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Agro-Bio Tech

STUDY OF THE INFLUENCE OF CHARGED BIOCHAR ON NUTRIENT AVAILABILITY AND YIELD OF SWEETCORN IN TAMIL NADU STATE, SOUTH EAST OF INDIA

PIERRE DERNIER

MASTER THESIS PRESENTED FOR THE OBTAINING OF A DEGREE IN BIOENGINEERING IN AGRICULTURAL SCIENCES

ACADEMIC YEAR 2023-2024

CO-PROMOTERS: PR. BENJAMIN DUMONT & DR. MARIE DINCHER

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This research was conducted through a joint effort between the Water-Soil-Plant Exchanges axis, Plant sciences axis of the Faculty of Agro-Bio Tech at Gembloux, Liege University, and the AuroOrchard farm in Auroville and ADN LABORATORIES PRIVATE LIMITED in Puducherry. The student was supported by the Erasmus+ programme.

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Abstract

With the world's population set to reach 9.7 billion by 2050, and with the expansion of agricultural land limited, the challenges facing agriculture have never been greater. The agricultural sector will have to find new techniques to feed the world while not aggravating climate change. Another challenge will be to increase the resilience of crops to climate change. These challenges will be particularly important for small-scale producers in tropical regions, who are likely to be more affected than large-scale producers. The aim of this work was to study an economically viable and effective method for improving soil fertility on a farm in the state of Tamil Nadu, in south-east India. To do this, a field study was carried out to compare the effects of charged biochar with urine or compost tea and applied at 3t/ha or 10t/ha on soil nutrient availability and sweetcorn yield. The experiment showed that urine-charged biochar had potentially better effects than compost tea-charged biochar. It also showed that BU3 has effects that could be compared to those of BT10 and BU10. Further studies are needed to investigate the potential of charged biochar on a small scale in tropical conditions.

Résumé

Avec une population mondiale qui va atteindre 9.7 milliards de personne en 2050 et avec une expansion des terres agricoles limités, les défis agricoles n’ont jamais été aussi grands. Le domaine agricole va devoir trouver de nouvelles techniques afin de nourrir le monde tout en limitant ses impacts sur le changement climatique. Un autre défi va être d’augmenter la résilience des cultures face au changement climatique. Ces enjeux vont être surtout important pour les petits producteurs en région tropicale qui sont les plus vulnérables. Ce travail de fin d’études a été réalisé afin de trouver une méthode économiquement viable et efficace pour améliorer la fertilité du sol d’une ferme se trouvant dans le sud-est de l'Inde, dans l'état du Tamil Nadu. Pour cela, une étude en champs a été réalisée afin de comparer les effets du biochar chargé, à l'urine ou au compost tea et appliqué à 3t/ha ou à 10t/ha, sur la disponibilité des nutriments dans le sol et le rendement du maïs doux. Selon les résultats de l’expérience, le biochar chargé à l'urine a potentiellement de meilleurs effets que celui chargé au compost tea sur la fertilité. Elle a également permis de montrer que le BU3 a des effets qui pourraient être comparable à ceux de BT10 et BU10. D'autres études doivent être réaliser afin d'étudier le potentiel du biochar chargé à petite échelle en conditions tropicales.

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Abbreviations	
BMP	Best management practice
BT10	Charged biochar (10t/ha)+ Compost Tea
BT3	Charged biochar (3t/ha) + Compost Tea
BU10	Charged biochar (10t/ha) + Urine
BU3	Charged biochar (3t/ha) + Urine
CC	Climate change
CEC	Cation-exchange capacity
DAS	Days after sowing
PF	Ploughed field
PRB	Permanent raised bed
T0	Control (0t/ha of charged biochar)
RCW	Ramial chipped wood

I INTRODUCTION

I.1 Contextualization

I.1.1 Global food security challenges

The latest estimate from the UN indicates that the global population currently stands at 8 billion, with projections suggesting that it may reach 9.7 billion by 2050 (United Nations, 2022). This rise is resulting in a surge in global food demand. It is projected that global food demand will increase by between 59% and 98% by 2050. In order to meet the demands of an expanding global population, farmers worldwide must increase crop production (Elferink et al., 2016). As the expansion of agricultural land is constrained, the challenge will be to increase production on existing agricultural lands. This will require the adoption of new and innovative methods that improve soil fertility, water management and pest, weed, and disease control emphasizing in-field biodiversity (Rashmi et al., 2017; Sutradhar et al., 2021; Verburg et al., 2013). It is imperative that these innovations be implemented in a manner that mitigates the impact of agricultural activities on climate change (CC). In addition, it is important to find techniques to make crops more resilient to CC. There is a strong consensus among academics that CC-driven water scarcity, rising global temperatures, and extreme weather will have severe long-term effects on crop yields (Elferink et al., 2016). The FAO has estimated that the global average annual cost of direct agricultural losses due to disasters is approximately US$13 billion. The global agricultural sector is facing an increasing risk of disruption from natural disasters in the future (The impact of disasters on agriculture and food security 2023, 2023). The negative impact of CC could result in a reduction in the productivity of various crops by 3 to 7% for every one-degree rise in mean temperature, thereby increasing the risk of hunger and undernourishment. The consequences of CC are more pronounced in the case of small farmers than in that of large farmers (Baraj et al., 2024).

I.1.2 Agriculture in Tamil Nadu

In the period between 2010 and 2021, the majority of farmers in Tamil Nadu (Figure 1) were classified as small and marginal, representing 93% of the total number of farmers. The population of Tamil Nadu is predominantly agricultural, with over 56% of the population engaged in farming (Dr. G. Yoganandham, 2023). The main plantation crops of Tamil Nadu are rice, maize, banana, pulses, vegetables and fruit (Senthilnathan et al., 2022).

Figure 1 : Location of Tamil Nadu state in India ("Tamil Nadu - Agriculture, Industry, Services | Britannica," 2024).

As in India, organic farming in Tamil Nadu has seen significant growth in recent years (Kalyani et al., 2018; Paramasivam et al., 2022). In recent years, farmers' collectives have been established with the objective of coordinating agricultural production. (Neelam et al., 2022). Moreover, in 2019 the Indian government initiated a programme designed to advance traditional

indigenous practices. This programme is entitled “Bhartiya Prakritik Krishi Paddhati programme”. It aims to advance agroecological diversified farming systems that integrate crops, trees and livestock with functional biodiversity, thereby reducing reliance on externally purchased inputs. One of the main aims of the programme is to help farmers become self-sufficient. The latest figures indicate that the programme supported a mere 0.032% of the total crop area in Tamil Nadu in 2021 (BPKP, 5 August 2024; Neelam et al., 2022).

The majority of farmers and researchers posit that organic farming possesses certain qualities, while also expressing reservations about its suitability for Tamil Nadu's agricultural context (Kalyani et al., 2018). Indeed, the government is still struggling to support small farms and to take measures to replace input-intensive agriculture (Kalyani et al., 2018; Neelam et al., 2022). Other significant challenges to the advancement of organic agriculture in Tamil Nadu include the limited awareness and expertise among smallholder farmers, the lack of belief in the natural agriculture of partnerships and the logistical difficulties associated with accessing organic fertilisers (Kalyani et al., 2018; Neelam et al., 2022).

Nevertheless, the practice of organic farming has the potential to enhance the financial stability and well-being of farming communities over the long term. It promotes the development of integrated, long-term and sustainable systems that are environmentally and economically viable (Paramasivam et al., 2022). The sustainable system created by organic farming has the potential to mitigate the impact of a range of extreme natural elements, including rainfall, as observed during the monsoon season (Dr. G. Yoganandham, 2023).

I.1.3 The leaching of elements

In tropical climates like in Tamil Nadu, the rainy season is characterised by frequent rainfall and high precipitation levels, which result in deep drainage and leaching of soil elements (Duchaufour et al., 2020). The weathering and leaching of these elements in these climates lead to the depletion of permanent charge minerals, which in turn results in an accumulation of pH-dependent charge minerals, mainly iron and aluminium oxyhydroxides.

This implies that a proportion of the essential nutrients are being leached out of the soil profile and this can lead to a deficiency. Furthermore, the poor ability to retain nutrients is compounded by the presence of very low mineral reserves and soil organic matter content (Cissé et al., 2021; Duchaufour et al., 2020). In general, leaching occurs when mineralisation and absorption by the plant are not synchronised, and the water flow is sufficient to transport the solute to a depth where it can be transported (Rashmi et al., 2017). Upon leaching, the elements can be transported in the form of mineral ions and may also be transported in the form of organo-mineral complexes or as silts (e.g., 2 to 10 µm) or particles (e.g., clay < 2 µm) (Baize, 2016). The leaching loss of nitrate, phosphate and potassium below the root zone represents a significant loss of valuable plant nutrients. The leaching of other cations, such as calcium, magnesium and potassium, may be considerable under acidifying conditions when ammonia fertiliser is used. It is imperative that novel methodologies be devised to mitigate the adverse effects of leaching on agricultural output. (Naik et al., 2020 ; Randolph et al. 2017 ; Savci, 2012 ; Rashmi et al., 2017).

I.2 Biogeochemical cycling of nutrients

The nutritional elements that are required by the majority of plants in order to complete their life cycle are as follows: Carbon, oxygen, and hydrogen are incorporated into the vegetable tissues through the absorption of water by the roots and the incorporation of carbon dioxide through photosynthetic processes. In addition, plants require macro- and micronutrients, which are indispensable for their growth and development. The macronutrients are listed in Table 1 in the form in which they are available to the plant (Reichardt et al., 2020).

Table 1: Macronutrients and their available form inspired by Reichardt et al., 2020.

Macronutrients	Available form
Nitrogen (N)	NO_3^- and NH_4^+
Phosphorus (P)	$H_2PO_4^-$ and HPO_4^{2-}
Potassium (K)	K^+
Calcium (Ca)	Ca^{2+}
Magnesium (Mg)	Mg^{2+}
Sulphur (S)	SO_4^{2-}

The biochemical cycle of the five macronutrients studied is illustrated in Figure 2 (N, P, K, Ca, Mg). The solid fraction of the soil, comprising both mineral and organic matter, acts as a reservoir for nutrients essential for plant growth. Nutrients can be in assimilable form, which is directly available to the plant. This is in contrast to the reserve form, which is not available to the plant (Duchaufour et al., 2020). In order for a nutrient to be absorbed by the plant, it must be present in the soil solution and in contact with the active surface of the root system. In general, it can be stated that the primary factors influencing the transition from the M (solid) to the M(solution) phase are solubility and oxidation potential. Once in solution, diffusion and mass transport are the two processes responsible for transferring a nutrient from the soil to the plant. Diffusion is the transport of a nutrient from the soil to the plant due to gradients of chemical potential, which are measured by the activity of the ion in question in the soil solution. This occurs when the soil is unsaturated in water. Mass transport refers to the movement of ions carried along by the flow of water in the soil. This occurs when the soil is saturated with water (Duchaufour et al., 2020; Reichardt et al., 2020).

