



## RESEARCH ARTICLE

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# Analysis of Plant, Tuber, and Soil Samples for Fertilizer Comparison Controlled Release (CRF) and Conventional Crops Sweet Potato (*Ipomoea batatas* L.) on Sandy Soil

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## Abstract

Sweet potato (*Ipomoea batatas* L.) is an important food commodity, but its productivity often declines in sandy soils due to low cation exchange capacity and significant nutrient loss. The use of Controlled Release Fertilizer (CRF) offers an alternative to improve fertilization efficiency and maintain soil chemical stability. This research was conducted at MARDI, Serdang, Malaysia, with three treatments: conventional fertilizer, CRF, and a combination of CRF with microbial inoculum. Observed parameters included soil pH, electrical conductivity (EC), cation exchange capacity (CEC), nitrogen (N), phosphorus (P), potassium (K) content, and nutrient use efficiency (NUE). Data were analyzed using ANOVA with the GLM procedure in SAS 9.4, followed by LSD tests at  $P \leq 0.05$ . The results showed that CRF and CRF combined with microbial treatment increased soil pH from 6.05 to 6.22, CEC from 2.01 to 2.78 meq%, NUE from 31.64% to 94.17%, and dry plant weight to 268.38 g. The combination of CRF and microbes proved more effective in improving soil chemical properties, enhancing nutrient uptake, and increasing fertilization efficiency in sandy soils. These findings demonstrate that applying microbe-based CRF can sustainably increase productivity and are recommended for farmers working with sandy soils to optimize harvest yields while preserving soil fertility.

**Keywords:** Absorption Nutrient, Efficiency Nutrition, Productivity Plants, Soil Fertility, Sustainable Agriculture

## 1. Introduction

Sweet potato (*Ipomoea batatas* L.) is a commodities food important in tropical and subtropical regions that provide energy, vitamins, minerals, and compounds bioactive such as  $\beta$ - carotene which plays a role as precursor of vitamin A for health public. Variety orange-nucleated like VitAto known contains  $\beta$ - carotene tall so that potential developed as food functional For overcome vitamin A (Izalin Binti Mohamad Zahari et al., n.d, 2012) deficiency. However, the productivity of sweet potatoes in sandy soils is often hampered by low organic matter content, limited cation exchange capacity, limited water retention, and low nutrient availability, which makes fertilization a key factor in determining cultivation success.

However, the productivity of sweet potatoes on sandy

land is often hampered because of low organic matter, low cation exchange capacity (CEC), limited water-holding capacity, and low nutrient availability. This problem makes fertilization and nutrient management strategies key factors in the success of production. Study roomy indicates that sweet potato requires proper fertilization to maintain yields on land with light/sandy soils (Fernandes et al., 2020).

Inorganic conventional fertilizer (soluble, fast) indeed increases temporary nutrient availability, but excessive use can lower nutrient-use efficiency, accelerate nutrient loss through leaching, degrade long-term land quality, and pose a risk of water pollution. To overcome this matter, controlled-release fertilizer (CRF) technology was developed to release nutrients gradually in accordance with plant needs. Review and study experimental report that

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CRF can increase the efficiency of nitrogen use, reducing loss of N through washing on the ground, sandy, and stabilize the availability of macro nutrients so that support productivity term length and sustainability system production (Lawrencia et al., 2021)

According to Chmelikova et al. (2021), conventional systems of agriculture in Europe show far greater nitrogen efficiency, which is lower than that of organic systems, with accumulation of excess nitrogen that can pollute the environment. Besides that, research (Kang et al., 2022) shows that applying inorganic fertilizer alone can increase volatilization of ammonia ( $\text{NH}_3$ ) and reduce soil quality, especially on farmland with a light texture. This finding is strong evidence that conventional fertilizer is not only inefficient but also has a negative impact on the ecosystem. In the context of sustainable agriculture, findings: this becomes the basis for looking for more efficient, environmentally friendly fertilizer alternatives.

research by Faez et al. (2024) shows that a layered polymer fertilizer can distribute nutrients more evenly on the ground, improving nutrient availability for up to 60 days after application. In addition, Morrow et al. (2025a) report that CR-based use of polymers increases corn growth on the ground under light and increases nitrogen efficiency by up to 2 times compared to conventional fertilizers.

