Earthline Journal of Chemical Sciences
E-ISSN: 2581-9003; CODEN: EJCSB4
Volume 12, Number 3, 2025, Pages 311-330
https://doi.org/10.34198/ejcs.12325.311330

Study of the agronomic performance of methanization digestate: the case of cucumbers

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Abstract

Soil Agricultural intensification in tropical regions faces significant challenges, including soil depletion and increasing reliance on chemical fertilizers, the environmental impacts of which are concerning. This study aims to assess the agronomic potential of methacompost, a solid residue derived from the anaerobic digestion of laying hen manure, as an alternative organic fertilizer for cucumber (*Cucumis sativus* L.) cultivation. A field experiment was conducted in the Gontougo region (Côte d'Ivoire), comparing seven methacompost formulations, an unfertilized control, and a reference treatment with NPK fertilizer (15-15-15). Physicochemical analyses revealed a high ammoniacal nitrogen content in all methacompost formulations. Agronomic results showed that the treatments MP75%, MP50%, MP25%, as well as the combination NPK50% + MP50%, resulted in vegetative growth and yields comparable to or exceeding those obtained with mineral fertilizer. These performances are attributed to the rapid mineralization of nutrients, ensuring their availability to plants. Economically, some methacompost formulations also demonstrated a lower cost per unit of fertilizer compared to NPK. This study confirms the potential of methacompost as a viable organic fertilizer for vegetable crops in tropical zones. It paves the way for the agronomic valorization of livestock waste in a circular and sustainable agricultural framework.

1. Introduction

The sustainability of agricultural systems, particularly in Sub-Saharan Africa, is increasingly questioned

Received: July 1, 2025; Accepted: July 30, 2025; Published: August 7, 2025

Keywords and phrases: methanization, methacompost, sustainable agriculture.

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due to soil degradation, rapid population growth, and the volatility of chemical inputs. The agricultural productivity of the region remains largely dependent on soil fertility, which is degrading due to intensive agricultural practices, erosion, climate change, and the excessive use of mineral fertilizers. In this context, the transition to more resilient and circular production systems has become a strategic priority for many developing countries.

In Côte d'Ivoire, horticulture, particularly the production of tropical fruits and vegetables, represents a major economic and nutritional sector [1]. In 2019, production amounted to approximately 740,000 tons for a population of 26 million, with forecasts reaching 38 million tons by 2025 [2]. These products include tomatoes, eggplants, okra, onions, peppers, cucumbers, and several others [3,4]. However, despite these ambitions, horticultural production systems remain vulnerable. The low level of mechanization, high input costs, and dependence on chemical fertilizers jeopardize the environmental and economic sustainability of these crops [5,6]. Furthermore, in this agricultural branch, smallholders predominate in an increasingly deteriorating environment marked by chronic soil fertility loss due to wind and water erosion, climate change, population explosion, and poor farming practices [1, 3].

Chemical fertilizers, although effective in the short term, present several long-term disadvantages, including soil acidification, groundwater pollution, and the reduction of microbial biodiversity in the soil [7, 8]. Moreover, the volatility of prices and dependence on imports exacerbate the sector's economic vulnerability. In response to these challenges, organic fertilizers, such as methacompost, appear as a promising alternative within the framework of agroecological agriculture.

Methacompost is a solid or pasty residue derived from the anaerobic digestion of organic waste, primarily of animal origin. This product has the advantage of valorizing agricultural waste while being rich in ammoniacal nitrogen, which is quickly assimilable by plants, unlike traditional compost, where nitrogen is bound in a stable organic form [9,10]. Several studies have demonstrated the positive effects of methacompost on the growth and yield of vegetable crops, due to the rapid mineralization of nutrients and their increased availability [11, 12].

However, its application in humid tropical zones, and specifically in Côte d'Ivoire, remains insufficiently documented. Local research on its agronomic effectiveness, compatibility with soil types, and economic viability is still limited. Cucumber (*Cucumis sativus* L.), a short-cycle vegetable with high market value, constitutes a relevant model to evaluate these performances under field conditions.

The aim of this study is to fill this gap by assessing the effectiveness of methacompost derived from laying hen manure on the growth, yield, and economic viability of cucumber cultivation in the Gontougo region (Northeastern Côte d'Ivoire). This project is part of an approach aimed at valorizing agricultural waste, reducing dependence on chemical inputs, and promoting sustainable and circular farming practices.

The specific objectives are as follows:

1. Characterize the chemical composition of methacompost formulations;
2. Evaluate their agronomic impact in comparison to a mineral fertilizer (NPK 15-15-15);
3. Analyze the interaction between soil type, amendment dosage, and plant response.

The expected results should support Ivorian agricultural policies related to sustainable farming, while providing a tangible solution for the valorization of livestock waste to benefit smallholder vegetable producers.

2. Materials and Methods

2.1. Materials

2.1.1. Plant Material

The variety used for cucumber cultivation (Figure 1) is "Poinsett +", an improved version of the standard variety in terms of productivity and earliness, developed by the company TECHNISEM. This variety was obtained from the Bondoukou market (Côte d'Ivoire). Its characteristics include: an earliness of 40 to 45 days after sowing, depending on the conditions and regions of cultivation; and an adaptation to open field cultivation, with a dark green color at maturity.

Figure 1. Cucumber seeds of the "Poinsett+" variety.

2.1.2. Soil

According to various sources, vegetable crops such as cucumbers typically have a root system with a depth ranging from 30 to 50 cm. For this reason, soil sampling was conducted randomly at the cultivation site, at a depth of 30 to 50 cm (Figure 2), prior to the installation of the crops. The soil samples were then transported to the laboratory for the determination of physical and chemical parameters.

Figure 2. Sampling of the soil.

2.1.3. Fertilizers

The digestate we used was obtained through the methanization of chicken manure from the poultry farm of the Brin Foundation, using the biodigester funded by FONSTI CRDI (Figure 3). After the production of the methacompost, three liters were collected in plastic containers for laboratory analysis. The analyses were conducted according to the different formulations of the methacompost, using the same type of methacompost collected from ponds (see Annex 1), which were combined in the production system for the establishment of cucumber cultivation. The NPK fertilizer (15-15-15), purchased from the Bondoukou market, was used as the chemical fertilizer for this experiment.