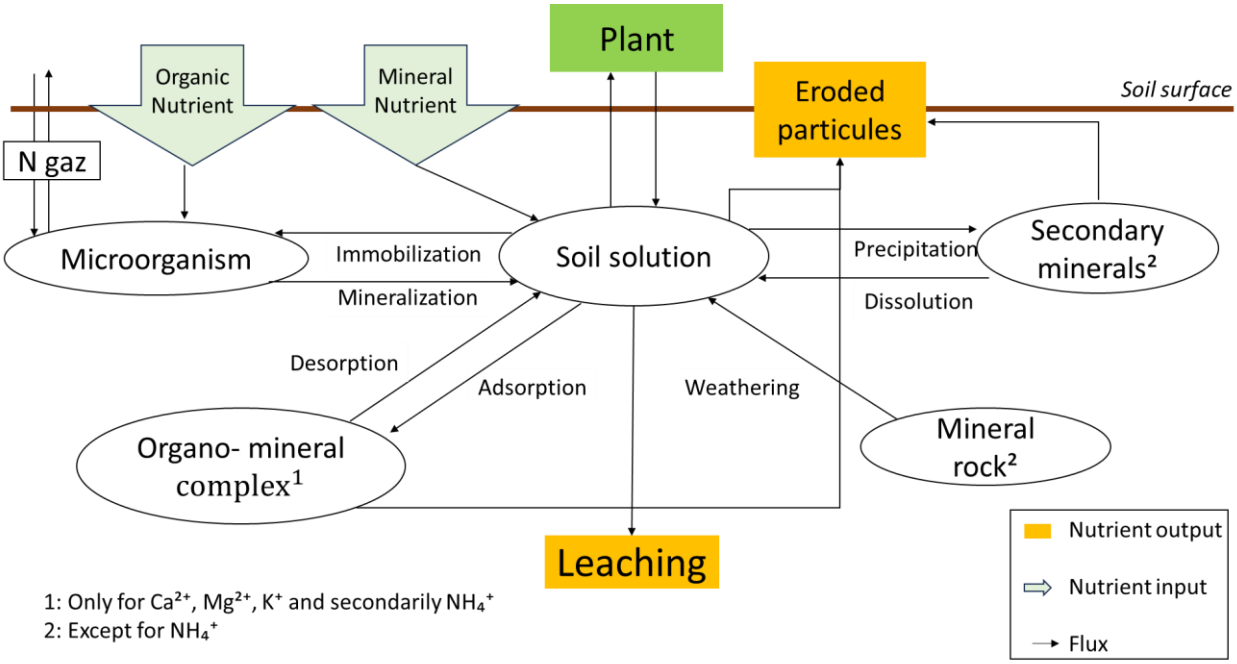


Figure 2: Biochemical cycle of studied nutrients (available form: NH_4^+ and NO_3^-, $H_2PO_4^-$ and HPO_4^{2-}, K^+, Ca^{2+}, Mg^{2+}) inspired by Duchaufour et al., 2020 and Reichardt et al., 2020.

I.3 Sweet corn

Sweet corn is a deep-rooted crop that requires a significant quantity of water and nutrients from the soil. Sweet corn is more susceptible to environmental stresses than grain corn. The corn plant is highly susceptible to both water stress and water excess during any physiological stage, which ultimately results in a reduction in yield (Pal et al., 2020; Tas et al., 2021).

Sweet corn (*Zea mays* L., convar. *saccharata* Koern.) is a variety of maize that contains a high concentration of sugar. The sweet corn variety results from a naturally occurring recessive mutation in the genes which control the conversion of sugar to starch inside the endosperm of the corn kernel (Canatoy, 2018; Singh et al., 2014). The harvesting of corn varieties is typically conducted when the kernels have reached a dry and mature stage (the dent stage). In contrast, sweet corn must be picked when the kernels are still immature (the milk stage) and prepared and consumed as a vegetable, rather than as a grain (Canatoy, 2018). The cultivation of sweet corn offers an economically opportunity, particularly given the high price

per ear. This makes it a suitable alternative to other forms of agricultural production in regions proximate to major urban centres and smaller-scale holdings (Mishra et al., 2018; Okumura et al., 2013). This crop is undergoing expansion in India. This growth can be attributed to three key factors: rising domestic consumption, the expansion of export markets, and the replacement of imported products (Pal et al., 2020; Singh et al., 2014). In 2020, sweet corn crop occupied an area of 11.9 million hectares with a production of 22.3 million tonnes in India (Pal et al., 2020; Singh, n.d.).

From a nutritional standpoint, sweet corn has been demonstrated to be the most demanding in terms of soil fertility, in comparison to common maize. The high sugar content, coupled with an intense metabolic rate and a shorter growth cycle, can be attributed to this greater demand for soil fertility. Conversely, the nutritional demands of both are comparable, with particular emphasis on nitrogen and potassium (Okumura et al., 2013). Table 2 presents four illustrative examples of the concentration of macronutrients in relation to the number of plants per hectare. The aforementioned values provide a general indication; however, it should be noted that the actual concentrations vary considerably depending on the specific growing conditions, varieties, and soil nutrient supply capacity (K D Subedi et al., 2011). In order to meet the nutritional requirements of sweet corn, it is essential to identify the most effective practices and alternative sources of chemical fertilisers. There has been a significant increase in the consumption of fertilisers globally, which has resulted in significant environmental issues (Savci, 2012).

Table 2: Productivity of grains and the accumulation of macronutrients in the aerial part of cultivars of common maize were obtained in four studies conducted in Brazil (Okumura et al., 2013). The data presented in each line represents the mean value obtained from a different study.

Number plants/ha	Grains	N	P	K
	kg/ha			
50,000	6,800	111.5	14.6	127.2
50,000	4,900	135.7	22.5	86.2
55,000	7,700	204	25	162
60,000	14,100	364	84	314

Number plants/ha	Grains	Ca	Mg	S
	kg/ha			
50,000	6,800	37.4	14.9	57.8
50,000	4,900	20.6	22.5	12.7
55,000	7,700	24	41	11
60,000	14,100	60.5	42	27

I.4 Best management practices

It is imperative that management practices be implemented to attenuate leaching losses of not only nitrogen but also other nutrients, with the aim of enhancing the efficiency with which nutrients are utilised in cropping systems. (Rashmi et al., 2017). Best management practices (BMP) were developed with the objective of reducing the loss of nutrients to the environment. Applying nutrients in the correct form, at the optimal dose, at the optimal time, and in the optimal location is a fundamental aspect of BMP for achieving optimal nutrient efficiency (Lam et al., 2011; Rashmi et al., 2017). A multitude of agricultural BMP can be employed to regulate diffuse source pollution. However, it is not possible to resolve leaching issues with a single type of BMP, as the individual practices do not typically provide the comprehensive control required at a given site. BMP to limit the leaching of nutrients include: soil samples to analyse the soil fertility conservation tillage cover crops, crop rotation practices that include legume crops, irrigation management, animal waste management, stream protection, nutrient management plans, etc (Farmaha et al., 2022; Hemantaranjan, 2014; Lam et al., 2011; Ward et al., 2018; Rashmi et al., 2017).

The application of organic fertilisers in conjunction with inorganic fertilisers is of significant importance in order to reduce the leaching of nutrients. The utilisation of slow-release fertilisers represents a pivotal strategy for the reduction of nutrient leaching. This is

achieved through the utilisation of organic fertilisers and the creation of additional adsorption sites, thus ensuring the retention of the applied mineral fertilisers (Kumar et al., 2020; Rashmi et al., 2017). Furthermore, the use of organic fertilisers has been demonstrated to enhance soil microbiology and fertility in both the short and long term (Sutradhar et al., 2021).

I.4.1 Biochar

I.4.1.1 Biochar production

Biochar is a highly porous and stable C-rich that is generated from the pyrolysis or thermochemical decomposition of organic material in an oxygen limited environment under controlled conditions (Gao et al., 2016; Kätterer et al., 2022; Saba et al., 2023). During pyrolysis, carboxyl and phenolic groups are decomposed, and properties like surface area, porosity, labile, or recalcitrance of chemical elements are altered (Kumar et al., 2020). Biochar can be made from several sources such as crop residues, manures, biosolid. Biochar nutrients could be less volatile, stable, and compact, which give room for its use as organic fertilizer (Kumar et al., 2020; Li et al., 2020).

I.4.1.2 Advantages and disadvantages of biochar

The impact of soil biochar application on crop yield varies across different geographical regions. In general, studies have reported a range of outcomes, from negative to positive, depending on the specific biochar type, soil type, and climate (Kätterer et al., 2022; Lai et al., 2024). However, there is a consistent trend of positive responses observed in studies conducted in subtropical and tropical regions (Kätterer et al., 2022).

The application of biochar to soil may contribute to climate change mitigation through the long-term carbon storage in soil that exceeds the residence time of classic organic amendments such as compost, manures, or raw crop residues or bulk soil organic matter.

It has been estimated that pyrogenic organic matter is 1.6 times more stable than bulk organic matter (Duchaufour et al., 2020; Kätterer et al., 2022; Schmidt et al., 2017). The slow degradation of biochar enhances soil properties by increasing soil organic carbon (SOC) and cation exchange capacity (CEC) (Randolph et al., 2017). Furthermore, biochar has a beneficial

impact on the efficiency with which fertilisers are utilised in soil. Biochar is capable of developing both negative and positive charges, suggesting that it is able to absorb either positively or negatively charged compounds. This enhances adsorption and decreases leaching more effectively than organic matter in soil (Das et al., 2022; Gao et al., 2016; Rashmi et al., 2017). Figure 3 provides a summary of the properties that are linked to nutrients for the plant.

Moreover, biochar has been demonstrated to enhance soil physical properties, including soil aeration, porosity, aggregate stability, bulk density, water holding capacity, hydraulic conductivity, and infiltration rate. Biochar may also enhance microbial abundance (Das et al., 2022; Gao et al., 2016; Kumar et al., 2020). It can mitigate the effects of drought, salinity, and heat stress during the plant growth period (Das et al., 2022). Furthermore, it can elevate soil pH due to its liming effect and the enhancement of base saturation, which is beneficial for acid soils (Cissé et al., 2021; Saba et al., 2023). Finally, it can reduce the bioavailability of contaminants to plants growing in contaminated soil, and can be widely applied for the adsorption of heavy metals and pollutants from wastewater (Duchaufour et al., 2020; Das et al., 2022; Patra et al., 2021).

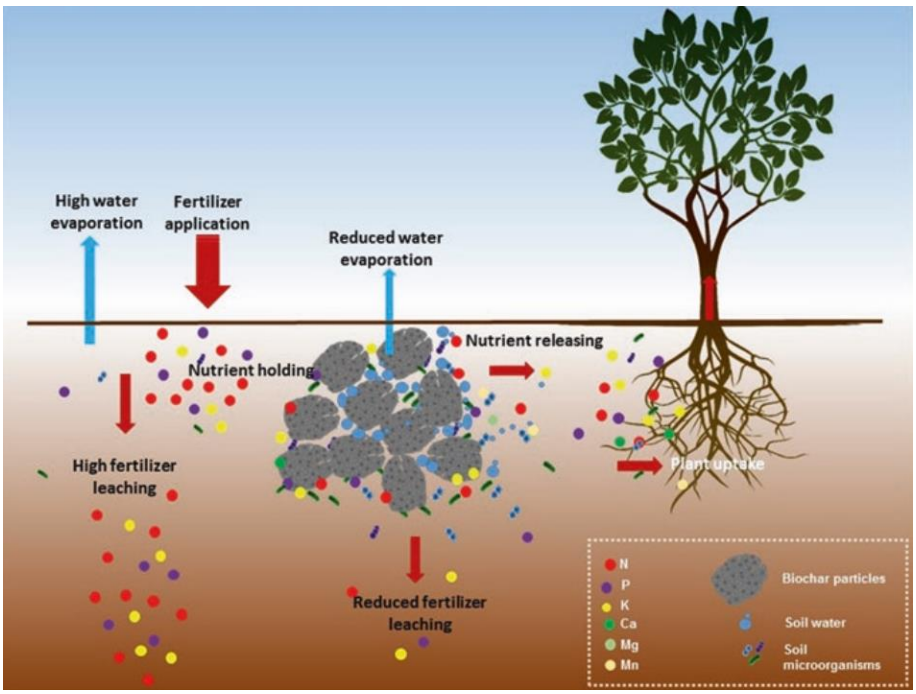


Figure 3: Possible effects of biochar on different parameters (Naeem et al., 2017).

