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Reduction of the mangosteen tree (Garcinia mangostana L) production cycle: effect of soil type and fertilizers

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Abstract

Background

The mangosteen tree (Garcinia mangostana L.) is a very slow-growing tree that takes between 8 and 15 years before bearing its first fruits. This slow growth and late fruiting of the plant constitute a real obstacle to its adoption and its propagation in rural areas. In Côte d'Ivoire, these constraints have led to the limitation of cultivation to small farms belonging to a few producers, whereas it could constitute an alternative to the diversification of agricultural income and contribute to poverty reduction in rural areas. This study was therefore initiated with the aim of evaluating the effects of soil type and fertilizers on the agronomic parameters of mangosteen tree growth in order to contribute to the shortening of its vegetative phase.

Results

The results of this study showed the significant effect of soil type and fertilizers on mangosteen growth parameters. The evaluation of the effect of soil type and fertilizers on the agronomic performance of mangosteen showed that lowland soil promotes better plant growth. The growth rates recorded after 36 months of monitoring were 53.08 ± 7.30% in mangosteen trees grown on lowland soil and 41.51 ± 13.43% in those grown on forest soil.. Also, foliar and granular N-P-K fertilizers favored a shortening of the onset of fruiting from the 5th year of cultivation.

Conclusions

The results testified to the clear importance of the contribution of fertilizers in the management and the shortening of the juvenile phase of the mangosteen tree. Fertilizers based on foliar fertilizer and NPK have recorded remarkable performances by favoring a shortening of the entry into fruiting of mangosteen trees from the fifth year of cultivation.

1. Background

The fruit sector is one of the Ivorian sectors of great economic interest in view of the currencies it generates. This sector alone generates more than 400 million dollars per year for the Ivorian State (Saiah, 2012). Ivorian fruit exports are literally dominated by bananas, pineapples and mangos, while some fruit crops do not benefit from the same interest as their counterparts, because they are wrongly considered minor crops. These crops lack for the vast majority of agricultural research work of valuation. Among these crops is that of the mangosteen tree (Haba et al., 2023 ; Koffi et al., 2022).

The mangosteen tree (*Garcinia mangostana* L) is a tropical fruit tree of the Clusiaceae family whose cultivation is mainly widespread in Southeast Asia (Indonesia, Thailand and Cambodia) (Setiawan et al., 2023). With an estimated world production of 700,000 t, Thailand remains to this day the main producing country with an average annual production of 240,000 t (Altendorf, 2018). Apart from its highly appreciated taste, which has earned it the title of queen of fruits, the mangosteen is also cultivated for its excellent medicinal properties. The research efforts made for this purpose have had the main objective of highlighting the therapeutic virtues of the plant (Buravlev et al., 2018; Aizat et al., 2019). Most of the research undertaken shows that mangosteen has remarkable antioxidant, antitumor, antiallergic, anti-inflammatory, antibacterial and antiviral properties (Milovanova-Palmer and Pendry, 2018 ; Gina, 2023). The plant and fruits mainly the pericarp are rich sources of bioactive substances including vitamin, catechin,

polysaccharide, polyphenol, but especially xanthones. It is precisely the abundance of xanthones (more than 40) in this fruit that makes it such an effective product in the prevention and treatment of many diseases. Among the beneficial effects of mangosteen, there is its role in limiting the actions of bad cholesterol, thus preventing the risk of atherosclerosis and the formation of blood clots. According to Muchtaridi et al. (2018) and Beatrice and Pietradewi (2020) mangosteen pericarp extracts would limit the growth of various cancer cells of the liver and pancreas.

In Côte d'Ivoire, the mangosteen tree was introduced in 1970 through the fruit program of the Research Institute for Colonial Fruits and Citrus (IFAC) in Azaguié. The work initiated by Bourdeaut and Moreuil (1970) on the possibilities of introducing the species in Côte d'Ivoire were convincing and encouraged some growers to move towards this crop. Since then, its cultivation has been limited to small farms belonging to a few producers, whereas it could constitute an alternative to the diversification of agricultural recipes (Florent et al., 2021). The culture of the mangosteen tree indeed faces many constraints which constitute a real obstacle to its propagation. To date, there is very little information on mangosteen production techniques in Côte d'Ivoire. The very slow growth and late fruiting of the tree are the main constraints that have led to the reluctance of its adoption by growers (Haba et al., 2023). To this end, the determination of the type of soil favourable to cultivation and the appropriate fertilizers seems necessary. Indeed, the vegetative development of the mangosteen tree would be influenced by the type of soil and the type of fertilizer applied. In such a context, it therefore becomes judicious to undertake research aimed at shortening the vegetative phase of the tree and its production time. The present study was therefore initiated with the aim of evaluating the effects of soil type and fertilizers on the agronomic parameters of mangosteen tree growth with a view to shortening the vegetative phase.

2. Material and methods

2.1 Presentation of the study area

The experimental studies presented in this study were carried out in the locality of Azaguié (region of Agneby-Tiassa) located in the south-east of Côte d'Ivoire about 40 km north of the district of Abidjan between the coordinates 5°35 and 6°15 North latitude and 3°55 and 4°40 West longitude (Kouadio et al., 2021). The commune extends over an area of 201.3 km2 and is limited to the north by the sub-prefecture of Agou, to the south by the commune of Anyama, to the east by the communes of Alépé, to the West by the municipality of Agboville (Fig. 1). The study site is located about 2.5 km from the village of Abbè-begnini (villages of the municipality of Azaguié). This site is located between coordinates 5°62 North latitudes and 3°98 West longitudes. The plant cover of the site is made up of an alternation of forest, fallow land and farms that are very characteristic of the region. The area of the site is about 60 hectares, of which mangosteen is the main crop and covers about 23 hectares.

The evolution of the temperature and rainfall of the study site over the three years (2019–2021) during which the experiments took place indicate that the site is characterized by high rainfall. The amounts of rainfall recorded were 1836 mm of rain for the year 2019, 2112 mm for 2020 and 2052 mm in 2021. The average temperatures recorded were 25.1°C, 26.1°C and 25.3°C were obtained, respectively, during these three years. The data collected made it possible to distinguish four growing seasons for each year. These seasons consist of a long dry season (November to March), a rainy season (April to June), a short dry season (July to August) and a rainy season (September to October).

2.2. Plant material

The plant material used for this study consisted of mangosteen seedlings divided into two age classes and placed on two types of soil. Young mangosteen trees (1 to 6 years old) were used for the evaluation of growth parameters (Fig. 2).

2.3. Methods

The growth of mangosteen trees has been studied in the field with the aim of determining the optimal conditions for the development of this plant. It consisted in evaluating the effect of soil type and fertilizers on the agronomic parameters of mangosteen tree growth. The study was therefore carried out on two types of soil and lasted 3 years (2019 to 2021). One of the experimental plots was set up on forest undergrowth and the other on an irrigated lowland.