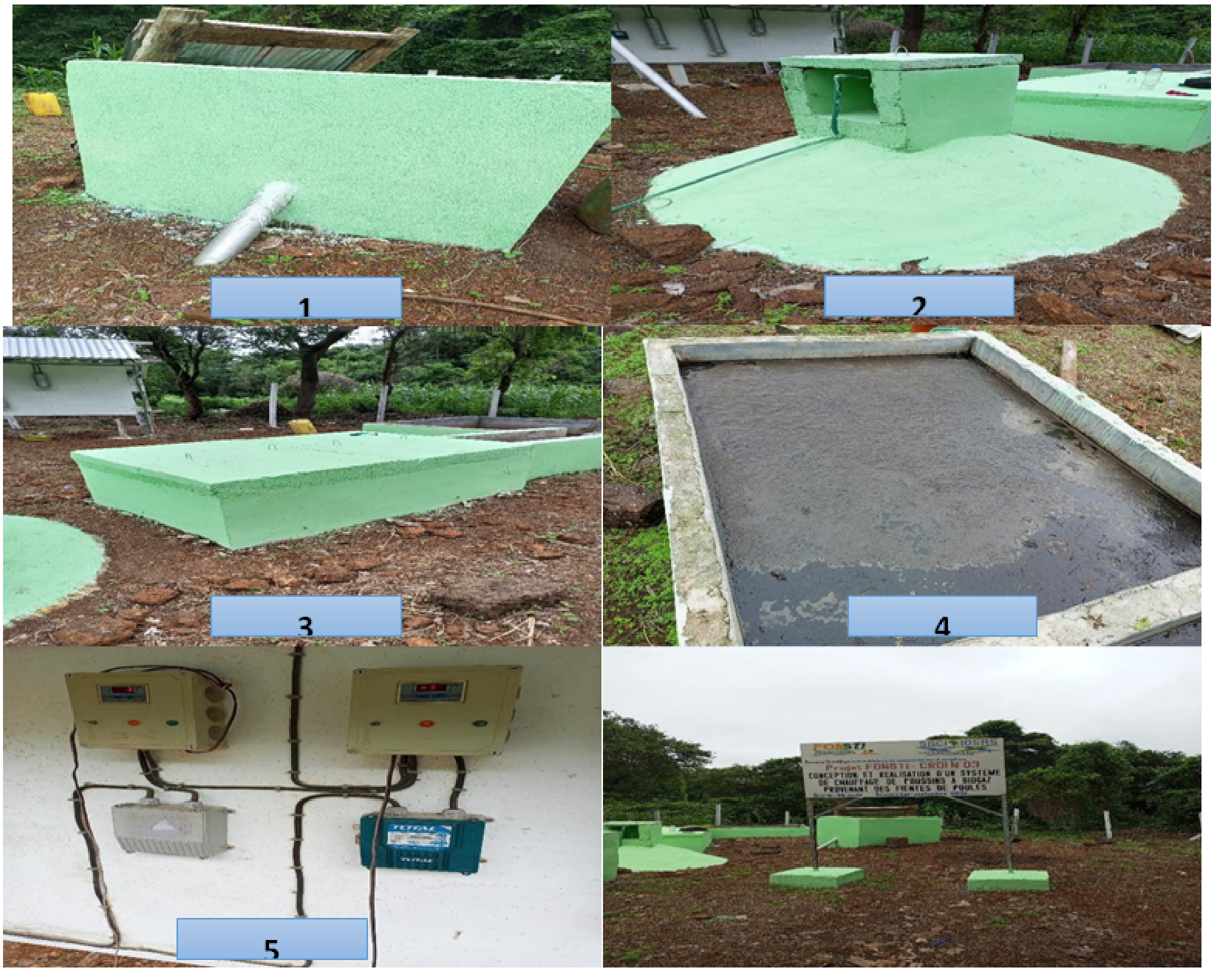

Figure 3. Biogas and methacompost production station.

2.1.4. Experimental equipment

For the analysis of soil samples and methacompost, laboratory glassware was used. Basic agricultural tools, such as the daba and machete, were also employed for the establishment of the plantation. The laboratory equipment used included:

- An oven for drying and sterilizing glassware;
- A BIOBASE electronic balance (precision to three digits);
- A Nabertherm muffle furnace (30-3000°C) for calcination;
- A magnetic stirrer for homogenization;
- A JASCO/V-530 UV-Visible spectrometer;
- A METTLER TOLEDO pH meter;
- An iCAP RQ inductively coupled plasma mass spectrometer;
- A GERHARDT sand bath.

2.2. Method

2.2.1. Site selection for cultivation

The study was conducted on a plot of land belonging to the "Brin Foundation", located in the village of Yaokokroko, within the sub-prefecture of Tabagane, in the Gontougo region of Côte d'Ivoire. The plot is situated at a latitude of 7°57'53.9" N and a longitude of 3°08'09.2" W.

2.2.2. Experimental protocol

For one month, the digester was continuously supplied with approximately 50 to 100 kg of manure per day, as illustrated in the diagram in Figure 4. Given this prior feeding, the hydraulic retention time was reduced to 5 days.

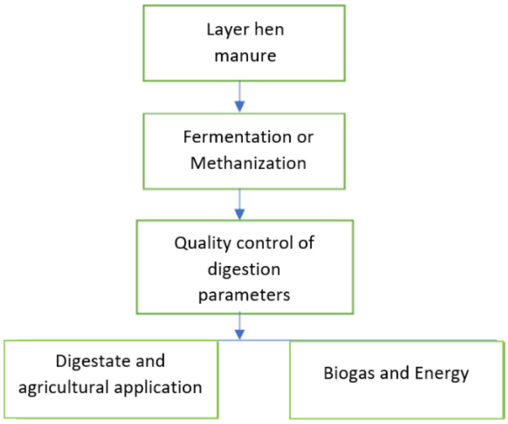

Figure 4. Graphical representation of the methacompost production system.

The sowing was carried out on a total of 20 boards, with row spacing of 0.5 meters and plant spacing of 1 meter. Each board contained 8 holes, in which 2 to 3 cucumber seeds were sown. Thus, the planting density was 160 plants per 10,000 plants per hectare.