Nevertheless, the long-term impact of biochar remains inconclusive. The potential negative impact on soil quality and the inability to remove the substance from the soil once it has been added are two significant factors to consider. For instance, biochar may encourage the loss of native soil organic matter, impede the efficacy of pre-emergent herbicides. Furthermore, the production of biochar can be highly polluting to the wider environment and detrimental to human health (Jones et al., 2012). Additionally, it may result in the stripping of forest areas for biochar production, which could lead to soil erosion and degradation (Jones et al., 2012; Kätterer et al., 2022). It is possible that excessive biochar may result in adverse consequences (Lai et al., 2024).

I.4.1.3 Biochar application rate

The positive effects of biochar on soils and crops were frequently observed in experiments utilising elevated application rates (between 10 and 50 t/ha) of biochar (Das et al., 2022; Schmidt et al., 2017). Biochar applied at higher rates (>10 t/ha) is not economically sustainable for small farming systems (Das et al., 2022; Hagemann et al. 2017). Indeed, the high application rates often exceed the availability of surrounding biochar feedstocks, thus rendering the practice unsustainable. Furthermore, the current high biochar cost may result in a very low return on investment, particularly when cropping cereals (Saba et al., 2023). According to Gao and al., (2016), a biochar application rate of less than 1 to 5 t/ha or more than 150 t/ha did not simulate significant yield increases.

I.4.1.4 Charged Biochar and pristine biochar

A number of experiments have indicated that the enrichment of biochar with fertilisers could result in a significant increase in yields and a reduction in nutrient losses when compared to non-enriched biochar, pristine biochar (Gong et al., 2019; Pandit et al., 2024; Saba et al., 2023; Schmidt et al., 2015). The biochar surface chemistry and high specific surface area permit the combination of the biochar charging process with liquid fertilisers, which is sometimes accompanied by the slow-release properties of nutrients. This allows for the gradual release of a small but steady amount of nutrients over time (Sutradhar et al., 2021). The present study examined the effects of charged biochar, prepared with the addition of urine and compost tea, on plant growth. The provision of these nutrient sources at a low cost allows small-scale farmers

to reduce their reliance on chemical fertilisers, thereby reducing the costs associated with fertilisers (Edenborn et al., 2018; Janjal et al., 2021).

The combination of urine and biochar will result in a reduction of the adverse effects of excess nutrients when urine is applied in isolation (Schmidt et al., 2015). Urine (of both animal and human origin) exhibits two distinctive advantages: firstly, it is ultra-filtrated, thereby enabling penetration even into the nanopores of biochar; secondly, it is a cost-effective and pervasive by-product (Schmidt et al., 2015). Nevertheless, the utilisation of human excreta for fertilisation is not a viable option for small-scale farmers due to the influence of cultural norms and the prevalence of sanitary concerns. The use of cow urine is less problematic and is already employed as a fertilizer (Mariwah et al., 2011; Sutradhar et al., 2021). The positive effects of cattle urine applications have been documented in a number of crops, including sweetcorn, with long-term use being a common practice in India (Jadhav et al., 2020). Compost tea, a liquid compound based on the diffusion of compost in water, can be prepared using a wide range of composts. The final characteristics of the compost are largely determined by the feedstock used, the processing method employed and the maturity of the compost (Bako et al., 2021; Pant et al., 2012). In contrast to composts, compost tea does not necessitate the transportation of substantial quantities of bulk composts over long distances. This is due to the fact that compost tea is typically produced on-site, or alternatively, compost concentration can be purchased (Bako et al., 2021). Finally, the use of compost tea to amend biochar has been proposed as a means of adding nutrients and beneficial microorganisms (Edenborn et al., 2018).

II OBJECTIVES OF THE STUDY

The principal objective of this study is to investigate the impact of biochar treated with cow urine and compost tea on soil nutrient availability and sweet corn yield under tropical conditions. The experimental design included two economically viable rates of application: 3 t/ha and 10 t/ha. The two types of biochar were produced locally. The experiment was realised on two different plots: permanent raised bed (PRB) and ploughed field (PF). The macronutrients that will be studied are: The following elements were analysed: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The following experimental objectives have been defined:

1. An assessment of the potential of charged biochar to enhance the accessibility of nutrients in the soil for the plant.
2. An assessment of the potential of charged biochar to enhance the sweet corn yield.
3. A comparison between the effect of charged biochar applied at a rate of 3t/ha and 10t/ha will be presented.
4. A comparative analysis of the impact of charged biochar in conjunction with urine or compost tea.
5. An evaluation of the potential of charged biochar to be utilised by small-scale farmers.

III MATERIALS AND METHODS

III.1 Study site

The experiment has been conducted in Auro-orchard, a 40 acres farm in Auroville, Tamil Nadu, Southern India (11°59'05.4"N 79°47'25.2"E). The farm was created in 1969 and has been converted into an organic farm since 2012. This farm is a mixed farming operation with 5 cows and over 2000 laying hens ("About us – AuroOrchard," n.d.). The native vegetation is a tropical dry evergreen forest. The area was cleared during the colonial period, resulting in the near-complete removal of vegetation 200 years ago. From the beginning of Auroville in 1968, Aurovilians were fully engaged in tree planting, organic farming and water conservation (Baldwin et al., 2011).

The average temperature is 27,8 ° C and the average annual rainfall is 1341 mm (Appendix 1). The cumulative rainfall recorded during the experiment was 20.39 mm distributed in 53 days ("AV Geomatics," May-3-2024). This period corresponds to the number of days that the sweet corn was left in the field. The climate is tropical savannah, classified as Aw by Köppen and Geiger (Peel et al., 2007).

III.2 Soil

The parent material is a red sandtone, from charnockite erosion, dating from Tertiaire (Middle Mio-Pliocene) (Lejoly et al., 2019). According to WRB, Soils are classified as Acrisol ("WRB_fourth_edition_2022-12-18.pdf," May-2-2024). A complete soil description is available in Appendix 2 for PRB, Appendix 3 for PF and Appendix 4 for a unused part of PF.

The primary experiment was conducted on permanent raised beds (PRBs). A soil analysis was conducted exclusively on the aforementioned field. Three random samples were obtained from the 0-20 cm and 20-40 cm depth intervals. Soil samples were collected using an auger. The samples were collected in accordance with the guidelines set forth by the Food and Agriculture Organization (*Guidelines for soil description*, 2006). The samples were collected

prior to the planting of the crops and to the application of charged biochar. Following the harvest, three samples were collected from each block at two depths: 0-20 and 20-40 cm. These samples were combined to create a single composite sample per block. Soil analyses were carried out to determine various parameters. These parameters are detailed in Table 3. At the time of harvesting, measurements were taken of the nutrient content, organic carbon, pH and cation exchange capacity.

Table 3: Physicochemical characteristics of the studied soil on PRB before planting. Values after ± represent the standard deviation.

Parameters	Mean 0-20 cm	Mean 20-40 cm
Total Nitrogen in Ammoniacal form (mg/kg)	1705 ± 384	854 ±156
Available Phosphorous (mg/kg)	96.7 ± 33.2	76.5 ± 13.1
Available Potassium as K (meq/100g)	<0.5	<0.5
Exchangeable Calcium as Ca (meq/100g)	<0.5	<0.5
Exchangeable Magnesium as Mg (meq/100g)	14.7 ± 2.89	8.37 ± 2.84
ph H20 (-)	6.77 ± 0.102	6.82 ± 0.068
Organic Carbon (%)	1.84 ± 0.435	0.783 ± 0.051
Cation Exchange Capacity (meq/100g)	14.7 ± 3.21	9.51 ± 0.857
Soil Texture (-)	CLAY LOAM	CLAY LOAM
Soil Texture - Sand (%)	36.3 ± 4.18	40.0 ± 3.13
Soil Texture - Silt (%)	32.1 ± 8.88	24.4 ± 7.98
Soil Texture - Clay (%)	31.6 ± 4.74	35.6 ± 5.46
Bulk Density (g/cm^3)	1.47 ± 0.08	1.52 ± 0.066
Water Holding Capacity (%)	52.0 ± 4.00	46.0 ± 3.41

III.3 Experimental design

The field experiment was conducted in two contrasting soil management practices. The main experiment was performed on PRBs. The secondary experiment was conducted on a PF. A control modality was implemented in both experiments and it received no charged biochar. The experimental setup was designed with two primary objectives in mind: firstly, to achieve the initial objectives in a cost-effective manner and secondly, to obtain results that were as statistically correct as possible. Each unit was separated by a buffer zone. The plantation density

was 33 333 plants per hectare, due to spatial limitations. The space between 2 beds was 0.5 m. For both experiments, the cultural precedent is detailed in Appendix 5.

III.3.1 Permanent raised bed

During the experiment, five modalities were studied using complete random block (Table 4). Indeed, the experiment was realised on 2 beds with a different cultural precedent (Appendix 5). The goal of realised a complete random block is to limited the effect of the variability cause by this difference. There were 3 units per treatment. One bed of 30 m was divided in two (part 1 and part 2 of bed 1) and a 15 m of a second bed was used (Figure 4). The end of each PRB had a 0.6 m buffer zone with no sweet corn plants. These beds were created in 2021.

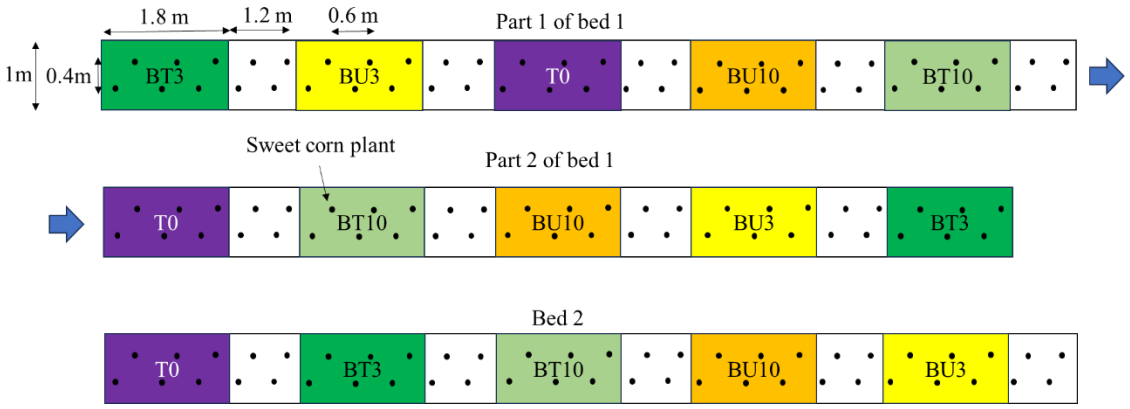


Figure 4: Experimental setup – randomized bloc design on PRB.

Table 4 : Experimental modalities and corresponding treatments on PRB.

Modality	Treatment
BT10	Biochar (10t/ha) + compost Tea
BU10	Biochar (10t/ha) + cow urine
BT3	Biochar (3t/ha) + compost Tea
BU3	Biochar (3t/ha)+ cow urine
T0	Control

III.3.2 Ploughed field

The experimental set-up was a double Latin square design (Figure 5). The first heterogeneity gradient is due to clay content, which increases with distance. The second gradient is due to the shade provided by a row of 3 m high acacia trees, which decreases with distance (Figure 5). There were 6 units per treatment. Due to space and financial constraints, three modalities were studied (Table 5). The soil was ploughed with a tractor to a depth of 20 cm 2 months before planting (Figure 6). Temporary beds were made using the top 10 cm of soil from the footpaths.