In sweet potato commodities, research related to the effectiveness of CRF is still limited, especially for varieties that are tolerant of sandy soils. Research on the effectiveness of Controlled Release Fertilizer (CRF) on sweet potato (*Ipomoea batatas* L.) is still very limited, especially on sweet potato varieties. Vitato is cultivated in sandy soil. Most previous studies focus on the influence of CRF on improving nitrogen efficiency and yield in field-grown plants under textured light. However, not yet many are studying comprehensively the characteristics of soil chemistry, nutrient absorption by plant tissues and tubers, as well as nutrient use efficiency (Nutrient Use Efficiency / NUE) through an integrated approach. The study conducted by Jalpa et al. (2024) in *HortScience* shows that the use of layered urea polymer as CRF on the ground sandy soil can increase nitrogen efficiency in general, significantly compared to the fertilizer late fast conventional.

Based on the background, the aim is to analyze and compare the effects of CRF and conventional fertilizer on sweet potato yields in sandy soil using a study sample of plants, tubers, and soil. Research results expected can serve as a reference for efficient fertilization management as well as support sustainable sweet potato cultivation.

## 2. Material and Methods

### 2.1. Place and Time of Research

Study This was carried out in the laboratory, Steel Technology, Research Center Soil, Water, and Steel Science at the Institute Research and Progress Malaysian Agriculture (MARDI), Serdang, Selangor, Malaysia, which

is located at coordinates  $3^{\circ}00'16''$  N and  $101^{\circ}42'48''$  E, with an elevation of  $\pm 59$  meters above sea level (masl). Research conducted from September 22 to October 10, 2025. From September 22 to October 10, 2025.

**Table 1.** Treatment Giving Fertilizer in BRIS/ Sand Land

Treatment	21 DAP	35 DAP	56 DAP
Control - Conventional (15:15:15 and 12:12:17:2)	200 kg/ha	200 kg/ha	200 kg/ha
T1 Green Coat (12:8:18:2)	300 kg/ha		
T2 Green Coat (12:8:18:2) + <i>BioPlus</i> ( $\rightarrow$ becomes T2)	300 kg/ha		

Table 1 shows the fertilization activity for cassava plants in the field under conventional care. On day 60, samples of cassava plants and bris soil were collected for analysis in the laboratory.

### 2.2. Materials and tools

Materials used sample BRIS/ Sandy soil, sample plants, distilled water, acid nitrate concentrated ( $\text{HNO}_3$ ), acid chloride concentrated (HCl), ammonium acetate ( $\text{CH}_3\text{COONH}_4$ ), potassium chloride (KCl), solution extraction phosphorus, sodium hydroxide (NaOH), methanol, acid borate, mixed indicator, reagent dye, paper filter (whatman).

Tools used include scales, analytical tools, test tubes, Erlenmeyer flasks, pipettes, leaching columns, ovens, hot plates, pH meters, conductivity meters (EC meters), UV-Vis spectrophotometers, ICP-OES, analytical tools for distillation, flame photometer, spatula, and glass measure.

### 2.3. Design Study

The design study will be analyzed using Analysis of Variance (ANOVA) through General Linear Model (GLM) procedures in the SAS (Statistical Analysis System) software version 9.4, developed by SAS Institute, Cary, North Carolina, USA. Analysis: This aim is to identify the influence of the treatment given on the observed variables. If ANOVA results show a significant difference, then further testing was carried out using the Least Significant Difference (LSD) method at the significance level  $P \leq 0.05$ . This test is used to compare mean values between treatments in a more in-depth way to determine which treatment provides results for the measured parameters.

### 2.4. Procedure Implementation Study

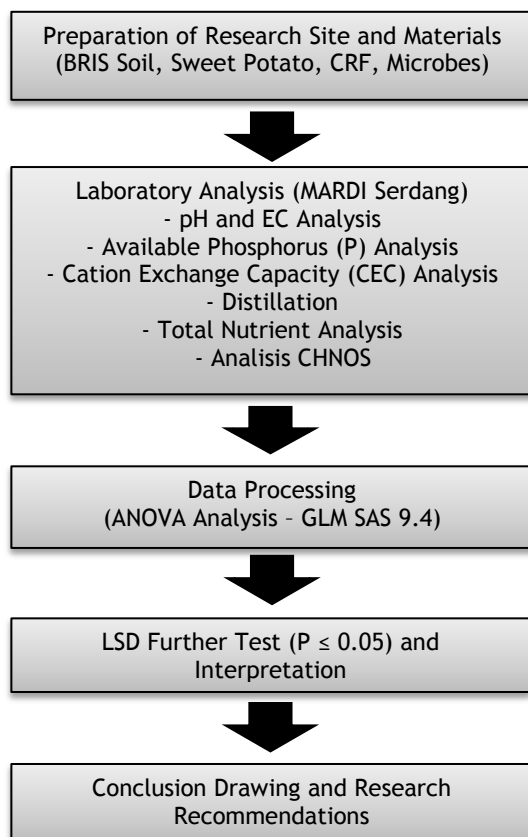
#### 2.4.1. pH analysis

pH analysis was performed by weighing 10 g of sample land, adding 25 ml of distilled water, stirring 40 times with a stirring glass, and leaving it overnight to reach equilibrium. The pH value of the solution was then measured using an existing pH meter calibrated with a standard buffer solution.