2.3.1. Physico-chemical soil analysis

The initial fertility status of the two soil types on which the experiments were conducted was determined. The chemical parameters determined were hydrogen potential (pH) and electrical conductivity (EC), organic matter (OM) and organic carbon (TOC) based on the methods of the Centre of Expertise in Evironemental Analysis of Quebec (CEAEQ, 2003). The determination of nitrogen (N) content was inspired by the Kjeldahl method NF V04-407 (AFNOR, 2004). As for phosphorus (P), potassium (K) and magnesium (Mg) content, the method used was inspired by that described by CEAEQ and AOAC (AOAC, 1990; CEAEQ, 2003). For the physical parameters, they concerned the particle size, i.e. the sand, clay and silt content determined from the method of Gee and Bauder (1986).

2.3.2. Preparation of experimental plots

All the experimental plots were subject to chemical weeding 8 weeks before the application of fertilizer treatments. The herbicide used for this purpose was glyphosate, sold under the trade name Glycel. After said weeding, the plots were cleared of residual plant debris to facilitate the spreading of fertilizers. Finally, a selection and marking of the mangosteen trees was carried out.

2.3.3. Experimental device

The experimental device used was a complete random block with 4 repetitions constituted on each type of soil. The factors studied were the effect of the type of fertilizers as a primary factor and the type of soil as a secondary factor. A total of 40 elementary plots of 950 m² each divided into 8 blocks were formed (4 blocks on each type of soil). On each elementary plot consisting of 10 plants, the performance of a single treatment was evaluated. Spacings of 10 and 20 m were respectively observed between the plants of the same elementary plot and between the elementary plots of the same block. The fertilizing treatments applied were:

T1 = NPK mineral fertilizer

T2 = organic fertilizer

T3 = foliar fertilizer

T4 = biostimulant

T0 = control (plants having received no treatment)

2.3.4. Description, quantity and mode of application of fertilizers

Fertilizers were applied according to manure recommendations, limiting the risk of soil loss and contamination (OFEV and OFAG, 2012). The quantities and methods of application were in accordance with the recommendations of the manufacturers. However, the doses and frequency of application of fertilizers were different depending on the class of plants. The choice of fertilizers used is justified by their specificities. Indeed, the latter differ from one another in their chemical compositions, their modes of application and their modes of absorption by the plant.

- **NPK Mineral Fertilizer**

The mineral fertilizer used was a complete granular NPK fertilizer with a 15-15-15 formula. This fertilizer was obtained from the firm Calivoir CI and was the subject of a formulation control in the laboratory before its use. The quantities of fertilizer given to the mangosteen trees depended on their class. Thus, using a scale, 250 g or 25 $kg.ha^{-1}$ and 500 g or 50 $kg.ha^{-1}$ of NPK were brought respectively to class 1 and 2 mangosteen trees according to an online location. The fertilizers were brought within the limits defined by crowns of 0.5 to 1 m in radius (radii of the rhizosphere of the mangosteen trees) then were covered with soil, thus limiting the risk of losses (Table 1).

- **Organic fertilizer: compost**

The compost used was made from poultry manure. This organic fertilizer was produced on the study site using a heap composting technique. After cleaning the hen houses, the collected manure was poured into ditches 1 m deep and 2.5 m long and watered regularly. The composting process lasted 4 months before the complete maturation of the compost. The mineralogical composition of the compost produced is presented in Table 2. Before its application, the compost underwent fungicide and insecticide treatments in order to eliminate the germs of harmful organisms (fungi and insects) which could be found there. The quantities of compost applied to the mangosteen trees were 10 kg or 100 $kg.ha^{-1}$ for class 1 and 20 kg or 200 $kg.ha^{-1}$ for those of class 2. The compost was applied by location in line in crowns of 0.5 m defined radius around each plant. The frequency of application for this fertilizer was 6 months for all classes (Table 1).

- **Foliar fertilizer**

The performances of an amino acid formula containing 12.3 $g.l^{-1}$ of nitrogen, 6.4 $g.l^{-1}$ of boron and 0.21 $g.l^{-1}$ of molybdenum were evaluated on the growth of the mangosteen tree. This fertilizer is marketed under the name Codamin and is distributed in Côte d'Ivoire by the AGRO services group. This fertilizer was applied at a dose of 300 ml per 100 l of water, i.e. 3 l/ha, in accordance with the manufacturer's instructions. The method used for applications was foliar application. It was carried out using a constant pressure sprayer with a capacity of 15 liters. The amount of spray received per plant was 100 ml every 30 days for class 1 mangosteen trees and 200 ml every 60 days for class 2 (Table 1).

- **Biostimulant**

The biostimulant used is a mixture rich in calcium and boron used in fruit growing. This product is distributed in Côte d'Ivoire by the Agritecno West Africa group and marketed under the name Tecnokel. It was applied using a constant pressure sprayer with a capacity of 15 litres. The amount of spray received per plant was 100 ml every 30 days for class 1 mangosteen trees and 200 ml every 60 days for class 2 (Table 1).

Table 1
Quantities, methods and frequency of fertilizer applications used for the evaluation of growth parameters

Fertilizers	Formulas	Quantities or doses/age class	Application method	Application frequency
NPK Compost Foliar fertilizer biostimulant	Granulated 15-15-15	-C1: 25 $kg.ha^{-1}$ -C2: 50 $kg.ha^{-1}$	Online localization	3 months
	Poultry manure	-C1: 100 $kg.ha^{-1}$ -C2: 200 $kg.ha^{-1}$	Online localization	6 months
	12.3 Nitrogen; 6.2 Boron; 0.21 Molybdenum	3 l/ha	Foliar application	-C1: 30 days -C2: 60 days
	Calcium ; Boron	3 l/ha	Foliar application	C1: 30 days -C2: 60 days

Table 2
Physico-chemical characteristics of compost

Settings	Values
pH water	6.47 ± 0.01
pH_{KCl}	5.95 ± 0.03
EC ($\mu S.cm^{-1}$)	281 ± 2.45
OM (%)	50.30 ± 1.24
TOC (%)	29.17 ± 0.72
N (%)	4.31 ± 0.06
C/N	6.76 ± 0.12
TP ($g.Kg^{-1}$)	21.63 ± 2.67
K^+ ($g.Kg^{-1}$)	32.4 ± 1.39

pH: hydrogen potential; **EC**: Electrical Conductivity; **OM**: Organic Matter; **TOC** : Total Organic Carbon; **N** : Nitrogen; **C/N** : Carbon/Nitrogen ratio; **TP** : Total phosphorus; **K^+** : Potassium

2.3.5. Parameters evaluated

- **Height (HP) and growth rate (Gr)**

Plant height growth remains one of the most important agronomic performance indicators. Within the framework of this study, the measurement of the height consisted in determining the length of the main axis of the mangosteen trees, starting from the collar to the ends of the last leaves. The measurements were taken using a tape measure. The periodic evaluation of the height of the seedlings made it possible to determine the growth rate of the mangosteen trees using the following formula:

$$Gr = \frac{HP2 - HP1}{HP2} \times 100 \qquad (1)$$

With :

Gr : as growth rate (%)

HP I : as initial height of the plants (m)

HP 2 : as plant height at last measurement (m)

- **Span of plants (SP)**

The wingspan is a parameter that reflects the level of growth and good health of a plant. The measurement of the wingspan of the plants consisted in determining, using a tape measure, the diameter of the ends of the foliage of the mangosteen trees following the North-South and EastWest orientations.