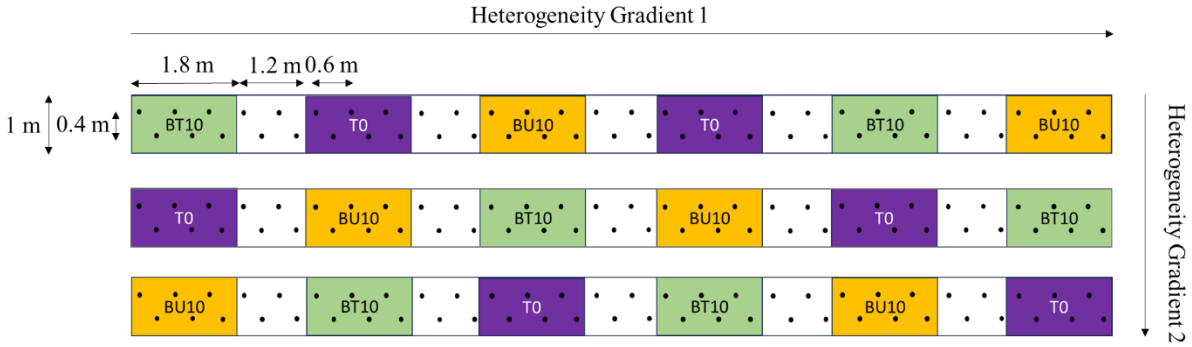


Figure 5 : Experimental setup – double Latin square design on PF.

Table 5 : Experimental modalities and corresponding treatments on PF.

Modality	Treatment
BT10	Biochar (10t/ha) + compost Tea
BU10	Biochar (10t/ha) + cow urine
T0	Control

Figure 6 : Disc plough use in the field.

III.4 Crop management

The early variety *Ashworth* was used for the experiment. The seeds were planted in pots with 160 g of substrate in a greenhouse. One seed was planted per pot at a depth of 3 cm. Nutrient content and composition of the substrate are detailed in Table 6. Furthermore, the specific materials utilized in the production of this substrate are delineated in Appendix 6. Transplanting was carried out 9 days after sowing. The maize crop was harvested after 65 days of growth.

Table 6 : Nutrients content of nursery substrate.

Parameters	Nursery Substrate
Total organic carbon (%)	6.21
Total Nitrogen in Ammoniacal form (%)	0.26
Available Phosphorus (mg/kg)	696
Available Potassium as K (meq/100g)	6.37
Exchangeable Calcium (meq/100g)	11.2
Exchangeable Magnesium (meq/100g)	5.58

The PRBs and the PF were irrigated by drip. There was one dripper per row and one dripper every 0.3 m. Plants were planted at each dripper and in staggered rows. The flow rate was 1.32 l/h and the general farm valves were opened twice a day for one hour (Figure 7). Each plant received 2.64 litres of water per day from a well.

Figure 7: Manual valves for drip irrigation.

All modalities received a treatment of 25.8 t/ha of compost and 7.8 t/ha of *Acacia auriculiformis* ramial chipped wood (RCW) 19 days before transplanting. Due to termite activities, *Mangifera indica* RCW was applied at a dose of 8,6 t/ha 29 days after the first application of RCW. The quantity of nutrients and organic carbon of compost and the total nutrient quantity of RCW for the two applications and are shown in Table 7 and Table 8 respectively. Moreover, the particular materials employed in the production of the compost are set forth in Appendix 6. The primary reasons for the implementation of RCW are its efficacy in mitigating the loss of soil moisture, soil temperature, and erosion (Barthès et al., 2010; Duchaufour et al., 2020; Wang et al., 2019).

Table 7 : The quantity of nutrients applied to PRB and PF prior to transplantation was achieved via compost.

Parameters	Compost kg/ha
Total organic carbon	2394
Total nitrogen	178
Total phosphorous	129
Total potassium	72
Total calcium	204
Total magnesium	62

Table 8 : The total nutrient quantity of RCW for the two applications.

Parameters	RCW kg/ha
Total nitrogen	149
Total phosphorous	20
Total potassium	48
Total calcium	56
Total magnesium	39

Integrated pest management was carried out in agreement with Indian Institute of Maize Research ("Pest Management – ICAR-Indian Institute of Maize Research," n.d.). Used products are detailed in Table 9. In advance of planting, a net structure has been constructed to deter the peacocks. In addition, a barrier comprising bamboo has been erected around the experimental area. Weed control was achieved by manual weeding once week.

Table 9 : Used products again pests.

Products	Method	Application date DAS	Concentration %	Quantity	Unit
Wood vinegar	Curative	17	0,002	130	ml/m²
Neem oil	Curative	17,31,41,49	5	0,25	ml/m²
Trichogramma chilonis card	Preventive	37	/	5	1 cards/60m²
Spodoptera frugiperda pheromone trap	Preventive	37	/	5	1 cards/60m²

III.5 Soil amendments studied

III.5.1 Charged biochar production

The biochar was produced via pyrolysis of *Acacia auriculiformis* logs in a locally produced Kon-tiki oven. The pyrolysis temperature in the Kon-Tiki is 650-700 °C, with brief temperature peaks close to the flames reaching up to 750°-800°C. In this temperature range, the biomass, including its lignin, is completely charred (Schmidt et al., n.d.). The produced biochar was then air-dried for 5 days before being subjected to the shredding and sieving process. The biochar was used after passing through a 4 cm x 1 cm sieve. It was saturated with compost tea or cow urine weight ratio of 1:3.33. The cow urine-charged biochar and compost tea-charged biochar were kept in a closed container during 72 h at ambient conditions, and regularly homogenized to promote the interactions between the nutrients, the biochar, when applicable. The nutrient-rich biochar was then air-dried during 48h, after which it was used. They were all analysed for their nutrient contents (Table 10).

III.5.2 Compost tea production

Compost tea was made by mixing 10 l of mature compost sieved at 2.5cm for 6 weeks, 6 kg of jaggery, 200 l of water, 1.5kg of rock powder and 0.5 kg of salt. The composition of the compost is detailed in the Appendix 6. In order to initiate aerobic fermentation of the microorganisms present in the solution, air was introduced via two 3-watt pumps. Furthermore, the solution was manually agitated on a daily basis. The aerobic fermentation process was completed over a seven-day period prior to the mixture being utilised for the loading of the biochar. It was analysed for its total nutrient composition (Table 11).

III.5.3 Cow urine collection

The urine sample was collected over the course of one night via a gutter (Figure 8). The urine samples were sieved, and the farmer ensured that no washing water was collected. The biochar was charged 2 days after the urine was collected. It was charged with a solution comprising pure urine and was analysed for its total nutrient composition (Table 11).

Figure 8: Gutter for the collect of cow urine.

Table 10: Nutrient content cow urine charged biochar and compost tea charged biochar.

Parameters	Compost Tea-charged biochar	Cow urine-charged biochar
Total Nitrogen in Ammoniacal form (%)	0.21	0.54
Available Phosphorus (mg/kg)	343	109
Available Potassium as K (meq/100g)	1.58	2.55
Exchangeable Calcium (meq/100g)	< 0,50	< 0,50
Exchangeable Magnesium (meq/100g)	35.0	20.0

Table 11: Nutrient content of cow urine and compost tea.

Parameters	Compost Tea	Cow urine
Total Nitrogen as N (mg/l)	43.0	6501
Total Phosphorous as P (mg/l)	75.0	3.65
Total Potassium as K (mg/l)	124	26000
Calcium as Ca (mg/l)	63.0	157
Magnesium as Mg (mg/l)	267	1216

III.6 Biomass measurements and analyses

The height of the plants in the PF and the PRBs was quantified. The height was measured at the BBCH stage of 70, R2 stage (Cissé et al., 2021). The kernels were harvested at the milk stage, which corresponds to BBCH 75, as defined in the "BBCH_STAGING_MANUAL_GENERAL_ALL_CROPS.pdf" (March 4, 2024) and the "Sweet Corn Growth Stages And GDUs" (March 12, 2024). The height was measured when 50% of the plants in a modality had reached the desired BBCH stage. Furthermore, the number of cobs per plant was quantified in both experiments at the time of harvest. One cob was quantified when it was filled to a level exceeding 80% and exhibited a size exceeding 12 cm (K D Subedi et al., 2011).

The aerial portion of three plants per unit was harvested, and the kernels were separated from the vegetative matter for the two experiments. In the first instance, separate weighing was carried out of the vegetative part of each plant and the kernels. Subsequently, kernels and the vegetative parts of randomly selected plants from each unit were placed in an oven drying for a period of 24 hours at a temperature of 105 °C. The dry matter of the samples was measured to calculate the Harvest Index (Equation 1). The index in question is employed in order to ascertain the proportion of marketable products in the total biomass production. In the absence of significant stress on the maize, the index is expected to fall within the range of 0.48 to 0.52 (K D Subedi et al., 2011). The general formula for calculating the harvest index is as follows:

Equation 1

$$HI = \frac{Kernels\ yield}{Total\ biomass\ with\ kernels} \times 100$$

The N percentage in above-ground dry matter will be employed in the calculation of the nitrogen critical dilution curve. The concept of critical N concentration (%Nc) has been put forth as the minimum percentage of N in shoots required to achieve the maximum aerial biomass at a given time (Equation 2 and Equation 3). The critical N model employed in this study was originally developed by Plenet and Lemaire (2000) for use in irrigated corn crops (Ciampitti et al., 2022, Plenet et al., n.d.). This model is valid to the development of the corn

crop between the emergence and silking stages, + 25 days. In the critical %N-W relationship, a decline in %N is observed when W exceeds 1 t/ha. The inclusion of W values below 1 t/ha in the regressions gives rise to a more complex allometry (Plenet et al., n.d.). The critical %N − W relationship model is proposed in maize as:

Equation 2

$$\text{If W} < 1 \text{ t/ha} \Rightarrow \%N_c = 3.40$$

Equation 3

$$\text{If } 1 \text{ t/ha} \leq \text{W} \leq 22 \text{ t/ha} \Rightarrow \%N_c = 3.40\ (W)^{-0.37}$$

Finally, the apparent recovery efficiency (ARE) for each nutrient was also calculated (Equation 4). The recovery efficiency of fertiliser demonstrates the apparent increase in plant nutrient uptake in response to the input of nutrients (Congreves et al., 2021). The unit of measurement for each parameter is kg/ha.

Equation 4

$$ARE = \frac{Nutrient\ uptake\ in\ fertilized\ treatment\ -\ Nutrient\ uptake\ in\ unfertilized\ treatment}{Nutrient\ applied}$$

III.7 Soil your undies

The test, designated "Soil Your Undies," was developed to serve as a complement to the soil analyses conducted prior to the plantation. In the PRB experiment, a brief was buried vertically in the centre of each experimental unit (Figure 9). The objective is to assess the microbial activity of each unit by measuring the rate of deterioration of cotton briefs over a period of two months ("Soil-Your-Undies-protocol-2016.pdf," May-7-2024). The test protocol can be found in Appendix 7. This test is a useful tool for qualitative comparison of the mean and variability of microorganism activity for each treatment.

Figure 9: The brief was positioned vertically in the centre of each experimental unit.

III.8 Exceptional events

During the experiment, three major events have perturbed the experiment. Figure 10 shows a chronology of the exceptional events that occurred during the experiment.

