyses constitutes a valuable tool for optimizing agricultural productivity. Such an approach enables more informed decision-making, differentiated soil management, and optimal use of inputs, thereby contributing to the sustainable improvement of the oil palm sector. The results also underscore the importance of integrating geospatial technologies into national strategies aimed at enhancing local production and reducing the structural deficit in palm oil.

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