- **Collar diameter (Dcol)**

The diameter of the intercession between the stem and the root of the mangosteen trees (the collar) was measured using a caliper on each of the plants used.

- **Robustness Quotient (RQ)**

The hardiness quotient is the ratio of the height of the stem and the diameter at the collar of the plants. According to this parameter, the most robust plants have a better chance of survival than the less robust ones. A plant is considered robust when this parameter is low. This parameter was evaluated according to the following formula:

RQ = HP/DC (2)

With :

RQ : as robustness quotient ($cm.mm^{-1}$)

HP : as stem height (cm)

DC : as neck diameter (mm)

- **Length and width of leaves (Le and wth)**

Leaf length was determined by measuring the distance from the point of attachment of the leaf petiole to the upper leaf tip. As for the width of the leaves, the measurement of the diameter of the leaf blade was considered. In class 1 seedlings, measurements were made on 5 randomly selected leaves. For those in class C2, 10 leaves located on each pair of branches were chosen at random. These parameters were measured using a ruler graduated to the nearest millimetre.

- **Number of branch peers (NPr)**

The branches which constitute ramifications in the plants were also counted. In general, this parameter evolves in the same direction as the height growth of the plants.

- **Leaf chlorophyll content (Tch)**

Leaf chlorophyll pigment levels were assessed before fertilizer applications and 4 weeks (30 days) after. The method used for the assay was that described by Mayor et al. (2023). After sampling, and extraction with ethanol, the absorbance of the leaf extracts was measured using a visible UV spectrophotometer. Absorbances were measured at wavelengths of 645 and 663 nm against a blank. Leaf chlorophyll concentration was determined using Aron's formula described by Mayor et al. (2022)

Tchl = 8,02(Do663) + 20,20(Do 645) (3)

With :

Tchl : as total chlorophyll concentration (mg/ml)

Do 663: as absorbance at 663 nm Do 645: as absorbance at 645 nm

2.4. Statistical analysis

The data obtained were subjected to statistical analyses using XLSTAT Pro version 7.5 2016 software. Multiple analysis of variance (MANOVA) was used to study the overall effect of the factors studied on the agronomic parameters of the mangosteen tree. Once the significant effect of a factor has been revealed, one-way analyses of variance (ANOVA 1) were carried out for each parameter examined in order to identify the one or those which contribute to the effect of the factor considered. For each discriminant variable identified, multiple comparisons were made by performing the test of the least significant difference *(ppds).* This test made it possible to identify the treatment(s) which differed significantly from each other. The Student's t test and the Mann-Whitney non-parametric test were used to compare the average mineral contents of the different types. These tests were also used to evaluate the significant effect of soil types and different treatments on the growth and production parameters of mangosteen trees. Finally, the quantitative data organized in a matrix grouping the individuals and the parameters measured were processed by a Principal Component Analysis (PCA). This descriptive analysis made it possible to identify the groups of homogeneous units and to evaluate the correlations between the variables.

3. Results

3.1. Physico-chemical parameters of soils

Particle size analysis of the soils revealed that the lowland soil consists of 47.12 ± 1.41% sand, 32.45 ± 1.32% clay and 20.43 ± 1.64% silt, which gives it a sandy-loamy texture. The forest floor is mostly made up of sand (72.61 ± 2.92%) and silt (21.65 ± 1.81%) which gives it a sandloamy texture (Table 3).

The organic matter (OM) content was statistically different between soil types ($p < 0.001$). The forest soil was richer in organic matter than the lowland soil. The mean OM values obtained were 4.44 ± 1.30% for the lowland soil and 9.77 ± 2.27% for the forest soil. In view of the pH values recorded, the two types of soil were acidic with average water pH fluctuating between 5.09 ± 0.33 and 4.97 ± 0.31 respectively with the lowland and forest soil. The mean of EC values were statistically identical on the two soil types ($p = 0.053$). However, the highest average value was obtained with the forest floor 101.45 ± 4.58 $\mu S.cm^{-1}$ against 98.68 ± 3.25 $\mu S.cm^{-1}$ with the forest floor (Table 3).

Regarding the composition of major minerals, the results revealed a significant difference depending on the types of soil. Indeed, the lowland soil was statistically richer in nitrogen (0.90 ± 0.04%), phosphorus (22.85 ± 3.25 $mg.kg^{-1}$) and potassium (0.22 ± 0.01 $cmol.Kg^{-1}$) than that of forest, which recorded respective average values of 0.78 ± 0.05% for nitrogen, 16.49 ± 1.02 $mg.Kg^{-1}$ for phosphorus and 0.08 ± 0.00 $cmol.kg^{-1}$ for potassium. A highly significant difference was also observed between the means of the carbon/nitrogen (C/N) ratio ($p < 0.001$). The mean values of the C/N ratio obtained for the lowland and forest soils were respectively 3.88 ± 0.95 and 7.19 ± 1.58 (Table 3).

Table 3
Mean values (± standard deviation) of the physico-chemical parameters of the two types of soil

Settings	Lowland soil	forest soil	F	P
Sand (%)	47.12 ± 1.41	72.61 ± 2.92	15.31	< 0.001
Silt (%)	20.43 ± 1.64	21.65 ± 1.81	2.16	0.061
Clay (%)	32.45 ± 1.32	5.74 ± 0.46	31.41	< 0.001
TH (%)	21.40 ± 0.74	4.95 ± 0.47	36.87	< 0.001
pH water	5.09 ± 0.33	4.97 ± 0.31	1.47	0.069
pH_{KCl}	5.01 ± 0.12	4.53 ± 0.64	10.36	0.042
EC ($\mu S.cm^{-1}$)	101.45 ± 4.58	98.68 ± 3.25	2.14	0.053
OM (%)	4.44 ± 1.30	9.77 ± 2.27	16.35	< 0.001
TOC (%)	2.57 ± 0.75	5.66 ± 1.31	16.35	< 0.001
N (%)	0.90 ± 0.04	0.78 ± 0.05	15.54	0.021
C/N	3.88 ± 0.95	7.19 ± 1.58	20.14	< 0.001
TP ($mg.Kg^{-1}$)	22.85 ± 3.25	16.49 ± 1.02	16.84	0.038
K ($cmol.Kg^{-1}$)	0.22 ± 0.01	0.08 ± 0.00	31.87	< 0.001