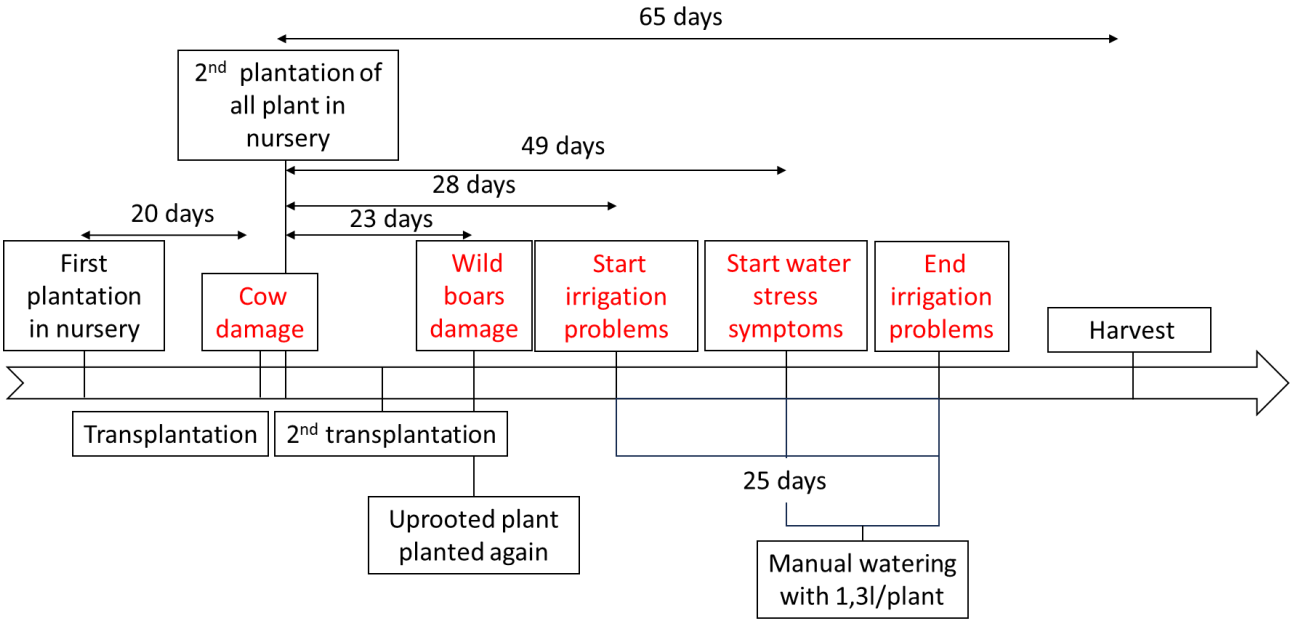


Figure 10: Timeline with exceptional events during experimentation.

First, one cow consumed all of the sweet corn and necessitated a second planting. Second, wild boars come and turn the soil without consuming the plants (Figure 11). As a consequence of this occurrence, the RCW was incorporated into the soil. All of the plant was

uprooted except the unit “BU3” in the half part of a PRB and one part of PF (Figure 12). The uprooted plants were planted again directly after the wild boars had passed through, and the experiment was carried out with these plants. Third, from 28 DAS, irrigation was disrupted by two factors: regular power cuts and a lack of pressure due to a malfunction in the irrigation system. Accordingly, the plants were subjected to an irregular irrigation, with water quantities ranging from 2.6 litres per day to complete lack of irrigation. Finally, the irrigation system of the experiment was connected to an alternative system without any issues with pressure at 53 DAS. With this system, the experiment was watered once per day with 2 litres. It is possible that these three events may have a negative impact on the outcomes of the experiment.

For the modality “biochar + compost tea (3 T/ha)”, 2 units on 3 were at the ends of a bed. The results of this method may be influenced by border effects, which may lead to a distortion.

Figure 11 : Damage caused by wild boar.

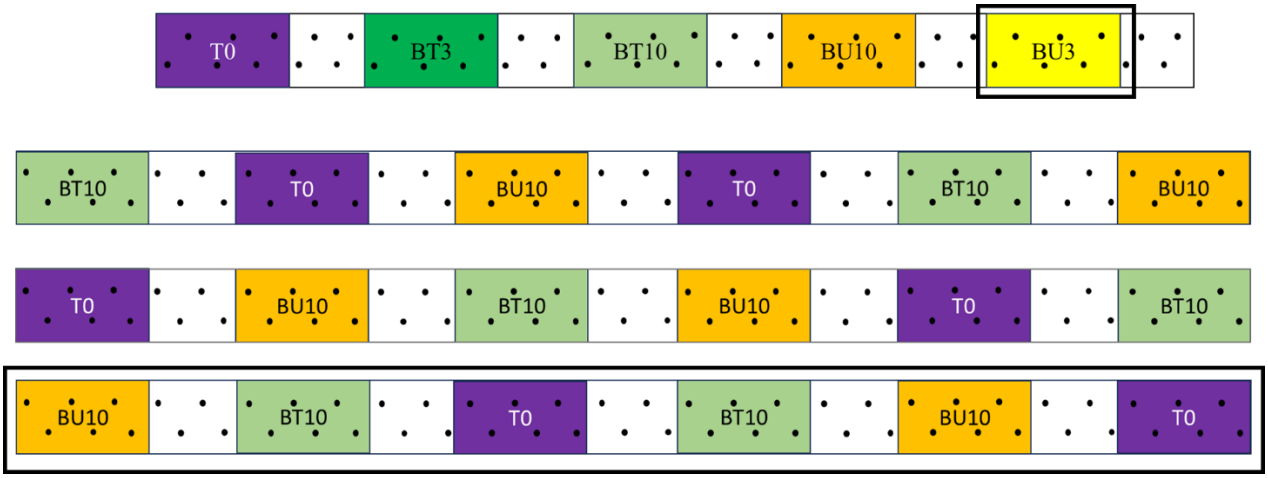


Figure 12 : The half PRB with unperturbed unit BU3 and the PF setup with the unperturbed units are framed.

III.9 Laboratory analysis

Soil analyses and analyses of the nutrient composition of plants and compounds were carried out by « ADN LABORATORIES PRIVATE LIMITED ». This laboratory is ISO 17025 certified. All the methods used to analyse the samples are detailed in Appendix 8.

III.10 Statistical analysis

All statistical analyses were performed on RStudio (version 2024.04.0-735). The statistical analyses of all the parameters were conducted in a uniform manner. For parametric data, which have normally distributed data (Shapiro's normality test) and homogenous variance (Levene's test) means were compared through two-way analyses of variance for PRB experiment with the factor treatment and the random factor for the block. A three-way analysis was employed for the purpose of biomass analysis in the PRB and PF experiment. The Poisson distribution and the GLM function were used for the counting data. The objective of these tests was to ascertain whether there were notable discrepancies between the various treatments when the p-value was less than 0.05. The Emmeans function was used to perform the Tukey test. For non-parametric data, the Kruskal Wallis test and Dunn's test was used. A regression graph was developed for each significant correlation based on ggpairs of each treatment. The significant correlation was calculated using the Pearson test. Subsequently, a Principal Component

Analysis (PCA) was conducted to ascertain the feasibility of visualising trends between each treatment. All the Packages used are detailed in Table 12.

Table 12 : Packages for statistical analysis.

Package	
agricolae	ggrepel
car	lmer
emmeans	multcomp
factoextra	nlme
FactoMineR	patchwork
ggplot2	rstatix

IV RESULTS

IV.1 Soil analyses

The soil samples were obtained exclusively from the PRB, with one composite sample taken from each unit at depths of 0-20 cm and 20-40 cm. Therefore, three samples were used for each treatment to compare results. The levels of $K^+$and Ca^{2+} were not studied due to the concentrations being below the detection limits of the analytical method employed (0.5 meq/100g). The p-values for each variable are detailed in the following table (Table 13), which present data for depths between 0 and 20 and between 20 and 40, respectively. The numerical results of soil analyses are presented in Appendix 9, while the boxplots are displayed in the following pages. No significant differences were observed between treatments for any of the variables, with the exception of total NH_4^+ at a depth of 0-20 cm. For this variable, Tukey test function aggregates all modalities within a singular group.

Table 13: P-value and meaning for each variable in the depth of 0-20 and of 20-40 cm for PRB. "Diff. weight Brief" is the difference between the initial weight of each cotton brief and the final weight after 2 months. NS is no significant difference as evidenced by a p-value greater than 0.05. S is significant difference as evidenced by a p-value lower than 0.05. The symbol "=" indicates that the Tukey test aggregates all modalities within a singular group for the variable "Total NH_4^+".

								Available		Exchangeable	
		pH H_2O	pH KCl	Total NH_4^+	CEC	Organic C	Diff. weight Brief	P	K	Ca	Mg
Depth of 0-20 cm	*p-value*	0.948	0.91	0.022	0.345	0.21	0.597	0.709	/	/	0.583
	Meaning	NS	NS	S =	NS	NS	NS	NS	/	/	NS
Depth of 20-40 cm	*p-value*	0.926	0.901	0.67	0.699	0.813	/	/	/	/	0.423
	Meaning	NS	NS	NS	NS	NS	/	/	/	/	NS

IV.1.1 pH KCl

Given the acidic nature of the soil, only the pH KCl graph was developed. The soil pH KCl for each treatment at depths between 0 and 20 cm and between 20 and 40 cm are presented in Figure 13. The "base" treatment was obtained prior to the commencement of the experimental procedure, whereas the T0 treatment was analysed at the time of the harvest. The boxplot graph indicates that BT3 exhibits a tendency to have a higher acidity level than T0, in comparison to the mean acidity level of the soil prior to the commencement of the experiment. The other

treatments had an acidity level below T0. Furthermore, it can be observed that BT3 exhibits a considerable degree of variability in comparison to the other treatments.

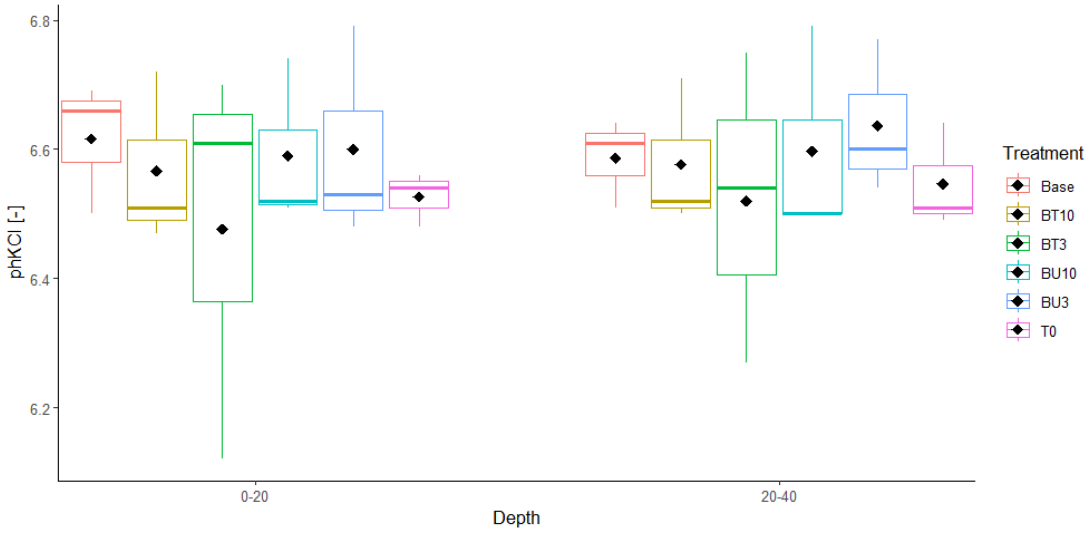


Figure 13 : Soil pH KCl for depths of 0-20 and 20-40 cm. The "base" treatment was obtained prior to the commencement of the experimental procedure, whereas the T0 treatment was analysed at the time of the harvest. The black dots represent the specific mean for each treatment.