Initially, the plot was cleared with a machete. The debris was not burned but was cleaned and removed from the activity areas. Subsequently, the soil was tilled with a hoe to form planting beds, followed by sowing. Due to variations in rainfall, manual watering was carried out, but not continuously throughout the growing season. After 25 days, a second tilling was performed to prevent weed growth and promote the development of the root system. Nutrients were supplied every 10 days starting from the appearance of the true leaves. Methacompost was applied at the plant's root level, with a spacing of approximately 5 cm. The application of insecticides and fungicides helped control diseases. Cucumber fruit harvesting began 6 weeks after sowing, taking place two to three times per week.

The compared treatments were as follows:

- T0: Control with no fertilizer applied
- T1: 100% mineral fertilizer
- T2: 100% methacompost
- T3: 50% methacompost + 50% mineral fertilizer
- T4: 50% methacompost + 50% water
- T5: 75% methacompost + 25% mineral fertilizer

- T6: 75% methacompost + 25% water
- T7: 25% methacompost + 75% water
- T8: 25% methacompost + 75% mineral fertilizer

2.2.3. Data collection

The recorded parameters focused on the physiology of the vegetative phase and the yield at harvest. These include: the number of leaves, leaf width, number of tendrils, number of flowers, as well as the size, length, and yield of cucumber fruits, measured on 5 plants for each treatment type. Data were collected every 10 days.

The yield was measured for each experiment and then converted to hectares (ha) using the following equation [13]:

$$\text{Yield (kg/ha)} = \frac{\text{weight of the fruit (kg)}}{\text{Cultivated area}} \times 10000\ \text{m}^2. \quad (1)$$

For the measurement, 1 m² was used for 5 cucumber plants.

2.2.4. Analysis of soil samples and methacompost

- **Measurement of soil pH and methacompost**

The pH measurements were performed using the electrometric method, employing a pH meter with a glass electrode for direct reading. The reference solution was prepared according to the 1/5 ratio [14], with a minimum volume of 5 mL. This solution was made using distilled water for the pH (water) and potassium chloride (KCl) at a concentration of 1.86 g for the pH KCl. The pH reading was taken after the solution was stirred for one hour.

- **Humidity rate**

The organic matter (MO) content was determined according to the AFNOR standard [15]. For this purpose, a sample of approximately 2 g, previously dried, was taken and placed in porcelain crucibles. These samples were then heated in an oven at 105 °C for 24 hours to obtain the dry matter (MS). The organic matter content was subsequently measured after the dry matter was calcined at 550 °C for 3 hours. The dry matter content is calculated as follows:

$$\%H = \frac{m_0 - m_1}{m_0} \times 100, \quad (2)$$

$$\%MS = \%H - 100, \quad (3)$$

$$\%MO = \frac{m_1 - m_2}{m_1} \times 100, \quad (4)$$

where %H represents the humidity content, m_o is the initial mass of the sample before drying, m_1 is the final mass of the sample after drying, and m_2 is the mass of the residue after calcination at 550°C for 3 hours.

- **Ammonium quantification using Nessler's reagent**

In the presence of potassium hydroxide, Nessler's reagent (alkaline potassium iodomercurate) reacts with ammonia (NH_3) to form a compound whose color changes from yellow-orange to brown. The method employed is as follows:

(a) Sample preparation:

- Pipette 1 mL of the different methacomposts.

- For the soil samples, take 5 g at room temperature and dilute them in a 200 mL flask.

(b) Preparation of the solution for analysis:

- In a 25 mL flask, take 5 mL of the diluted solution.
- Add 2 mL of ammonium acetate solution and 2 mL of Nessler's reagent.
- Fill with distilled water up to the calibration mark.

(c) Analysis:

- Take 5 mL of the prepared solution and transfer it into a test tube.
- Mix and allow the reaction to proceed for 15 minutes.
- Measure the absorbance using a UV/VIS spectrometer.

(d) Calculation of concentrations:

- For liquid samples, the NH_3-N concentration is calculated using the following formula:

$$C \text{ (mg/L } NH_3\text{-N)} = A \times F \quad (5)$$

For the soil:

$$C \text{ (mg/kg } NH_3\text{-N)} = \frac{A \times V \times F}{P} \times \frac{100}{100 - \%H} \quad (6)$$

where

C represents the ammonia concentration in the sample (mg/kg NH_3-N or mL/L);

A denotes the ammonia concentration in the titrated solution (mg/kg NH_3-N or mL/L);

V indicates the final volume of the solution used for the extraction (mL);

F is the dilution factor, if applicable; *P* refers to the weight of the sample used (g).

- **Nitrate determination using sodium salicylate**

A yellow compound is formed by the reaction of nitrates with sulfosalicylic acid, following the addition of sodium salicylate and sulfuric acid, along with an alkaline treatment.

The method used to measure nitric nitrogen is as follows:

(a) Sample preparation:

- For soil samples: Weigh 5 g of soil and place it into a 200 mL flask.
- For methacomposts: Pipette 1 mL of each sample and add it to a 200 mL flask.
- Add distilled water to the mark in each flask.

(b) Preparation of the solution for analysis:

- Mix 5 mL of the solution taken from each sample with 0.2 mL of acetic acid and 1 mL of sodium salicylate in porcelain dishes.
- Place the porcelain dishes in a sand bath and evaporate the solution completely for 20 minutes.

(c) Processing and measurement:

- Add 10 mL of alkaline solution to each evaporated sample.
- Add 15 mL of distilled water and 1 mL of sulfuric acid.
- The concentration of nitric nitrogen is measured following the same method as for ammoniacal nitrogen, using a UV/VIS spectrophotometer to measure the absorbance of the yellow compound formed.

- **Determination of orthophosphate**

Orthophosphate ions react with molybdate to form a yellow phosphomolybdic complex. Arsenates and silicates may also react, but ascorbic acid specifically reduces the phosphomolybdic complex, resulting in a blue precipitate, enabling a sensitive colorimetric assay [16].

The method for measuring ortho-phosphate ions is described as follows:

(a) Preparation of samples:

- For soil samples: Weigh 5 g of soil and place it into a 200 mL flask.
- For methacomposts: Pipette 1 mL of each sample into a 200 mL flask.
- Add distilled water to each flask up to the calibration mark at room temperature.