TH : Humidity Rate; **EC** : Electrical Conductivity; **TOC** : Total Organic Carbon; **OM** : Organic Matter; **N** : Nitrogen; **C/N** : Carbon/Nitrogen ratio; **TP** : Total phosphorus; **K^+** : Potassium

3.2. Effect of soil type on mangosteen tree growth

The results relating to the effect of the type of soil on the growth parameters of the mangosteen tree are presented in Table 4. The analysis of the data by the non-parametric Mann-Whitney test revealed a significant effect ($p \leq 0.05$) of the type of soil on three of the nine parameters measured. Parameters significantly affected were plant height (HP), growth rate (Gr) and hardiness quotient (RQ). The average height of plants growing on lowland soil was greater than that of those growing on forest soil (3.86 ± 0.61 m against 3.16 ± 0.65 m). The growth rates obtained were 53.08 ± 7.30% for the plants evolving on the lowland soil and 41.51 ± 13.43% for those on the forest soil.

The growth rate of class 1 dishes was greater than those of class 2 on both types of soil. This result was statistically confirmed by the Student test, which revealed a significant difference between the growth rates according to the class of plants ($p \leq 0.05$). Indeed, after 12 months of monitoring, the growth rate of class 1 plants was 23.53% against 9.22% for those of class 2. This speed was relatively slowed from the 18th month and reached 50.58% and

21.63% after 36 months of follow-up. The growth curves of mangosteen trees of the different classes are presented in Figs. 3 and 4.

Table 4
Mean value (± standard deviation) of mangosteen growth parameters according to soil type

Settings		HP (m)	Gr (%)	SP (m)	Dcol (cm)	RQ	Le (cm)	Wth (cm)	Chc ($mg.ml^{-1}$)	NPr
Soil type	Lowland soil	3.86 ± 0.613	53.08 ± 7.30	3.01 ± 0.64	5.76 ± 0.75	0.67 ± 0.11	22.82 ± 1.13	12.25 ± 1.63	24.49 ± 1.40	11.57 ± 1.79
	forest soil	3.16 ± 0.65	41.51 ± 13.43	2.81 ± 0.66	5.43 ± 0.89	0.55 ± 0.10	23.63 ± 7.47	13.03 ± 1.29	24.29 ± 2.00	12.00 ± 1.87
Statistical	F	4.99	4.99	0.69	0.021	4.35	0.001	0.69	0.03	0.57
	P	0.028	0.028	0.42	0.82	0.021	0.98	0.42	0.86	0.47

HP : Height of Plants; **Gr** : Growth rate; **SP**: Wingspan; **Dcol** : Diameter at the collar; **RQ** : Robustness Quotient; **Le** : Leaf length; **Wth** : Leaf width; **Chc** : leaf chlorophyll content; **NPr** : Number of pairs of branches

3.3. Effect of fertilizers on mangosteen growth parameters according to soil type

The experimental results of the effect of fertilizers on the growth of the mangosteen tree according to the type of soil revealed a significant effect of the factors studied on the parameters measured ($p < 0.05$). Fertilizers based on foliar fertilizer and NPK induced a shortening of the onset of fruiting of mangosteen trees. Indeed, at five and six years of age, the plants fertilized with foliar fertilizers and NPK bore their first fruits (**Figure 5**). Fruit formation was observed in 6.66% of plants fertilized with NPK and in 11.66% of those fertilized with foliar fertilizer

Comparison analyzes of growth parameters by analysis of variance (ANOVA) indicated a highly significant difference ($p < 0.01$) between growths in heights (HP), growth rates (Gr), wingspans (SP) and the collar diameters (Dcol) obtained according to the fertilizers and according to the type of soil (Table 5). NPK and organic fertilizers were the ones with the highest growth parameters. However, the highest values of the parameters evaluated were observed in plants growing on lowland soil, unlike those on forest soil. After 36 months of monitoring, the highest average growth rates were obtained with the NPK treatments (78.56 ± 1.65%) and the organic fertilizer (69.67 ± 2.79%). The lowest growth rate was obtained with plants that had received no treatment (41.51 ± 13.43%) (Fig. 6).

The analysis of the results also revealed a significant difference in the ANOVA test between the lengths of the leaves, as well as between the quotients of robustness (RQ) according to the fertilizers ($p < 0.001$). Leaf width (wth) and chlorophyll content remain, however, the only parameters for which no significant difference was observed between the different treatments evaluated ($p \geq 0.05$). The chlorophyll contents fluctuated between 23.13 ± 0.99 $mg.ml^{-1}$ and 24.49 ± 1.40 mg.ml (Table 5).

The principal component analysis (PCA) carried out with the aim of identifying the groups of homogeneous units and evaluating the correlations between the variables is presented in Fig. 7. Factorial axis 1 which extracts more than 40% of the information is positively correlated with plant height (HP), growth rate (Gr), wingspan (SP) and collar

diameter (Dcol). Axis 2, which extracts 17.09% of the information, is positively correlated with leaf length and width (Le and wth) and leaf chlorophyll content (Tch) (Fig. 7A).

The organization of the populations on the plane of axes 1–2 presents a distribution of the individuals into three distinct groups (Fig. 7B). Group 1 (in the positive part of axis 1) includes plants fertilized with NPK and organic fertilizer, mostly grown on lowland soil. The latter are characterized by significant growth, wingspan and diameter at the neck. Group 2 (in the positive portion of axis 2) includes plants fertilized with foliar fertilizer and some of those fertilized with biostimulant grown on the forest floor. These plants are characterized by significant leaf lengths and widths, as well as a high hardiness quotient. Group 3 (in the negative part of the two axes 1 and 2) includes the plants that have not received any treatment and those fertilized with the biostimulant. This group includes both plants grown on both types of soil. These plants are opposed to those of group I and are characterized by reduced growth and by an undeveloped wingspan and collar diameter.