IV.1.2 Nutrient content

Box plots of NH_4^+, available P and Mg^{2+} comparing each treatment at depths between 0 and 20 cm and between 20 and 40 cm are shown in Figure 14, Figure 15 and Figure 16 respectively. The overall trend indicates by these figures is that the mean content of each treatment for a variable is lower at a depth of 20-40 than at a depth of 0-20. According to Anova test, there is a significative difference between treatments for total NH_4^+ at a depth of 0-20 cm. The mean content of BU10 is lower than that of the other treatments, while that of BU3 is greater. The mean content of BU10 is lower than that of the other treatments, while BU3 has a higher mean content. The mean content of the other treatments is approximately the same. It is important to note that all treatments have a lower mean content than the initial content, with the exception of BU3. A similar trend is observed at depths of 20–40. At last, a distinction is observable between values at the 0-20 and 20-40 depths, with a reduction in variability at the latter depth.

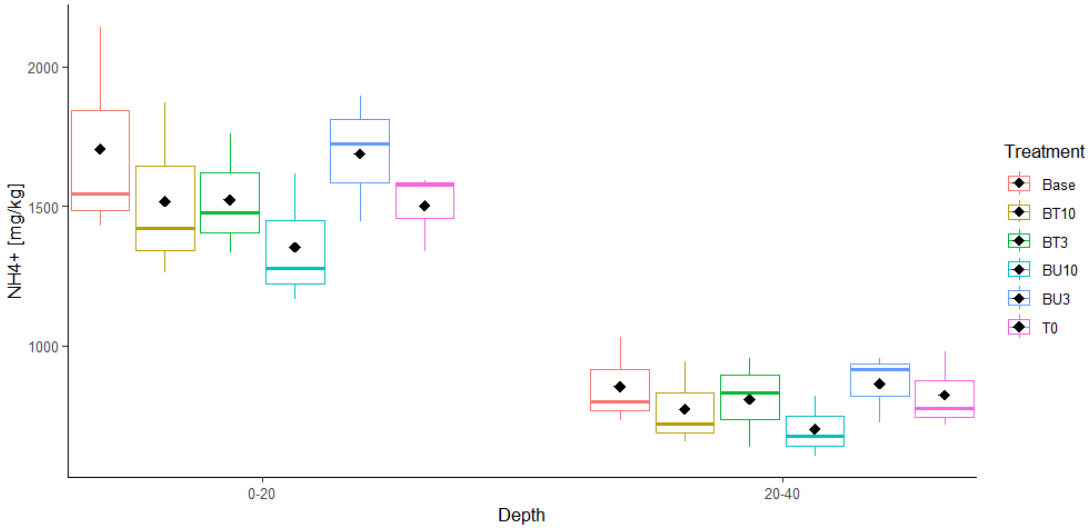


Figure 14 : NH_4^+ content [mg/kg] for depths of 0-20 and 20-40 cm. The "base" treatment was obtained prior to the commencement of the experimental procedure, whereas the T0 treatment was analysed at the time of the harvest. The black dots represent the specific mean for each treatment.

In the case of available P, the mean concentration of each treatment displays a trend wherein it is lower than the initial concentration for both depths (Figure 15). The BU3 treatment exhibits a comparatively lower decrease in depth between 0 and 20, while demonstrating a relatively higher decrease between 20 and 40. For other treatments, the trend is the same for depths 0-20 and 20-40.

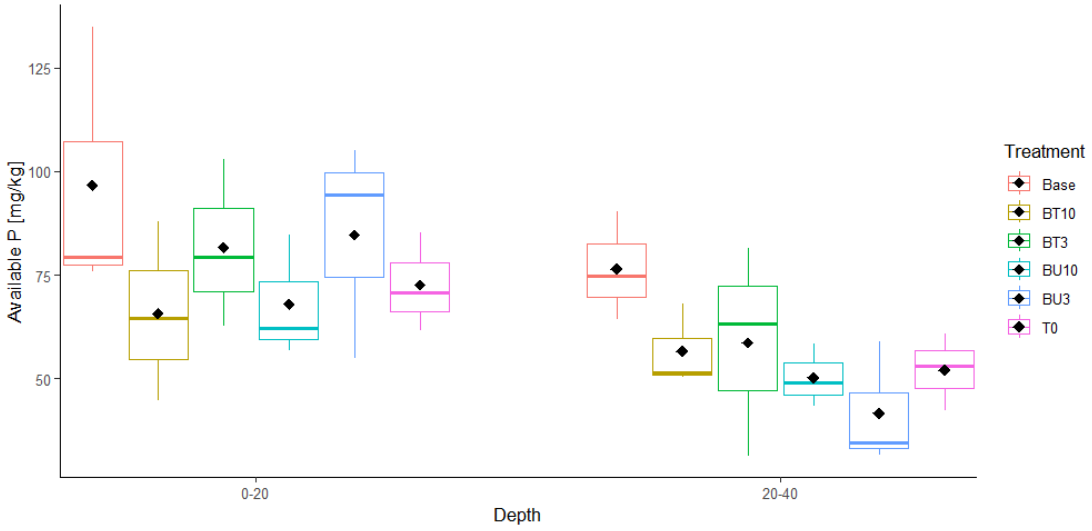


Figure 15 : Available P content [mg/kg] for depths of 0-20 and 20-40 cm. The "base" treatment was obtained prior to the commencement of the experimental procedure, whereas the T0 treatment was analysed at the time of the harvest. The black dots represent the specific mean for each treatment.

In regard to exchangeable Mg, there are two trends. First, the mean content of BU10 is the lowest, while BU3 has the highest for 0-20 depth (Figure 16). Secondly, a greater mean content was observed for BT3 and BU3 at a depth of 20-40 than in other treatments. At last, a distinction is observable between values at the 0-20 and 20-40 depths.

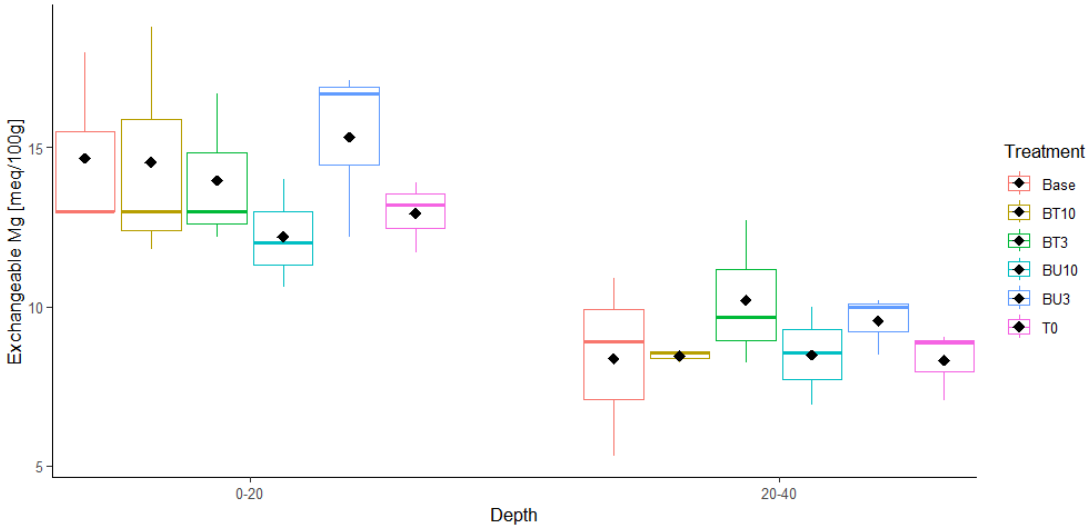


Figure 16 : Exchangeable Mg content [meq/100g] for depths of 0-20 and 20-40 cm. The "base" treatment was obtained prior to the commencement of the experimental procedure, whereas the T0 treatment was analysed at the time of the harvest. The black dots represent the specific mean for each treatment.

IV.1.3 CEC and organic carbon

Box plots of CEC, organic carbon comparing each treatment at depths between 0 and 20 cm and between 20 and 40 cm are shown in Figure 17 and Figure 18 respectively. For CEC boxplot, BT3 exhibits a high degree of variability in comparison to other treatments at a depth of 0-20. This is also observed in the case of BU3 at a depth of 20-40. The mean content of each treatment displays a trend wherein it is lower than the initial content except for BT3 at a depth of 0-20. The mean content of BU10 is the lower at a depth of 0-20. In the depth of 20-40, a trend emerges wherein BT10 exhibits a resemblance to the initial content, while BT3 and BU10 display a comparable similarity.

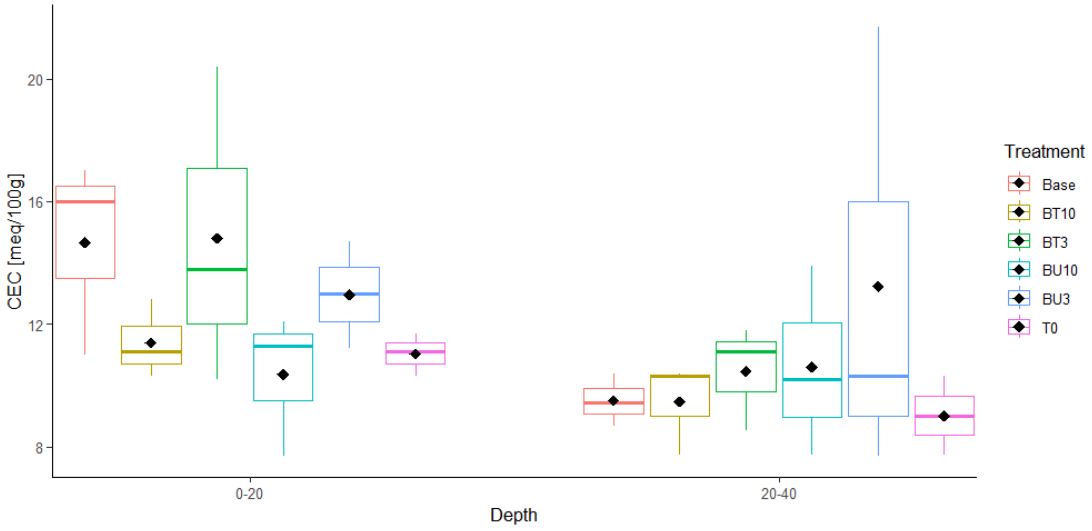


Figure 17 : CEC [meq/100g] for depths of 0-20 and 20-40 cm. The "base" treatment was obtained prior to the commencement of the experimental procedure, whereas the T0 treatment was analysed at the time of the harvest. The black dots represent the specific mean for each treatment.

The concentration of organic carbon is observed to be lower in all treatments at a depth of 20-40 than at 0-20 (Figure 18). BT10, BT3 and BU10 have a high variability compare to BU3 and T0. The mean content of BU10 is the lower at a depth of 0-20. In the depth of 0-20, a trend emerges wherein BT10 exhibits a resemblance to BT3, while BU3 and T0 display a comparable similarity.