#### 2.4.2. Determination of electrical conductivity (EC)

Conductivity of soil (EC) is measured in solution using

the same sample as the pH measurement. After stirring, the solution was soil- and water-tested with the previous EC meter, calibrated. The tool is cleaned with distilled water after each measurement to prevent cross-contamination between samples.



**Figure 1.** Flowchart Procedure Study

#### 2.4.3. Analysis of phosphorus available

Analysis of available phosphorus was done by weighing 2 g of soil into a 100 mL Erlenmeyer flask. Sample extracted with 20 mL of 0.1 N HCl + 0.03 N  $\text{NH}_4\text{F}$  solution, then shaken for 1 minute and filtered using Whatman paper No. 2. The filtrate obtained, pipette 1 mL into a pumpkin, measure 25 mL, add reagent dye, and diluted until the sign limit. Absorbance solution measured in length 880 nm wavelength using a UV-Vis spectrophotometer with a curve standard phosphorus as a comparison.

#### 2.4.4. Determination Capacity Swap Cation (CEC)

To determine CEC, as much as 10 g of soil is mixed with 10 g of clean (acid-washed) sand, then placed in the leaching tube. The soil is extracted with 100 mL of ammonium acetate solution ( $\text{CH}_3\text{COONH}_4$ ) and left overnight. The tube was then rinsed with 100 mL of methanol, and 100 mL of solution KCl 0.1 N was added for exchange of  $\text{NH}_4^+$  ions. Solution results extraction used for CEC analysis.

#### 2.4.5. Distillation

Solution KCl results extraction was taken as much as 25 mL into a measuring cup, then 12–13 mL of 40% NaOH solution was added and distilled for 4 minutes. Distillate was accommodated in a solution of sour borate with indicator mix, then titrated with 0.05 N HCl until the color changed from green to red. Titrant volume noted as  $V_1$ , while the titration volume blank (without sample and land) was recorded as  $V_2$ . The CEC value is calculated based on the difference between  $V_1$  and  $V_2$  in accordance with the established formula.

#### 2.4.6. Analysis Determination of Total Nutrients

Analysis of total nutrient content in plant tissue was done using the wet destruction method. A total of 1 g of sample was dry-weighed into a test tube, then 10 mL of concentrated  $\text{HNO}_3$  was added and left overnight. The sample was heated to 110 °C until the solution became clear. 5 mL of concentrated HCl was added, and the mixture was heated back. After it cooled, the solution was filtered through Whatman No. 2 paper to a volume of 100 mL, then diluted with distilled water until the signal boundaries were reached, and data were collected using the ICP-OES instrument.

#### 2.4.7. CHNOS Analysis

CHNOS analysis uses a combustion method with an elementary CHNOS tool to obtain total elemental analysis. CHNOS analysis is performed by combustion using an elementary CHNOS tool to determine the total content of carbon (C), hydrogen (H), nitrogen (N), oxygen (O), and sulfur (S). The dry sample is weighed into a metal capsule, then completely burned at high temperature under an oxygen flow. The resulting combustion gas is flowed through a reduction column and detected using a thermal or infrared detector.

#### 2.5. Data analysis

Research data was analyzed using Analysis of Variance (ANOVA) with the General Linear Model (GLM) procedure on the device.

SAS software (Statistical Analysis System version 9.4, SAS Institute, Cary, NC). This analysis aims to determine whether there is a significant difference between the treatments administered. If a significant difference is found, the average values between treatments will be compared using the Least Significant Difference (LSD) test at the  $P \leq 0.05$  significance level to determine whether the differences are statistically significant.

### 3. Results and Discussion

Research results show that the use of controlled-release fertilizer (CRF), combined with microbial inoculum, influences the chemical characteristics of soil in sandy ground where sweet potatoes are grown. CRF treatment can

improve soil pH and cation exchange capacity (CEC) and maintain nutrient stability compared to conventional fertilizers. The chemical parameter values for each treatment are presented in Table 2 below.