Table 5
Average value (± standard deviation) of the growth parameters of the effect of fertilizers on the growth of the mangosteen according to the types of soil

Parameters		HP (m)	Gr (%)	SP(m)	Dcol (cm)	RQ	Le (cm)	Wth (cm)	Chc ($mg.ml^{-1}$)	NPr
treatments	LS CMP	5.88 ± 0.54b	69.67 ± 2.79b	5.13 ± 0.82b	8.70 ± 0.47e	0.06bc	26.19 ± 0.76A	13.97 ± 1.22a	23.93 ± 1.15a	13.80 ± 0.88ab
	FS CMP	4.88 ± 0.54c	63.32 ± 4.09c	3.73 ± 0.47c	5.30 ± 0.74ab	0.09a	24.72 ± 1.66ab	13.39 ± 1.84a	23.13 ± 0.99a	12.80 ± 1.53ab
	LS NPK	8.31 ± 0.68A	78.56 ± 1.65a	6.94 ± 0.63A	10.33 ± 1.18e	0.08ab	23.32 ± 0.55b	12.17 ± 0.98a	24.41 ± 1.60a	14.58 ± 0.93c
	FS NPK	6.21 ± 0.80b	71.01 ± 3.94b	4.94 ± 0.73b	8.33 ± 1.24 of	0.07bc	22.72 ± 1.28b	11.97 ± 1.35a	24.31 ± 1.85a	13.58 ± 1.83ab
	LS BST	4.32 ± 0.86cd	57.503 ± 8.63cd	3.89 ± 0.12c	6.96 ± 0.58cd	0.06bc	23.35 ± 0.67b	12.08 ± 1.31a	23.83 ± 1.27a	13.68 ± 0.84ab
	FS BST	3.52 ± 0.33d	49.30 ± 5.11d	3.33 ± 0.52c	4.40 ± 0.53A	0.08ab	23.55 ± 1.41b	12.08 ± 1.31a	23.13 ± 1.14a	13.68 ± 0.84ab
	LS EFL	4.50 ± 0.53c	60.11 ± 5.59c	3.41 ± 0.35c	7.19 ± 0.84cd	0.06bc	23.23 ± 1.13b	12.19 ± 1.35a	23.97 ± 2.38a	13.59 ± 1.15ab
	FS EFL	4.30 ± 0.69cd	57.85 ± 7.19cd	3.31 ± 0.52c	6.29 ± 0.78bc	0.06bc	23.14 ± 1.88b	12.05 ± 1.21a	23.52 ± 2.51a	12.40 ± 1.18a
	LS Tem	3.86 ± 0.61cd	53.08 ± 7.30cd	3.01 ± 0.64c	5.76 ± 0.75b	0.06bc	22.82 ± 1.33b	12.25 ± 1.63a	24.49 ± 1.40a	11.57 ± 1.79a
	FS Tem	3.16 ± 0.65d	41.51 ± 13.43d	2.81 ± 0.66c	5.76 ± 0.75a	0.05c	22.69 ± 1.17b	13.03 ± 1.29a	24.29 ± 2.00a	12.00 ± 1.87a
Statistical	F	16.91	16.91	26.35	82.35	41.56	35.93	19.14	8.89	33.02
	P	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.054	0.447	0.000

HP : Height of Plants; **Gr** : Growth rate; **SP** : Wingspan; **Dcol** : Diameter at the collar; **RQ** : Robustness Quotient; **Le** : leaf length; **Wth** : leaf width; **Chc** : leaf chlorophyll content; **NPr** : Number of pairs of branches; **LS**: Lowland soil; **FS** : Forest soil; **CMP** : organic fertilizer; **BST** : Biostimulant; **EFL** : Foliar fertilizer; **Tem** : control. *The mean values of the same column assigned different letters are statistically different at the 5% threshold (ppds)*

4. Discussion

The results obtained showed the significant effect of soil type on height growth, growth rate and mangosteen hardiness quotient. These parameters were more important in the plants growing on the lowland soil, unlike those on the forest soil. This difference could be explained by the different nature of the soil types used. The clayey texture

(32.45 ± 1.32%) and the mineral composition of the lowland soil would have favoured a constant supply of mineral elements necessary for the development of mangosteen trees. Indeed, the C/N ratio, an indicator of the rate of decomposition of soil organic matter, was lower for the lowland soil (3.88 ± 0.95) than it was for the forest floor (7.19 ± 1.58). According to Kouadio et al. (2021), for low C/N ratios, the release of ammonium and nitrates are significant and the nitrogen supply of plants becomes possible from the nitrogen reserves of the soil. The greater growth of mangosteen trees on lowland soil could therefore be the consequence of the rapid mineralization of organic matter and in particular of nitrogen in this type of soil.

On the other hand, the mangosteen tree being a plant very sensitive to drought, it therefore requires particularly high humidity conditions for better development. The high humidity rate of the lowland soil would have contributed to the satisfaction of the water nutrition and the photosynthesis of the plants, thus contributing to the good growth of the latter. Indeed, the water deficit also induces a deficit of mineral nutrition (nitrogen and phosphate) mainly due to reductions in the flow of elements to the roots which would result in a reduction in the growth of the plants (Boughdiri et al., 2020 ; Toure et al., 2021). It would therefore be the combined action of these factors which would explain the best results obtained on the lowland soil. These results corroborate those of Gomes Júnior et al. (2019) and Martias et al. (2021) who reported that soils composed of 60 to 75% clay proved to be favourable to the good development of mangosteen trees. Similar observations were also reported by Hapsari et al. (2018) who observed growth disorders in mangosteen trees under the effect of water stress.

The results also marked the significant effect of fertilizers on the growth of the mangosteen tree, depending on the type of soil. Fertilizers based on foliar fertilizer and NPK recorded remarkable performances by favouring a shortening of the onset of fruiting of mangosteen trees. This result suggests on the one hand that the late entry into fruiting of the mangosteen tree (one of the major constraints of the culture) would be influenced by fertilization. On the other hand, they testify to the clear importance of the contribution of adequate fertilizers in the management and the shortening of the juvenile phase of the plant. The richness of the foliar fertilizer and the NPK in nitrogen would be at the origin of the good performances obtained. Nitrogen is one of the most important basic plant elements for plant growth. This compound participates in the formation of plant proteins and amino acids by combinations with carbohydrates. It is thus involved in the main processes of plant development and yield determination (Fengying et al., 2023 ; Puja et al., 2023).

The addition of these nitrogen-rich fertilizers would therefore have contributed to ensuring good growth of the mangosteen trees, thus causing the tree's juvenile phase to be shortened. Several research works have highlighted the importance of nitrogen in plant growth (Sadi et al., 2020). According to N'djolosse *et al.* (2018), the cashew tree would be sensitive to mineral fertilizer inputs and its growth would be greatly accelerated by nitrogen inputs. According to Rawia et al. (2022) the growth of young mango seedlings would be positively influenced by nitrogen inputs.

These results could also be due to the specificity of the fertilizers used. The NPK and the foliar fertilizer with which shortenings of the vegetative phase have been obtained are in fact mineral fertilizers. This type of fertilizer provides plants with known and constant quantities of minerals in assimilable forms. Access to these minerals would have allowed young mangosteen seedlings to put in place the foundations allowing them to express their full potential (Misbah et al., 2022 ; Choudhary et al., 2023).

Besides the remarkable performance of foliar fertilizer and NPK fertilizers, organic fertilizer also recorded satisfactory growth performance. This resulted in the demarcation of this treatment to Principal Component Analysis (PCA) which revealed that plants fertilized with NPK and organic fertilizer were characterized by significant growth, wingspan and

collar diameter. The richness of poultry manure in nitrogen could explain this result. This confirms the important role of nitrogen in the growth process of mangosteen. However, the slow degradation and gradual release of minerals were the cause of the late effect that fertilizer would have on the fruiting of mangosteen trees (Neethu and Vardhanan, 2023 ; Hou et al., 2023).