(b) Preparation of the solution for analysis:

- Take 5 mL of the diluted solution for each sample.
- Mix 5 mL of the sampled solution with 2 mL of ammonium acetate solution and 2 mL of Nessler's reagent in a 100 mL volumetric flask.
- Add distilled water up to the calibration mark.
- Transfer 5 mL of the mixture into a test tube and mix thoroughly.

(c) Processing and measurement:

- After a 15-minute reaction time, measure the concentration of orthophosphate ions using a UV/VIS spectrophotometer.
- The measurement is performed by assessing the blue color formed, which is proportional to the concentration of orthophosphate ions in the sample.

(d) Calculation:

The results are calculated according to the method outlined by the Centre of Expertise in Environmental Analysis of Quebec [17].

This method allows for precise measurement of ortho-phosphate ions through the formation of a specific colored complex, which is detected using UV/VIS spectrometry.

- **Determination of mineral elements by ICP-MSMS**

(a) Preparation of samples:

- The liquid samples were initially filtered after being diluted 50 times in a volumetric flask.

- An aliquot portion of the filtered samples was then transferred directly into 10 ml tubes for measurement.

(b) Determination of elements:

- The concentrations of Ca, Cd, Co, Cr, Cu, K, Mg, Mo, P, Pb, S, and Zn in the soil were determined after extraction using aqua regia and in the methacompost following filtration.
- The measurement of these element concentrations was performed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) [18, 19].

- **Fertilizing equivalent**

The equivalences of the digestate derived from laying hens have been estimated in kilograms, using the NPK mineral fertilizer (15-15-15) as a reference. The price of one kilogram of NPK mineral fertilizer (15-15-15) is set at 1000 CFA francs, with one tonne equivalent to 1000 kg.

The digestate equivalences are calculated based on the nutrient content in kilograms, compared to the nutrients provided by NPK mineral fertilizer (15-15-15). The cost estimation is based on these equivalences to determine the relative cost of each fraction of digestate in comparison to the mineral fertilizer per tonne.

- Volume fraction in %:

$$v_i = \frac{Volume\ of\ the\ solute\ (mL)}{Volume\ of\ the\ solution} \times 100 \quad (7)$$

For clarity, the element percentages are converted into oxide percentages according to the equations provided in equation 8 below:

$$\%P_2O_5 = \%\ PO_4^{3-} \times 2.3$$

$$\%K_2O = \%K^{+} \times 1.2 \quad (8)$$

- Quantity of each fraction in kilograms per tonne:

$$\text{Quantity in kg} = \frac{\%v}{100} \times 1000\ \text{kg}$$

- Price of each fertilizing element per tonne:

$$\text{Price per tonne} = \sum \text{All the elements constituting balance} \times 1000 \quad (9)$$

- Price of each fertilizing element per tonne

$$\text{Price per tone} = \sum \text{All the elements constituting a balance} \times 1000 \quad (10)$$

- **Statistical analysis**

The data analysis was conducted using STATISTICA software, version 12.5. To compare the differences between treatments, an analysis of variance (ANOVA) was performed using Excel 2019. The comparison of treatment means was carried out using the Least Significant Difference (LSD) test, with a significance level set at 5%.

After homogenizing the collected methacomposts, a representative fraction of each sample, as well as soil samples, were used for physical and chemical measurements in the laboratory. Simultaneously, a planting was established to observe various traits based on the applied treatments. Following the statistical analysis of the collected data, all these observations will be analysed, interpreted, and will form the basis for recommendations in the next section of the paper.

3. Results and Discussion

Like major crops, vegetable crops face various challenges, including issues related to phytosanitary products, weed control, water management, difficulties in obtaining harvests that meet standards, fertility management, and fluctuations in mineral fertilizers. However, this section will focus on fertility. Specifically, the aim is to demonstrate that methacompost, an organic fertilizer produced through a methanization process, contains a significant amount of mineralized minerals that are immediately available to plants.

3.1. Characteristics of ionized elements in methacompost

For organic fertilizers, including methacompost, the minimum concentrations of nitrogen, phosphorus, and potassium must be 3%, 0.684%, and 1.78%, respectively [20]. The data in Table 1 confirm this information, with nitrogen concentrations significantly higher than the threshold (21.31% > 3%), as well as potassium and phosphorus levels in methacompost at 100%, 75%, 50%, and 25%, depending on the formulations composed of water and methacompost. The high concentration of mineral nitrogen is explained by the research of Smith et al. [21] and Lukehurst et al. [22], which show significant mineralization during the anaerobic process compared to the exposure of organic matter to open air. Holm-Nielsen et al. [23] and Arthurson [10] state that NH_4^+ in digestate can account for between 10.2% and 70%, providing immediate NH_4^+ to the plant, which is assimilated as NO_3^- [24]. When compared to raw manure, these results align with the different compositions. However, there is a risk of toxicity if the levels of NH_4^+ and NO_3^- are too high relative to the plant's needs [25]. Faqinwei et al. [26] confirm that the rapid increase in NH_4^+ can lead to rapid mineralization, with notable effects within a month. Similarly, for macroelements, certain elements such as aluminum (Al), lead (Pb), cadmium (Cd), and mercury (Hg) are assimilable, even though they are not essential for the plant and can be harmful to humans.

Table 1 shows that the metal content is very low, with lead being almost nonexistent in the methacompost.

In accordance with the European Parliament regulations of June 5, 2019, the following threshold limits are established: cadmium — 100 mg/kg of dry matter; lead — 120 mg/kg of dry matter; nickel — 50 mg/kg of dry matter; chromium — 2 mg/kg of dry matter [27]. The use of digestate is considered an effective method for managing nutrients and reintroducing them into the biological cycle [28]. Chojnacka and Moustakas [29] observed that the pH of methacompost varies from alkaline to neutral, depending on the type of raw material. Table 2 supports this observation, showing a pH range between 8.24 and 7.34, which may make methacompost a beneficial fertilizer for the agronomic development of vegetable crops.

Table 1. Chemical composition of various formulations based on MP, NPK, and soil.