**Table 2.** Soil Chemical Properties at 60 Days of Sweet Potato Plant Age for Each Treatment

Treatments	Soil Chemical Characteristics										
	pH	EC (µs)	N (%)	C (%)	Avail-P (ppm)	Exch-K (meq %)	Exch-Ca (meq %)	Exch-Mg (meq %)	Exch-Al (meq %)	Total Fe (mg/kg)	CEC (meq %)
Conventional	6.05 ± 0.12 <sup>b</sup>	35.67 ± 1.05 <sup>a</sup>	0.36 ± 0.02 <sup>a</sup>	1.51 ± 0.08 <sup>a</sup>	26.22 ± 0.94 <sup>a</sup>	0.23 ± 0.01 <sup>a</sup>	1.02 ± 0.04 <sup>b</sup>	0.42 ± 0.03 <sup>a</sup>	0.07 ± 0.01 <sup>a</sup>	14.12 ± 0.25	2.01 ± 0.10 <sup>a</sup>
T1: GreenCoat	6.12 ± 0.11 <sup>ab</sup>	29.37 ± 1.12 <sup>a</sup>	0.42 ± 0.03 <sup>a</sup>	1.67 ± 0.09 <sup>a</sup>	21.76 ± 1.02 <sup>a</sup>	0.26 ± 0.02 <sup>a</sup>	1.82 ± 0.05 <sup>a</sup>	0.45 ± 0.04 <sup>a</sup>	0.06 ± 0.01 <sup>a</sup>	14.13 ± 0.28	2.67 ± 0.12 <sup>a</sup>
T2 <sup>''</sup> GreenCoat + Inoculum Microbes	6.22 ± 0.10 <sup>a</sup>	37.74 ± 1.08 <sup>a</sup>	0.49 ± 0.04 <sup>a</sup>	1.71 ± 0.07 <sup>a</sup>	24.01 ± 0.85 <sup>a</sup>	0.28 ± 0.01 <sup>a</sup>	1.73 ± 0.04 <sup>a</sup>	0.48 ± 0.02 <sup>a</sup>	0.07 ± 0.01 <sup>a</sup>	15.16 ± 0.22	2.78 ± 0.09 <sup>a</sup>

Note: \*Values with the same letter show no significant differences in levels of significance, P < 0.05.

**Table 3.** Study of Determining the Effect of Fertilizer Application on Nutrient Absorption in Plants

Treatment	Stem			Sweet potato			Amount ( Stem + sweet potato)		
	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Conventional	0.72 ± 0.03 <sup>b</sup>	0.88 ± 0.05 <sup>a</sup>	1.62 ± 0.08 <sup>b</sup>	4.32 ± 0.10 <sup>a</sup>	3.76 ± 0.09 <sup>a</sup>	6.12 ± 0.15 <sup>a</sup>	5.04 ± 0.11 <sup>b</sup>	4.64 ± 0.10 <sup>b</sup>	7.74 ± 0.20 <sup>b</sup>
T1: GreenCioat	1.53 ± 0.05 <sup>a</sup>	1.45 ± 0.04 <sup>a</sup>	1.83 ± 0.07 <sup>a</sup>	4.48 ± 0.12 <sup>a</sup>	3.89 ± 0.11 <sup>a</sup>	7.13 ± 0.18 <sup>a</sup>	6.01 ± 0.13 <sup>a</sup>	5.34 ± 0.10 <sup>a</sup>	8.96 ± 0.19 <sup>a</sup>
T2: GreenCoat + inoculum Microbes	1.64 ± 0.04 <sup>a</sup>	1.42 ± 0.05 <sup>a</sup>	1.92 ± 0.06 <sup>a</sup>	4.86 ± 0.14 <sup>a</sup>	3.87 ± 0.10 <sup>a</sup>	6.66 ± 0.17 <sup>a</sup>	6.50 ± 0.12 <sup>a</sup>	5.29 ± 0.11 <sup>a</sup>	8.58 ± 0.21 <sup>a</sup>

Note : \*Values with the same letter show no significant differences in levels of significance, P < 0.05.