5. Conclusions

This study is part of a vast program to improve mangosteen production techniques. The results of this study showed the significant effect of soil type and fertilizers on mangosteen growth parameters. Lowland soil was found to be more suitable for growing mangosteen. This type of soil has indeed favoured a better growth of the plants. With regard to the effect of fertilizers, the results testified to the clear importance of the contribution of fertilizers in the management and the shortening of the juvenile phase of the mangosteen tree. Fertilizers based on foliar fertilizer and NPK recorded remarkable performances by favouring a shortening of the onset of fruiting of mangosteen trees.

On the basis of the results obtained, it is necessary to make some recommendations to the producers and to the bodies responsible for the extension of agricultural techniques. Indeed, the results of this study gave satisfactions to most of the constraints which constitute an obstacle to the culture of the mangosteen tree. Therefore, we suggest the following recommendations:

- for the establishment of mangosteen plots, favour moist soils with a clay texture (claysandy, clayey loam or clayey-sandy loam);
- for fertilization to promote the use of foliar fertilizer rich in amino acids and balanced NPK mineral fertilizers for the fertilization of plants in the growth phase.

Abbreviations

AOAC
Association of Official Analytical Chemists
BST
Biostimulant;
C/N
Carbon/Nitrogen ratio;
CEAEQ
Centre of Expertise in Evironemental Analysis of Quebec
Chc
leaf chlorophyll content;
CMP
Organic fertilizer;
Dcol
Diameter at the collar;
EC
Electrical Conductivity
EFL
Foliar fertilizer;
FS

Forest soil;
Gr
Growth rate;
HP
Height of Plants;
IFAC
Research Institute for Colonial Fruits and Citrus
K +
Potassium
Le
Leaf length;
LS
Lowland soil;
N
Nitrogen;
NPr
Number of pairs of branches
OFAG
Office Fédéral de l’Agriculture Suisse
OFEV
Office Fédéral de l’Environnement Suisse
OM
Organic Matter
PCA
Principal Component Analysis
pH
hydrogen potential
RQ
Robustness Quotient;
SP
Wingspan;
Tem
Control
TOC
Total Organic Carbon
TP
Total phosphorus;
Wth
Leaf width;

Declarations

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Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Competing interests

The authors have no competing interests to declare relevant to this article's content.

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Authors' contributions

The authors contributed at all levels, from conducting and carrying out the work to writing the manuscript. All authors read and approved the manuscript.

JFH : Conducted the trials collected the data, analyzed the results and was one of the main editors of the manuscript.

NS, EDPand AKL : Helped carry out the protocol and conduct the trials.

AD and KJK: Were the investigators of the research project and were the artisans of its implementation by creating the carder of its realization. They also supervised the writing of the manuscript.