	Elements	Soil	MP100%	NPK50%-%P50%	MP50%	NPK25%-MP75%	MP75%	MP25%	MPK75%-MP25%
	H (%)	0.83	8.51	5.97	97.93	8.19	7.65	8.43	8.58
	MS (%)	99.16	91.49	94.03	2.06	91.81	92.35	91.57	91.42
	MO (%)	1.27	0.08	0.12	0.05	0.06	0.061	0.03	0.19
	pH	6.43	7.6	7.73	7.53	7.56	8.24	7.53	7.34
	NH_4^+ ml/L	689.29	28132	29992	10802.67	38867.33	14376.67	8523.33	6002
Macro-elements	**NO_3^- (ml/L)**	8.24	252.67	203.33	236	254.67	262	238	260
	PO_4^{3-}(ml/L)	4.03	256	528	246	466	284	126	682.67
	K^+(mg/L)	30.91	1944.15	4307.03	912.80	360.20	3448.17	1125.37	5530.383
Secondary elements	**Mg^{2+}(mg/L)**	39.98	3.17	0.37	0.00	0.75	0.00	0.00	0.00
	Ca^{2+}(mg/L)	196.19	343.18	25.27	125.28	113.75	49.43	73.10	44.75
	Fe^{2+}(mg/L)	7153.66	25.78	10.51	14.24	4.60	27.34	10.75	4.45
	Mn^{2+}(mg/L)	39.98	3.17	0.37	0.00	0.75	O.00	0.00	0.00
traces elements	**Zn^{2+}(mg/L)**	2.75	5.40	0.78	0.73	0.87	0.72	0.62	0.37
	Cu^{2+}(mg/L)	1.59	1.15	0.34	0.64	0.29	0.00	0.33	0.50
	Al^{3+}(mg/L)	2132.87	6.15	2.07	0.51	0.39	2.64	1.88	1.04
heavy metals	**Cd(mg/L)**	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Hg(mg/L)	8.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Pb(mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

3.2. The effect of methacompost on growth factors

The number of leaves, leaf width, and tendril count, presented in Tables 2, 3 and 4, are factors that allow for easy measurement of cucumber growth. The number of leaves increases proportionally with leaf width, while the number of tendrils indicates the physiological stage of growth.

Table 2. Effect of different fertilizers on cucumber at the 15th day.

Treatments	15 days after emergence	
	Number of leaves	**Leaf width (cm)**
control	2 ± 0.27a	6.8 ± 1.38a
NPK100%	2 ± 0.00b	7.4 ± 0.63b
Methacompost100%	3 ± 0.39c	8.8 ± 1.76c
NPK50%-methacompost50%	3.2 ± 0.43dbi	9.96 ± 1.38d
Methacompost50%	3 ± 0.28eb	9.22 ± 0.94e
NPK25%-methacompost70%	3 ± 0.39f	9.98 ± 1.76f
Methacompost75%	3.2 ± 0.33gai	11.28 ± 0.91ga
Methacompost25%	2.6 ± 0.21hbc	10.5 ± 0.59h
NPK75%-methacompost25%	1.6 ± 0.21icef	6.72 ± 1.35ie
Least Significant Difference	0.18	0.01

Table 3. Effect of different fertilizers on cucumber at the 25th day.

Treatments	25 days after emergence		
	Number of leaves	**Leaf width (cm)**	**Number of tendrils (cm)**
control	2.8± 0.7a	13.1 ± 3.2ah	0.2 ± 0.17a
NPK100%	3.8 ± 1.18b	20.3 ± 1.41b	0.4 ± 0.35b
Methacompost100%	5.4 ± 0.81c	22.66 ± 0.84caf	1.8 ± 0.97c
NPK50%-methacompost50%	5± 0.39dab	21.28 ± 0.60d	2.4± 0.9d
Methacompost50%	5.6 ± 0.71ea	18.12 ± 0.40ecdh	1.6 ± 0.86e
NPK25%-methacompost70%	5.2± 0.51fa	18.58 ± 0.40fdh	1.6 ± 0.71f
Methacompost75%	5.6 ± 0.45gabd	22.26 ± 1.66ga	2.2 ± 0.51gab
Methacompost25%	5 ± 0.45hab	22.26 ± 1.05hef	1.4 ± 0.53h
NPK75%-methacompost25%	5.2 ± 0.00i	19.12 ± 1.05ic	1 ± 0.55i
Smallest significant value	0.05	0.004	0.8

Table 4. Effect of different fertilizers on day 35.

Treatments	35 days after emergence			Number of flowers
	Number of leaves	**leaf width (cm)**	**Number of tendrils (cm)**	
Control	7.6± 2.19a	14.86 ± 3.56a	3.8 ± 1.16	1.2 ± 0.64
NPK100%	11 ± 0.92b	18.94 ± 1.68b	6.2 ± 1.01	4.2 ± 0.33
Methacompost100%	13 ± 1.64c	21.76± 1.13c	6.4 ± 0.59	6 ± 2.35
NPK50%-methacompost50%	13± 0.96d	23.74 ± 1.69d	7.4± 0.9	6 ± 2.35
Methacompost50%	12.6 ± 2.12e	21.8 ± 0.94e	5 ± 1.18	5 ± 1.14
NPK25%-methacompost70%	13.4± 1.831f	23.9 ± 0.97f	6.8 ± 0.70	6.4 ± 1.26
Methacompost75%	17.4± 2.65ga	23.76± 1.09gi	8 ± 0.88	8 ± 1.90
Methacompost25%	13.8 ± 0.94h	22.24 ± 1.08h	6.8 ± 0.64	5 ± 0.73
NPK75%-methacompost25%	13.8 ± 1.83i	17.72 ± 1.97if	6 ± 0.96	2.8 ± 0.85
Smallest significant value	0.15	0.03	0.21	0.2

After the first application, 15 days post-germination, the number of leaves was found to be statistically insignificant overall, and the t-test for two variances revealed a degree of homogeneity in the leaf count (Figure 5). Similarly, the number of leaves was not significantly affected after 25 days. However, plants fertilized with 100%, 75%, and 50% methacompost showed very similar results and a more advanced progression compared to other fertilization treatments (Figure 5). By day 35, although the number of leaves remained statistically insignificant, it was higher than that observed after the first two applications. The 75% methacompost treatment yielded the best results.