**Table 4.** Nutrient Use Efficiency (NUE) Values in Stems and Tubers to Determine the Effect of Fertilizer Application on Plants

Treatment	Stem	Sweet potato	Amount ( Stem + sweet potato)		
	Heavy Dry (g)	Heavy Dry (g)	Heavy Dry (g)	Amount of nutrients application (g/ main)	NUE (%)
Conventional	100.68 ± 2.14 <sup>a</sup>	100.25 ± 3.05 <sup>a</sup>	200.93 ± 4.88 <sup>b</sup>	6.35	31.64 ± 1.15 <sup>b</sup>
T1: GreenCioat	113.23 ± 2.25 <sup>a</sup>	151.72 ± 2.94 <sup>a</sup>	264.95 ± 5.12 <sup>a</sup>	2.85	92.97 ± 2.08 <sup>a</sup>
T2: GreenCoat + inoculum Microbes	120.15 ± 2.01 <sup>a</sup>	148.23 ± 3.22 <sup>a</sup>	268.38 ± 4.95 <sup>a</sup>	2.85	94.17 ± 2.02 <sup>a</sup>

Note : \*Values with the same letter show no significant differences in levels of significance, P < 0.05

Based on the data analysis, treatment with controlled-release fertilizer (CRF), alone or in combination with microbial inoculum, significantly improves soil chemical properties, enhances plant nutrient absorption, and increases nutrient use efficiency compared to conventional fertilizers.

### 3.1. Improvement of Soil Chemical Quality

It is known that soil pH and CEC indicate greater improvement in CRF treatment than in the control. An increase in pH indicates that the reaction is acid-base neutralization and is progressing. Things. Because nutrients are released both in controlled and uncontrolled manners,

an initial nutrient surge often occurs. Analysis results show that the use of controlled-release fertilizers (CRF) T1 and T2 increases soil pH and cation exchange capacity (CEC) more than conventional fertilizers. The soil pH in the conventional treatment reached only 6.05, while it increased to 6.12 in T1 and 6.22 in T2. Meanwhile, the CEC value increased from 2.01 meq% in the conventional treatment to 2.67 meq% in T1 and 2.78 meq% in T2. These increases demonstrate that the CRF system can improve soil chemical quality by stabilizing pH and enhancing the soil's ability to retain cations.

Besides that, the available phosphorus content is relatively more stable in the CRF treatment, measured at

21.76 ppm (CRF) and 24.01 ppm (CRF + microbes), compared to 26.22 ppm in the control. Although the available phosphorus value in the control is slightly higher, this condition indicates a greater release potential, leading to greater element loss through leaching. Govil et al. (2024) reported that in CRF-based experiments using polymer coatings, the available phosphorus content increased by approximately 8–12% and remained sustainable for 60 days after planting, whereas conventional fertilizers showed a sharp decrease of more than 30% due to leaching. Thus, the results of this study demonstrate a similar pattern, in which CRF maintains phosphorus stability more effectively, with fluctuations of only around 10%.

### 3.2. Improvement of Absorption Nutrients by Plants

From the results table, study chemistry land shows that Plants in the CRF (and CRF + microbe) treatments absorbed more N, P, and K than the control. The data in Table 3 show improved absorption of nitrogen (N), phosphorus (P), and potassium (K) in plants and tubers with CRF treatment. Total N uptake increased from 5.04% conventional to 6.01% at T1 and 6.50% at T2. P uptake increased from 4.64% to 5.34% T1 and 5.29 % T 2, while increased K absorption from 7.74% to 8.96% T1 and 8.58% T2.

Ascension: This shows that CRF is capable of releasing appropriate nutrients that plants need, so that absorption is ongoing more efficiently. Additionally, the increased N content in leaves, from 0.72% to 1.64%, indicates that the plant can maintain nutrient supply until the end of the vegetative phase. This finding aligns with the results of Lawrenca et al. (2021), who found that CRF can increase N use efficiency and reduce lost consequence washing.

### 3.3. Efficiency Nutrient Utilization (NUE) and Biomass

Analysis results: Controlled Release Fertilizer (CRF) treatment showed significant improvement in nutrient use efficiency compared to the treatment control, as reflected in the increase in heavy dry plants. Efficiency: Nutrient use or NUE indicates a drastic difference between treatments. Research results show that the use of Controlled Release Fertilizer (CRF) increases nutrient utilization efficiency (NUE) from 31.64% (control) to 92.97% and 94.17%, and increases the heavy dry plant from 200.93 g to 264.95 g and 268.38 g. In quantitative terms, this increase is equivalent to 2.9 times the efficiency of the conventional treatment. The findings are consistent with the report (Lawrenca et al., 2021) that states it can increase efficiency up to 2–3 times Thus, the results of the study This finding shows that a combination of CRF + microbes give improvement in nutrient and weight efficiency, dry more plants 20-40% higher compared to the average value of improvement in research previously. This confirms that CRF based on microbes is superior in terms of repair

efficiency, nutrient uptake, and plant growth on sandy soils.