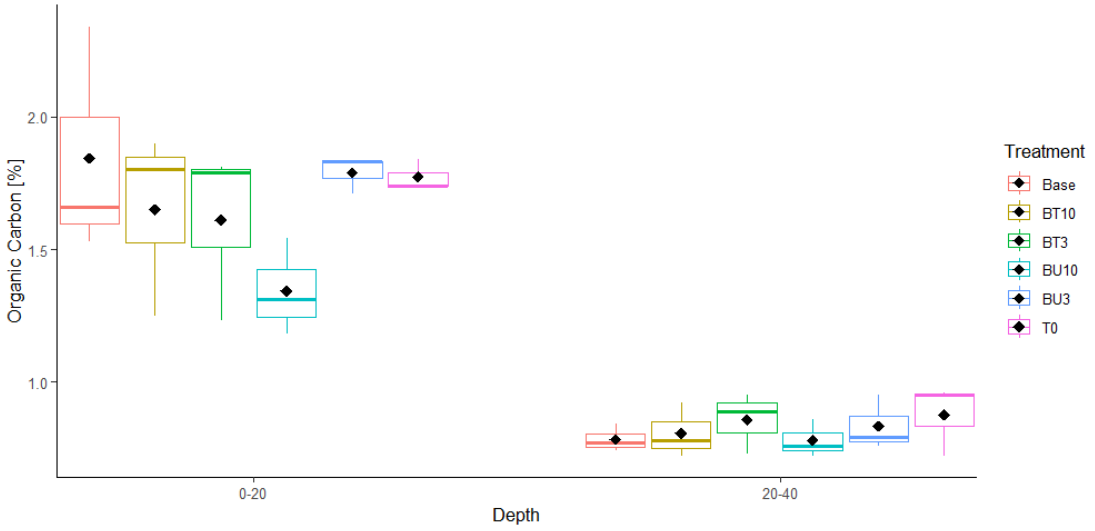


Figure 18 : Organic carbon content [%] for depths of 0-20 and 20-40 cm. The "base" treatment was obtained prior to the commencement of the experimental procedure, whereas the T0 treatment was analysed at the time of the harvest. The black dots represent the specific mean for each treatment.

IV.2 Biomass

The only parameters measured in relation to nutrient uptake were those pertaining to PRB, while the other biomass characteristics were assessed in relation to PRB and PF. The mean and the standard deviation of biomass measures are presented in Appendix 9, while the boxplots are displayed in the following pages.

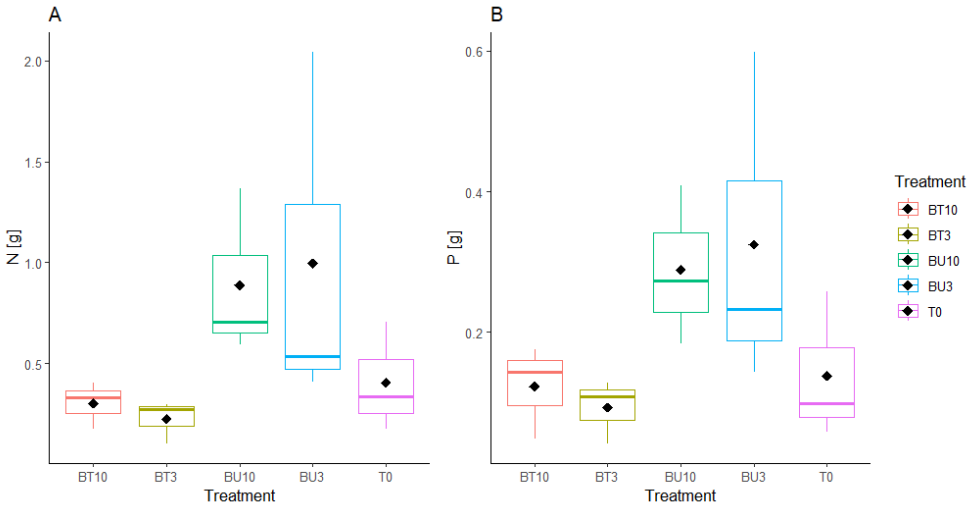
IV.2.1 Nutrient uptake for permanent raised beds

A single plant was randomly selected from each experimental unit for analysis. Consequently, each treatment effect is represented by three plants. In order to circumvent the potential confounding effects of dilution, the percentage content of nutrients was weighted by dry matter and subjected to analysis. The two-way analysis for Ca uptake is the only one in which a significant difference between treatments is observed. The Tukey test categorises all of the treatments in the same group for this parameter (Table 14). There are 3 general trends and the Ca boxplot follow these trends (Figure 19). Firstly, BU10 and BU3 absorbed on average a

greater quantity of nutrients than the other treatments. Secondly, BU3 has a high variability. Thirdly, the Mg uptake appears to be better for BT3 than for the other treatments.

Table 14: p-value and significance of this p-value for the nutrient uptake of biomass for PRB. NS is no significant difference as evidenced by a p-value greater than 0.05. S is significant difference as evidenced by a p-value lower than 0.05. The symbol "=" indicates that the Tukey test aggregates all modalities within a singular group for the variable "Ca".

		N	P	K	Ca	Mg
	p-value	0.225	0.19	0.196	0.048	0.718
PRB	Meaning	NS	NS	NS	S =	NS



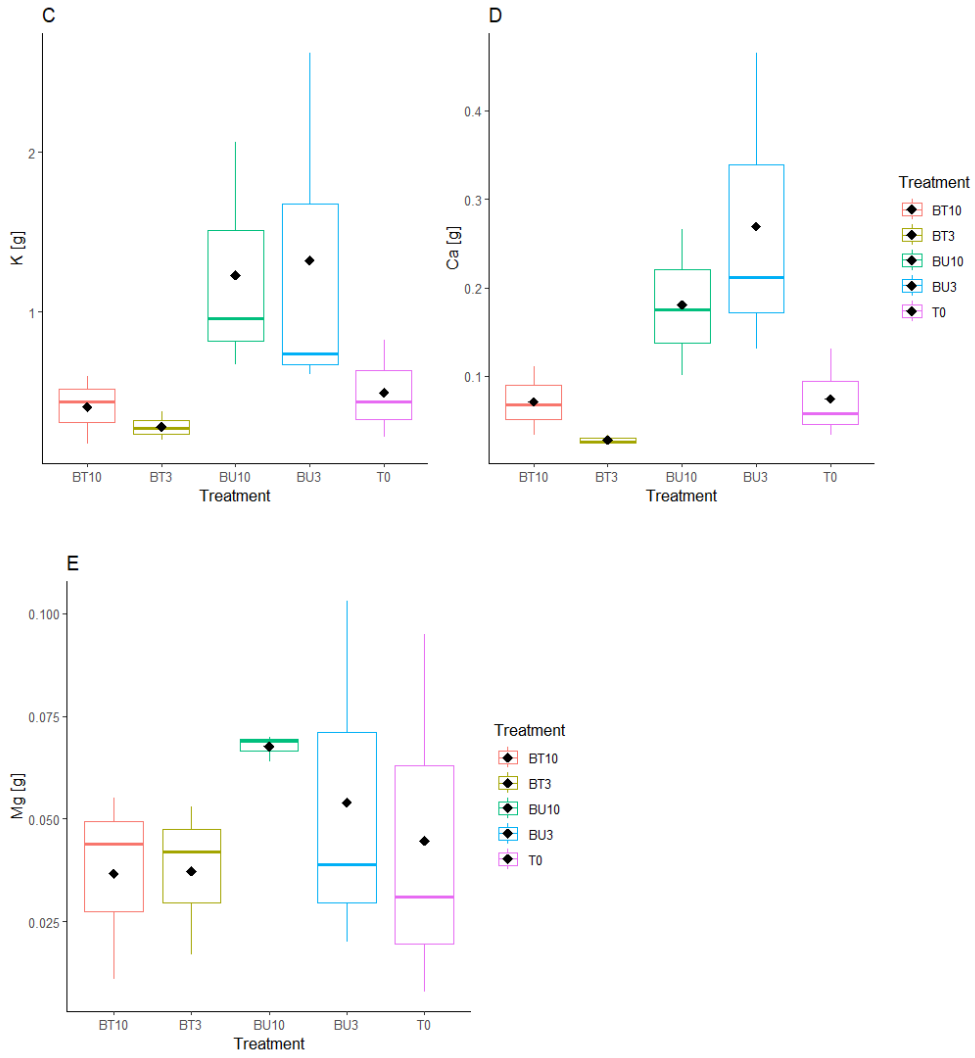


Figure 19 : (A) Total above ground biomass N uptake, (B) P uptake, (C) K uptake, (D) Ca uptake and (E) Mg uptake [g]. The black dots represent the specific mean for each treatment.

IV.2.2 Crop characteristics

The manual measurements carried out to characterise above-ground biomass are compared in following figures. It was measured on PRB and PF. For PRB, three plants were randomly selected from each unit. Consequently, each treatment effect is represented by a total of nine plants. For PF, each treatment effect is represented by a total of 18 plants and for PRB

9 plants. The p-value of the different variables are presented in Table 15. For PRB, BT10, BU10 and BU3 have a significantly higher height than T0 and BT3. T0 is significantly higher than BT3 (Figure 20). In terms of dry matter, the mean dry matter per plant for BU3 is significantly higher than for the other treatments. The dry matter of T0, BT10 and BU10 was found to be equal and significantly greater than that of BT3 (Figure 21). For PF, BT10 has on average significantly more kernels per plant than BU10 and T0. BU10 has significantly more kernels per plant than T0 (Figure 22).

For variability trends, BT10 has a high variability for the number of cobs on the 2 plots compared to the other variables (Figure 23). This is the case for BU3 for the number of cobs on PRB and dry matter. T0 has a high variability for the height at R2 stage.

For other trends, the mean values of the variables are greater for BT10 and BU10 than T0 on the 2 plots. BU10 always has higher average values for the PRB plot than PF. This is also the case for BT10 except for the average number of kernels per plant.

Table 15: P-value and meaning of this p-value of biomass parameters for PRB and PF. "=" for Tukey test is for parameters where all of the treatments are in the same group for the parameter. BT3 ≠ T0 ≠ (BT10, BU10, BU3) means that the treatments are significantly different by Tukey test at α =0.05. T0≠BT10≠BU10 means that the treatments are significantly different by Tukey test at α =0.05.

		Height R2	Dry matter	Cobs num.	Kernels num.
PRB	*p-value*	0.00024	0.0304	0.023	0,00023
	Meaning	HS	S	S	HS
		BT3 ≠ T0 ≠ (BT10,BU10,BU3)	BT3 ≠ (T0,BT10,BU10) ≠ BU3	=	=
PF	*p-value*	0.316	0.255	0.681	0.023
	Meaning	NS	NS	NS	S
					T0≠BT10≠BU10

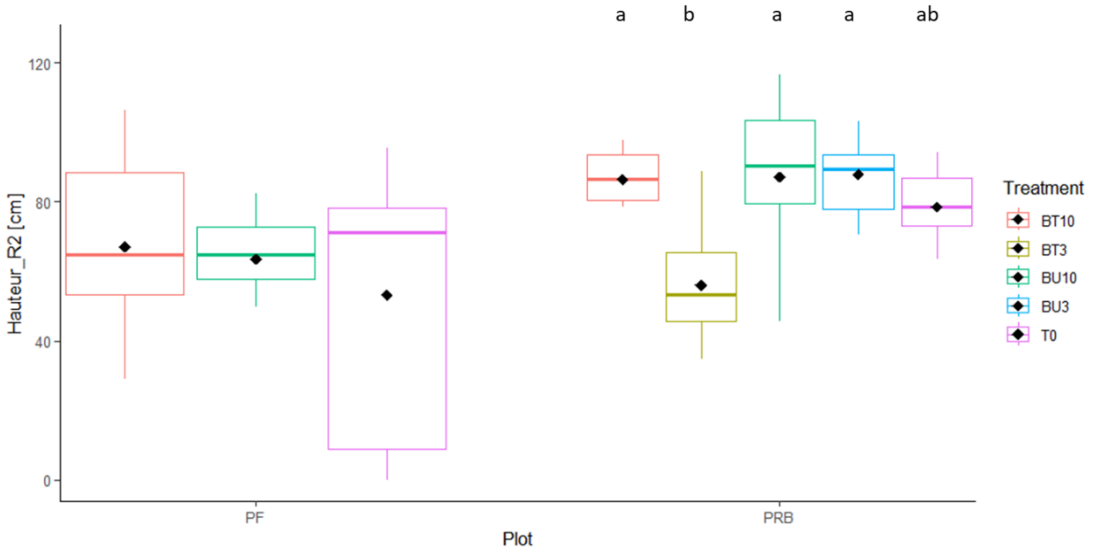


Figure 20: Height at BBCH R2 stage [cm] for PF and PRB. The black dots represent the specific mean for each treatment. The letters on the graph represent the different groups created by Tukey test.