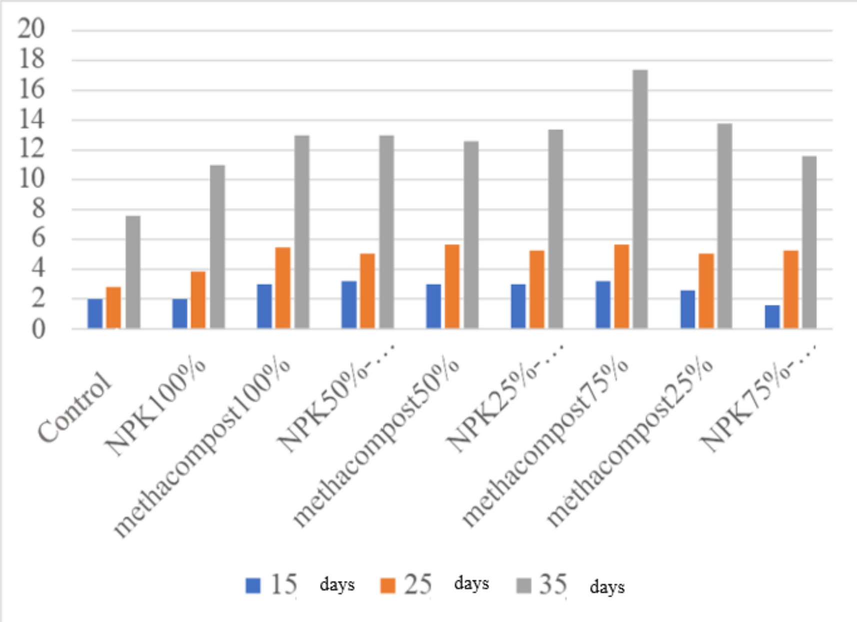

Figure 5. Number of sheets after 15, 25, and 35 days.

The various contributions on the 15th, 25th, and 35th days (Tables 2, 3 and 4) demonstrated that leaf width was highly variable. A significant change was observed starting from the 25th day, particularly with the following treatments: NPK50% + methacompost50%, NPK25% + methacompost75%, and methacompost75%. Additionally, treatments with 100% methacompost, 25%, and 100% NPK also exhibited notable changes.

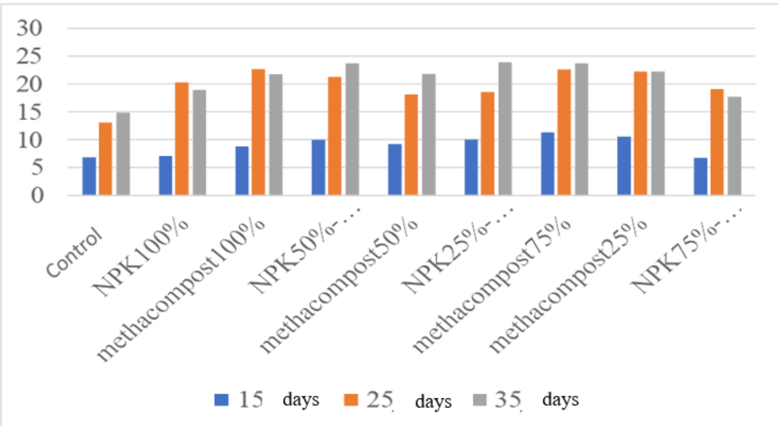

Figure 6. Leaf width after a series of 15, 25, and 35 days.

In the second application (Table 3), the tendrils had already begun to appear. Their number was not significant on the 15th and 25th days. However, as shown in Figure 6, the treatment with 75% methacompost exhibited the best performance, closely resembling the results obtained with the 50% NPK + 50% methacompost mixture. Subsequently, the treatments with 100% methacompost, 25% methacompost, and 25% NPK + 75% methacompost demonstrated comparable results.

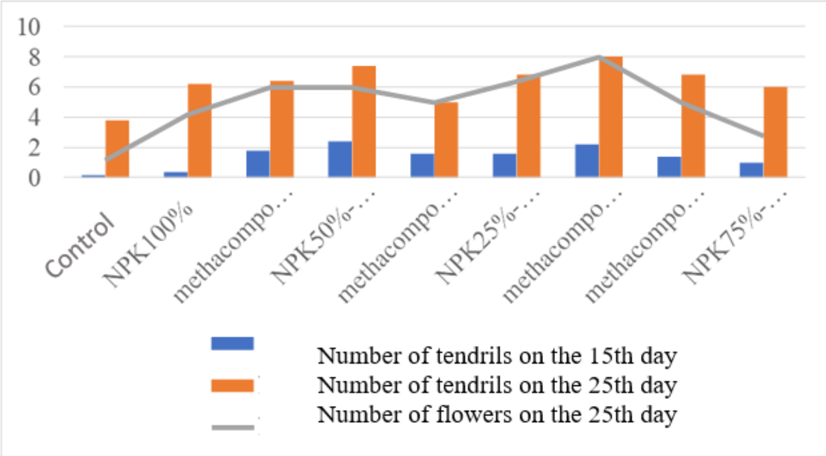

Figure 7. Appearance of spiral numbers after 25 and 35 days.

The results of the various analyses indicate that the methacompost significantly influenced the physiological stage of cucumber plants, as evidenced by the number of leaves (Figure 5), leaf width (Figure 6), and the number of tendrils and flowers (Figure 7). During the initial application, the absence of a significant variance in the number of leaves may be attributed to the developmental stage of the plants, which has not yet allowed for optimal nutrient absorption, or to an insufficiency of available nutrients in the soil.

Nitrogen is often the most deficient nutrient in the soil [30]. Compared to the various formulations (Table 1), nitrogen availability in the soil can affect absorption, which also depends on the developmental stage of the plants and biochemical processes such as respiration, photosynthesis, and protein synthesis. Nitrogen is particularly crucial for non-leguminous plants like cucumber. Taylor et al. [31] assert that digestate is an excellent source of available nitrogen (NH_4^+), which is quickly nitrified and assimilated by the plant. They add that phosphorus can complement the soil supply, and the use of digestate should primarily focus on nitrogen and phosphorus [22].