### 3.4. The Role of Inoculum Microbes in Combination with CRF

The combination of controlled-release fertilizer (CRF) and microbial inoculants delivers superior performance compared to CRF alone. The presence of microbes plays a crucial role in soil structure repair, enhances enzyme activity, mobilizes phosphate, and, in many cases, contributes to nitrogen fixation, thereby optimizing nutrient absorption by plants. The use of CRF combined with microbial inoculum (T2) consistently yields better results than CRF alone (T1). Quantitatively, these findings align with those of Samantaray et al. (2024), who reported that bioinoculum-based microbes can increase plant nitrogen uptake by 25–40% and biomass production by 30–35%, primarily through nitrogen fixation mechanisms involving genera such as *Rhizobium*, *Azotobacter*, and *Bacillus*. In addition, inoculated microbes have been shown to increase soil activity and phosphorus availability by secreting organic acids, thereby increasing fertilization efficiency significantly. Based on the results, N uptake increased by 29% and biomass by 33.6% in the study. This finding aligns with the range of the same effectiveness, even A little more, compared to the average increase reported by (Samantaray et al., 2024)

Additionally, Li & Li (2024) confirm that combination fertilizer off controlled (CRF) with biological agents, such as microbes, is a trend in global research, as it can increase nitrogen nutrient efficiency by 2-3 times compared to conventional fertilizer. Therefore, the results of this study, in a sense, demonstrate a synergistic performance between CRF and microbes in the land, which not only increases nutrient efficiency but also enhances the fertility and sustainability of the agroecosystem.

### 3.5. Limitations of the Application Field and Challenges in the Development of Microbial CRF

Although the combination of Controlled Release Fertilizer (CRF) and microbes can increase fertilizer efficiency, its application in the field is still limited by environmental factors and the stability of the coating material. (Suwardi et al., 2023) report that on the ground sandy, 40–60% of the ammonium nitrogen ( $\text{NH}_4 - \text{N}$ ) from CRF is released in two Sunday first and descending become almost 0% in the 14th week, whereas nitrate ( $\text{NO}_3 - \text{N}$ ) increases up to 100% in the same period, indicating that texture land and rainfall Rain tall can lower nitrogen efficiency (NUE) of 25-30% due to nutrient leaching. The results in line with findings (Morrow et al., 2025) which shows that in the condition field temperature height and rainfall Rain excess , rate release nutrients increased by more than 20% fast and NUE plants corn decreased by 30-35% compared to normal conditions , although results harvest increased by 18-25% compared to fertilizer

conventional . The second quantitative study shows that temperature and rainfall fluctuations can reduce CRF efficiency by up to one-third from the potential optimal level. Therefore, it is necessary to use a biodegradable coating with resilience to thermal stress, as well as inoculum-adaptive microbes , to condition the agroclimate for tropical agro-ecological CRF technology, enabling microbes to function at maximum efficiency and sustainability in the field.

### 3.6. Implications, Practical and Recommendations for the Development of Microbial CRF Technology

For agricultural practice, the use of controlled-release fertilizers (CRF), especially those coated with polymers or innovative materials, can help reduce the intensity of fertilizer application, minimize nutrient loss, and increase the actual efficiency of nutrient use. The combination of CRF with appropriate microbial inoculants can create a positive synergy, as microbes help utilize available nutrients that are still slowly released. When implementing this approach, it is essential to customize it according to the local climate and rainfall patterns to ensure that the benefits of CRF are not lost due to heavy rain or extreme heat. Further research is needed to test CRF and microbial combinations over extended periods (multi-season), across various land types, and to evaluate cost aspects and environmental sustainability, such as coating degradation and the impact of microplastics.

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## 4. Conclusion

Using controlled-release fertilizers (CRF), especially those combined with microbial inoculants, has been proven to increase soil pH, cation exchange capacity (CEC), nutrient uptake (N, P, K), and nutrient use efficiency (NUE), as well as significantly enhance dry plant biomass compared to conventional fertilizers. The combination of CRF and microbes can increase fertilization efficiency by nearly threefold while simultaneously improving the chemical quality of sandy soils. These results recommend the use of CRF combined with microbial inoculants as a sustainable fertilization strategy for farmers to increase productivity and maintain long-term soil fertility.

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