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Figures

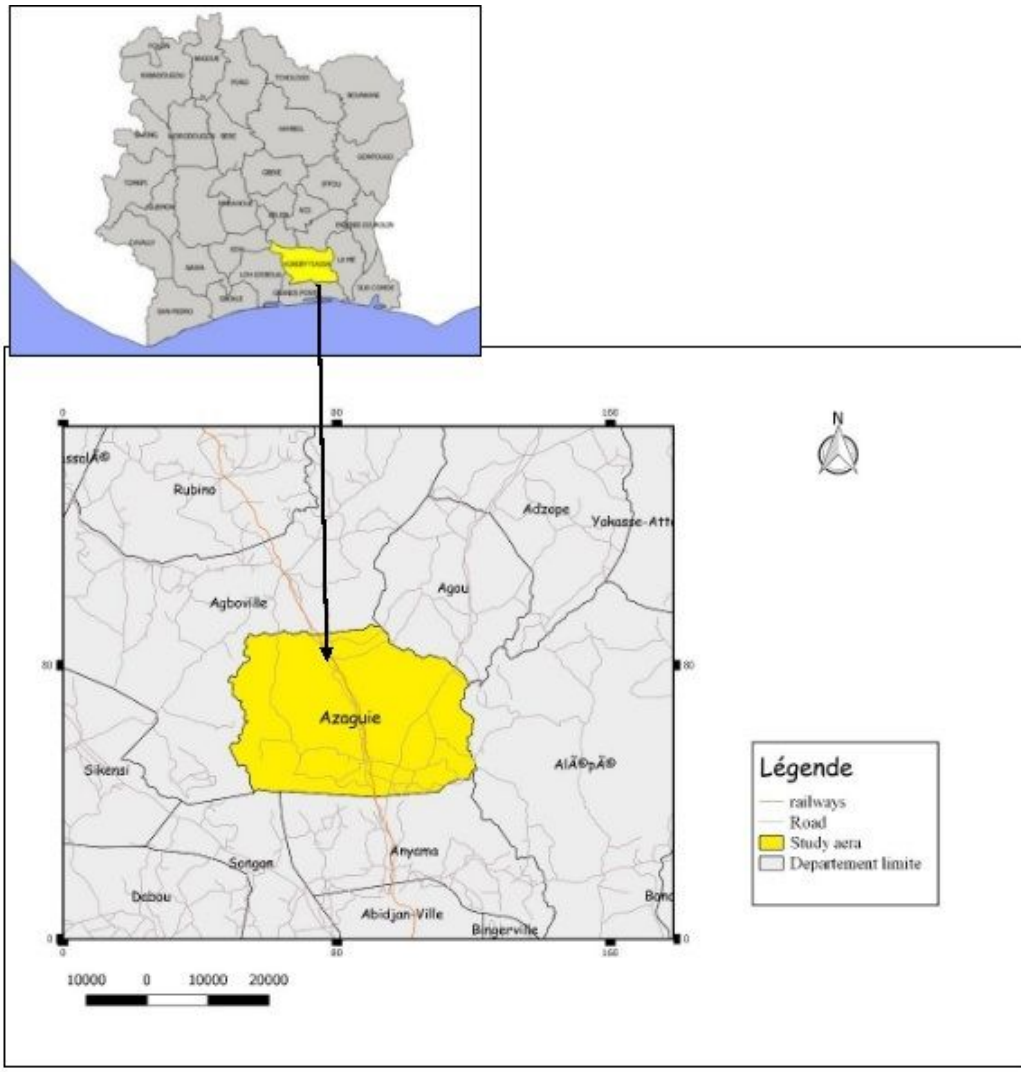


Figure 1

Localisation of the study area



Figure 2

1 year old mangosteen seedling

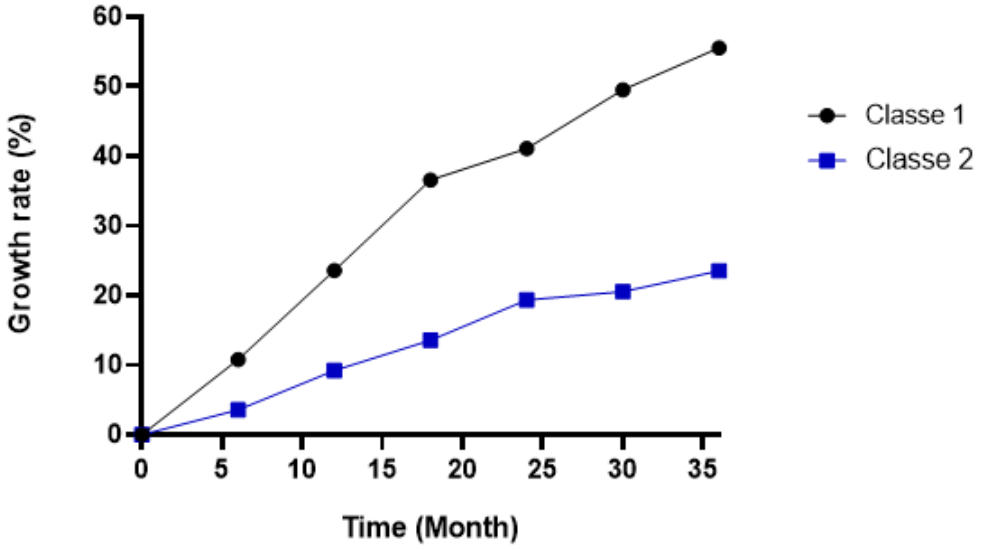


Figure 3

Growth chart of mangosteen trees on lowland soil

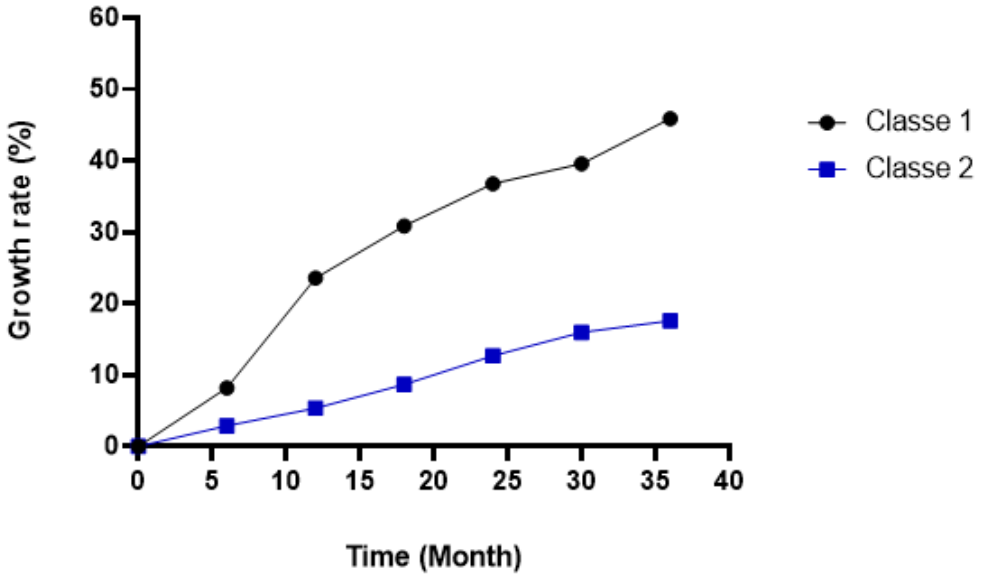


Figure 4

Growth chart of mangosteen trees on forest floor

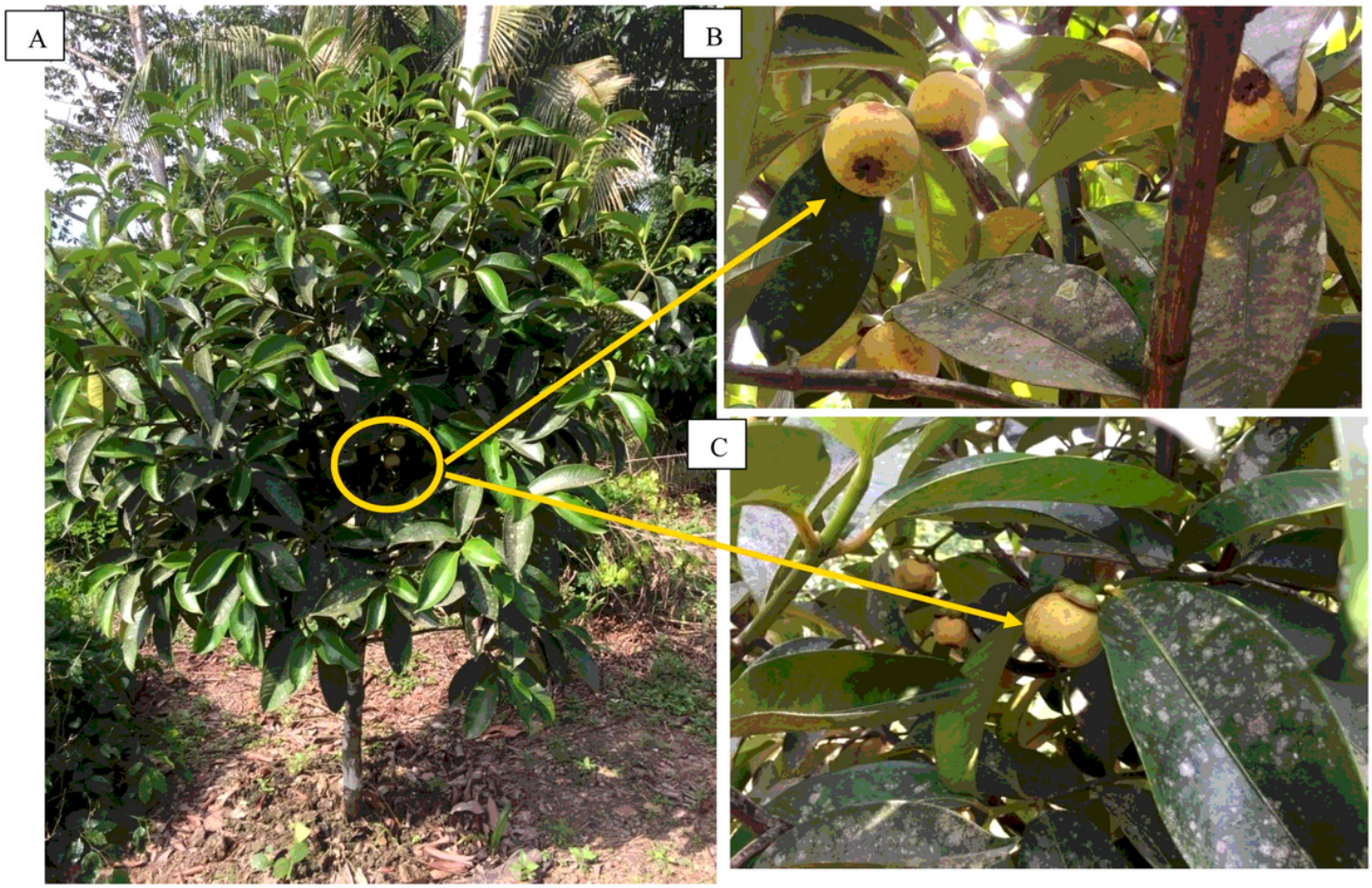


Figure 5

5-year-old mangosteen plant bearing its first fruits

A : mangosteen plant; **B** and **C** : mangosteen fruits