Regarding mineral fertilizers, the presence of macroelements (N, P, K) as well as secondary elements like S, Mg, and CaO is essential. All formulations used contain these elements. Baghoun et al. [32] and Guohua et al. [33] confirm that the availability of these elements is critical for the development of the number of leaves and leaf width [32, 33].

In general, good growth results were achieved with partial methacompound use, particularly at 75%, 50%, and 25%, with the 75% methacompound treatment being particularly effective. Buligon et al. [34] support the idea that these results may be due to the superior quality of the methacompound compared to NPK 15-15-15, suggesting that digestate could partially or fully replace synthetic fertilizers. De Groot et al. [35] and Cernusak et al. [36] also report an increase in the number of leaves within a two-week period, attributed to the availability of nitrogen and phosphorus. Akpan et al. [13] obtained similar results with poultry manure, but composting time is a key factor, which is not the case for methacompound. Annex 2 presents images illustrating the effects of methacompound on cucumber plants after treatment.

3.3. Performance evaluation

The results of the variance analysis presented in Table 5 show that the number of fruits per plant, as well as the length and diameter of the fruits, vary significantly ($p < 0.05$) between treatments. Figure 7 illustrates that the most effective treatment for the number of fruits per plant is the one with 50% NPK and 50%

methacompost, followed by the 25% NPK and 75% methacompost treatment, and then the 100%, 75%, and 25% methacompost treatments. Regarding fruit length, the control and 100% NPK treatments yielded poor results, with a similar trend observed for fruit diameter. The 75% methacompost formulation produced the highest yield (27,200 kg/ha), followed by the 25% NPK and 75% methacompost treatments, as well as the 100%, 75%, and 25% methacompost treatments, which also showed good yields.

The results indicate a significant improvement in cucumber yield with methacompost and NPK fertilizer formulations. The increase in yield observed with poultry manure after mineralization is likely due to a vigorous vegetative phase during growth [37, 38]. Oke et al. [11] suggest that good yield and high fruit numbers result from the soil's water retention capacity and the availability of nutrients in the methacompost, leading to accelerated metabolism and meristematic tissue division. Furthermore, a high number of leaves promotes light capture and photosynthesis, thereby contributing to better yield. Agu et al. [12] confirm this proposal by emphasizing the significant role of NH_4-N.

Costa et al. [39] assert that yield is influenced not only by high NH_4-N levels but also by rapid nitrification and efficient absorption of trace elements, which facilitate metabolic reactions. Buligon et al. [34], as well as Lamolinara et al. [40], support the notion that the total or partial replacement of synthetic fertilizers with methacompost can explain the obtained results.

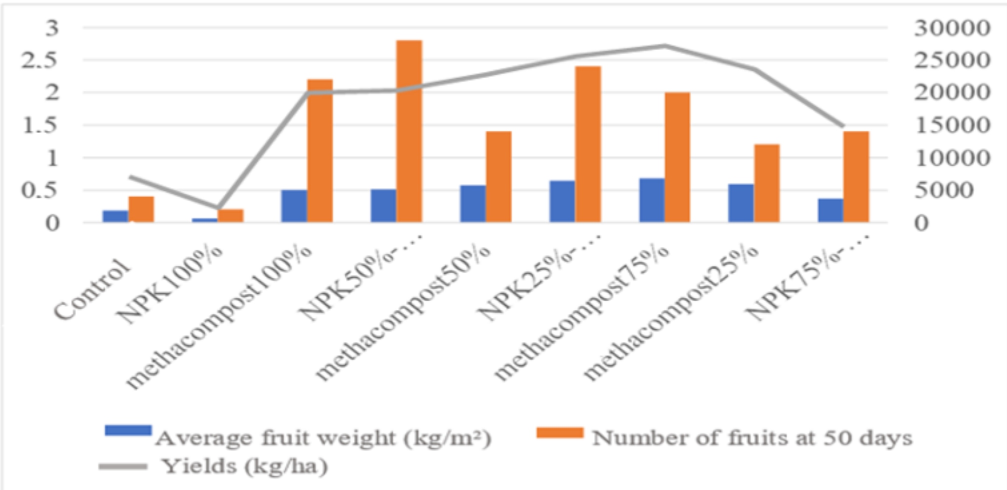

Figure 8. Measurement of performance parameters for a harvest.

In light of the discussion, the results confirmed that methacompost has significant agronomic value. Due to its availability of ammoniacal nitrogen, methacompost emerges as an effective organic fertilizer, which can be used as a complete or partial substitute (1/4, 1/2, or 1/3) for vegetable crops.

The means with the same alphabetical letter indicate that they are significant, according to the t-test.

Table 5. Effect of different fertilizers on yield.

Treatments	50 days after emergence			
	Number of fruits	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight
Control	0.4 ± 0,21a	5 ± 4.86a	8.2 ± 4,42a	0.18 ± 0.11a
NPK100%	0.2 ± 0.18bh	3.8 ± 3.3b	3.7 ± 3.2b	0.06 ± 0.05b
Methacompost100%	2.2 ± 0.18cb	24.6 ± 1.31cab	21.46 ± 0.55cab	0.5± 0.07cb
NPK50%-methacompost50%	2.8 ± 0.33da	22.4 ± 1.02dab	21.2 ± 0.74dab	0.51 ± 0.03dab
Methacompost50%	1.4 ± 0.35eb	21 ± 4.83eb	18 ± 4.03eb	0.57 ± 0.16eb
NPK25%-methacompost75%	2.4 ± 0.53fa	25.2 ± 1.34f	22.2 ± 0.70fab	0.64 ± 0.06fab
Methacompost75%	2 ± 0.55gb	27.2± 1.69gab	21.8 ± 0.33gab	0.68 ± 0.09gab
Méthacompost25%	2 ± 0.18 hab	25 ± 1.32hb	22.2 ± 0.85hab	0.59 ± 0.05hab
NPK75%-methacompost25%	1.2 ±0.35iab	17.6 ± 4.06ia	15.8 ± 0.347i	0.37 ± 0.09ibgf
Smallest significant value	0.0003	0.00002	0.0003	0.0005

4. Conclusion

The objective of this study was to assess the agronomic effectiveness of methacompost derived from laying hen manure as an organic fertilizer for cucumber (*Cucumis sativus* L.) cultivation under the pedoclimatic conditions of the Gontougo region (Côte d'Ivoire). Specifically, the study aimed to compare various methacompost formulations, both alone and in combination with NPK mineral fertilizer, to determine their impact on vegetative growth and yield.

The results of this study confirmed the potential of methacompost as a highly effective soil amendment. Treatments MP75%, MP50%, MP25%, as well as the NPK50% + MP50% combination, resulted in significant improvements in vegetative growth and yield. The MP75% treatment achieved the highest yield of 27,200 kg/ha, followed by NPK25% + MP75% (26,100 kg/ha) and MP100% (25,000 kg/ha), all of which surpassed both the absolute control and the NPK-only treatment (24,700 kg/ha).

These improved performances can be attributed to the high ammoniacal nitrogen (NH_4^+) content of the methacompost, a form that is readily assimilable by plants, as well as its organic matter content, which enhances soil structure and biological activity.

However, this study is limited to a single growing cycle and does not include a long-term evaluation of soil dynamics. Further research, incorporating microbiological analysis and extended monitoring over multiple agricultural seasons, is necessary to validate the sustainability of the observed effects.

In conclusion, the use of methacompost as an organic fertilizer represents a credible and sustainable alternative to mineral fertilizers in vegetable production systems in Sub-Saharan Africa. It aligns with circular economy principles and agroecological transition strategies, contributing to the valorisation of livestock organic waste and enhancing the resilience of local agroecosystems towards a more circular and sustainable agricultural future.

Acknowledgements

The authors thank the Fund for Science, Technology, and Innovation (FONSTI) of Côte d'Ivoire and the International Development Research Centre (IDRC) of Canada for funding this research work. The authors also express their sincere gratitude to CEA-VALOPRO of INP-HB, Yamoussoukro, Côte d'Ivoire, and the "Laboratoire de Biomasse Energie, Institut de Recherche sur les Energies Nouvelles, Université Nangui Abrogoua, Abidjan, B.P. 801, Abidjan 02, Côte d'Ivoire", for providing the necessary facilities for conducting the review work.

Conflict of interest

The authors declare no competing financial interest.

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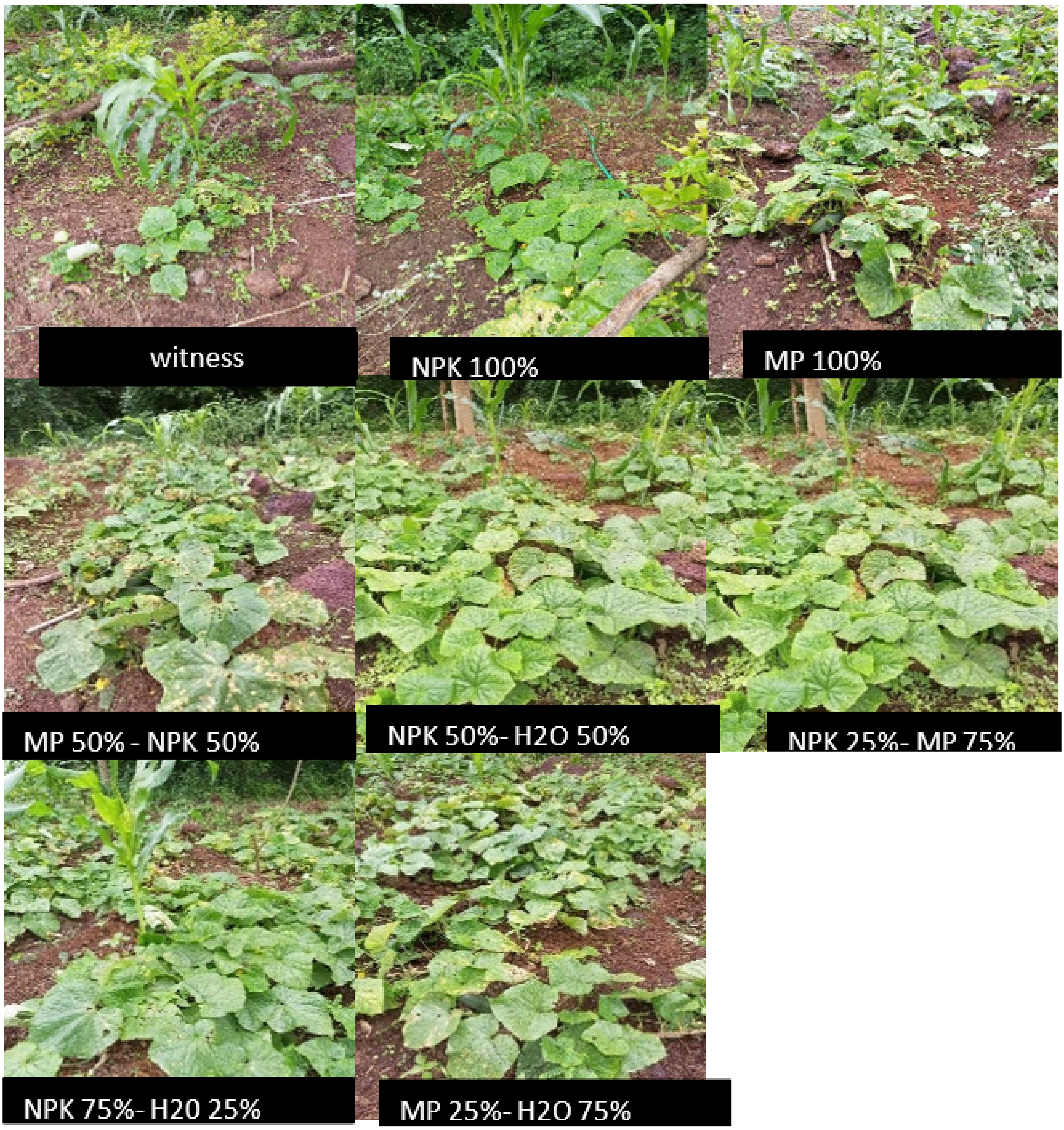
ANNEX



Presentation of the various plots according to the formulations at fruition.