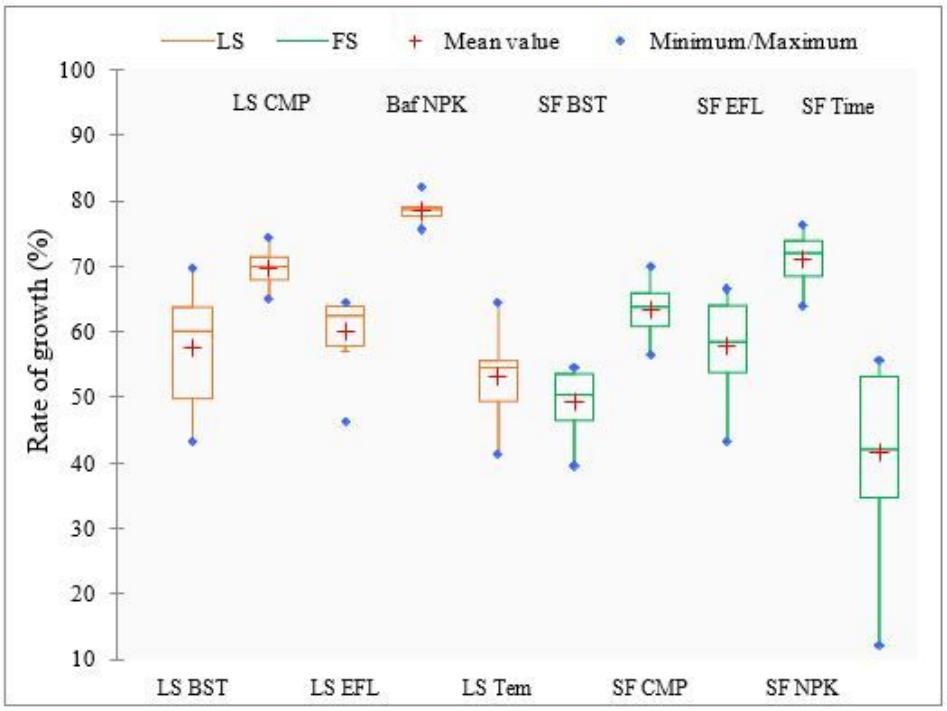


Figure 6

Descriptive statistics of growth rate according to fertilizers and soil type

LS: Lowland soil; **FS**: Forest soil; **CMP**: organic fertilizer; **BST**: Biostimulant; **EFL**: Foliar fertilizer; **Tem**: control

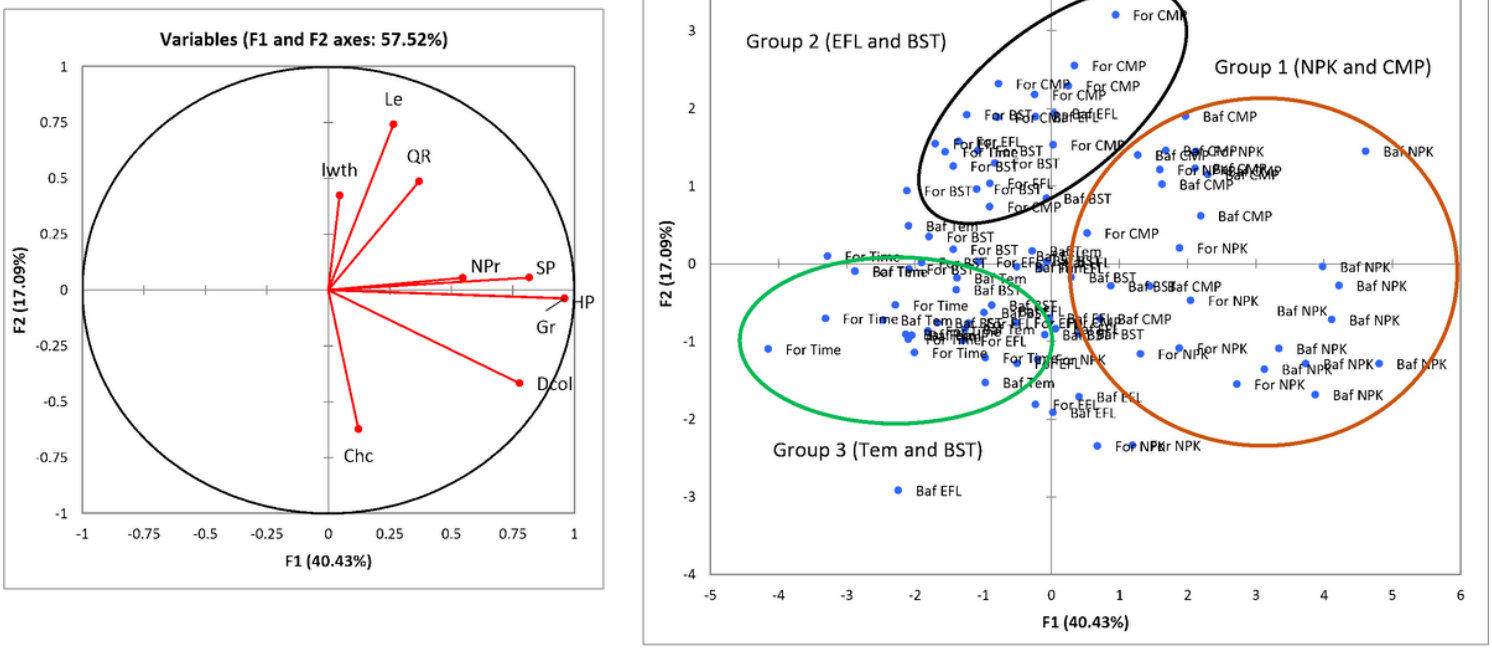


Figure 7

Descriptive statistics of growth rate according to fertilizers and soil type

LS: Lowland soil; **FS**: Forest soil; **CMP**: organic fertilizer; **BST**: Biostimulant; **EFL**: Foliar fertilizer; **Tem**: control