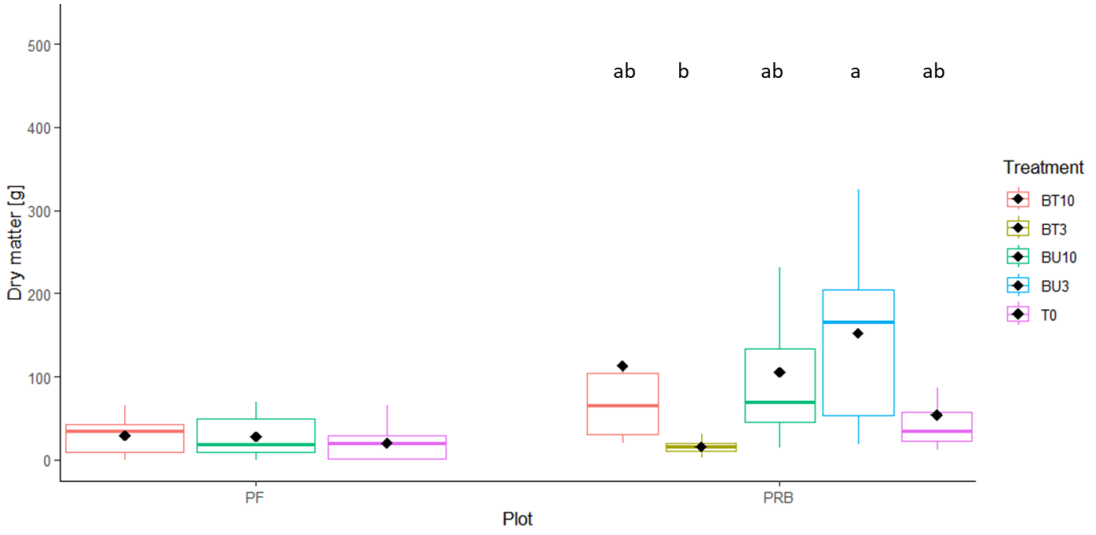


Figure 21 : Dry matter at harvest per plant [g] on PF and PRB. The black dots represent the specific mean for each treatment. The letters on the graph represent the different groups created by Tukey test.

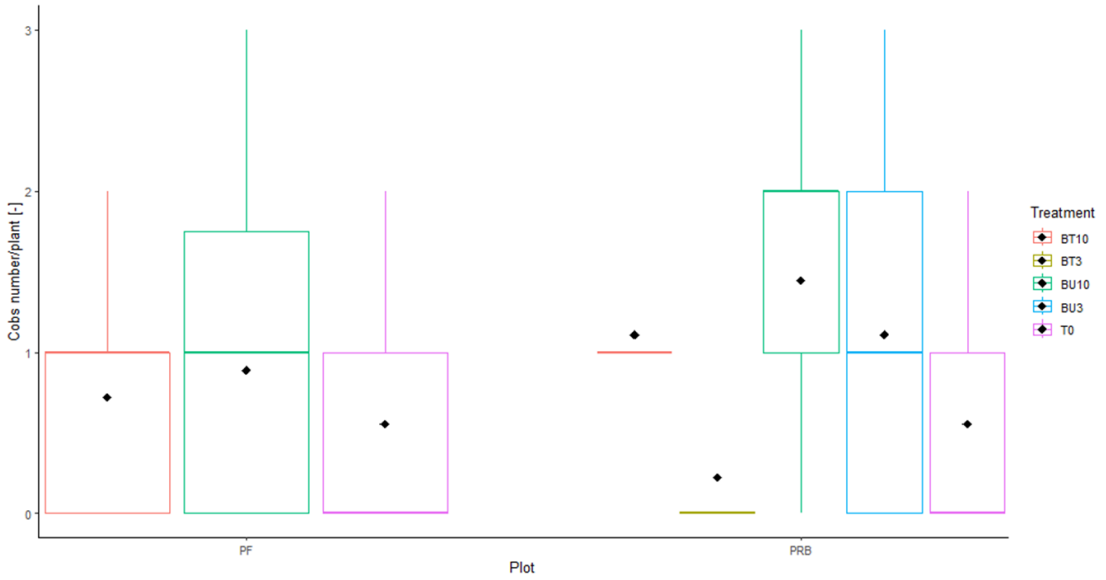


Figure 22: Cobs number per plant on PF and PRB. The black dots represent the specific mean for each treatment. The letters on the graph represent the different groups created by Tukey test.

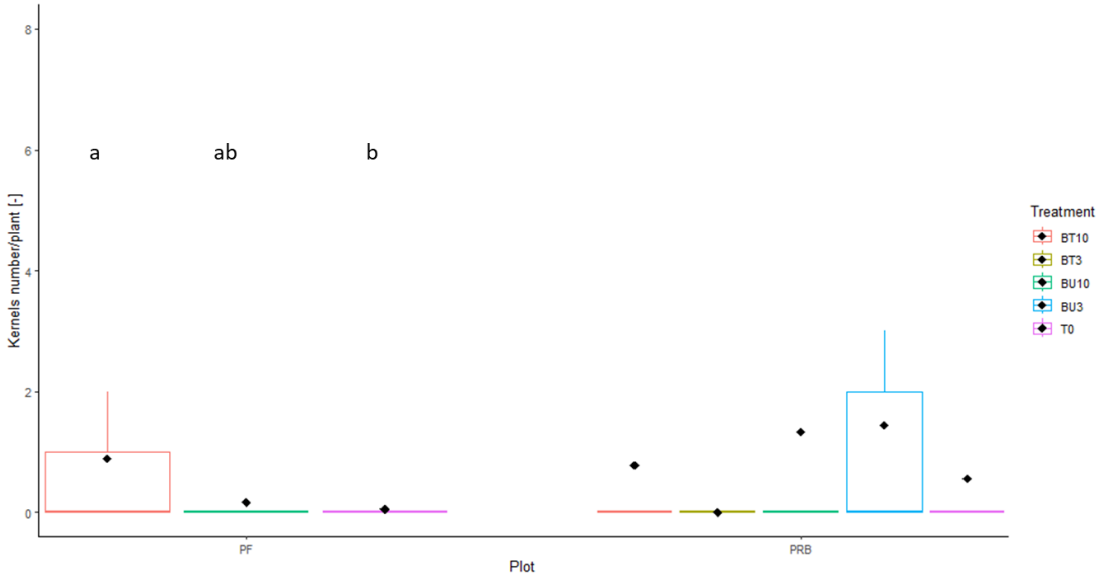


Figure 23: Kernels number per plant on PF and PRB. The black dots represent the specific mean for each treatment. The letters on the graph represent the different groups created by Tukey test.

IV.2.3 Harvest index

At the time of harvest, the number of seeds per plant was insufficient to allow for the collection of seed samples. Consequently, the vegetative part and the ears were collected in a single sample.

IV.2.4 Nitrogen critical dilution curve for permanent raised beds

The nitrogen critical dilution curve for sweet corn is presented in Figure 24. The red curve represents the minimum percentage of nitrogen in shoots that is required to produce the maximum aerial biomass at a given time. The dotted line represents the total dry matter yield of 1 t/ha.

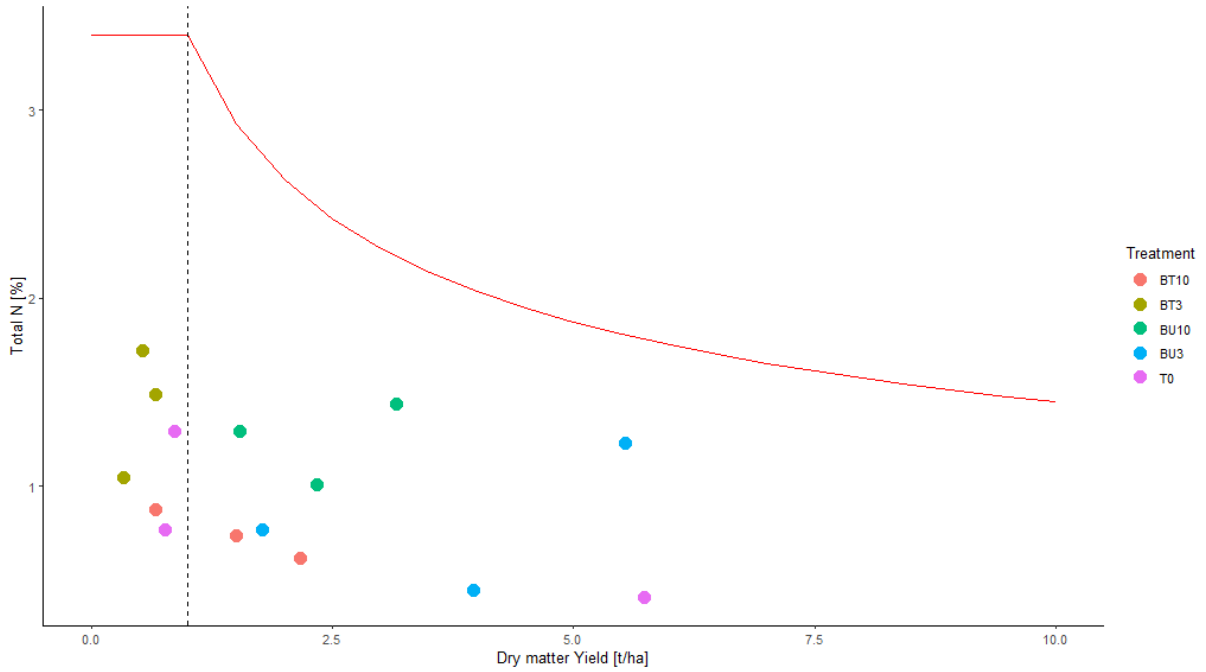


Figure 24 : Relationship between total nitrogen [%] in above-ground biomass and dry matter yield [t/ha] of the above-ground biomass. The data points represent the individual measurements for each block of PRB.

IV.2.5 Apparent recovery efficiency

The apparent recovery efficiency (ARE) was calculated on the basis of the nutrient applied [kg/ha] and the nutrient uptake [kg/ha]. For each observation (n=15), the specific ARE was calculated based on the mean ARE of T0. The standard deviation was calculated for each treatment. The general trend is that the standard deviation is high. The results of the ARE are presented in detail in Table 16. Another trend is that BU10 and BU3 are more efficient to absorb nutrients than BT10 and BT3. BU3 has the highest values and BT3 the lowest.

Table 16 : Apparent recovery efficiency for each treatment on PRB. It was not possible to measure the ARE for Ca due to the Ca applied below the detection limits of the analytical method employed.

	Apparent recovery efficiency									
Treatment	N_ARE	N_SD	P_ARE	P_SD	K_ARE	K_SD	Ca_ARE	Ca_SD	Mg_ARE	Mg_SD
BT10	-0.161	0.185	-0.152	0.647	-0.489	1.154	/	/	-0.0030	0.0088
BT3	-0.951	0.558	-1.47	1.46	-3.87	1.62	/	/	-0.0098	0.0238
BU10	0.299	0.258	4.60	3.47	2.47	2.45	/	/	0.0155	0.0021
BU3	1.21	1.87	19.0	24.56	9.24	12.6	/	/	0.0163	0.0902

IV.3 Soil your undies

The values of “diff.briefs” is the difference between the initial weight of each cotton brief and the final weight after 2 months (Figure 25). A photo of each brief is shown in Appendix 7. All the treatments show a high degree of variability compared with T0. The trend observed in this figure is that the BU10 has the highest mean, while the BU3 has the lower mean.

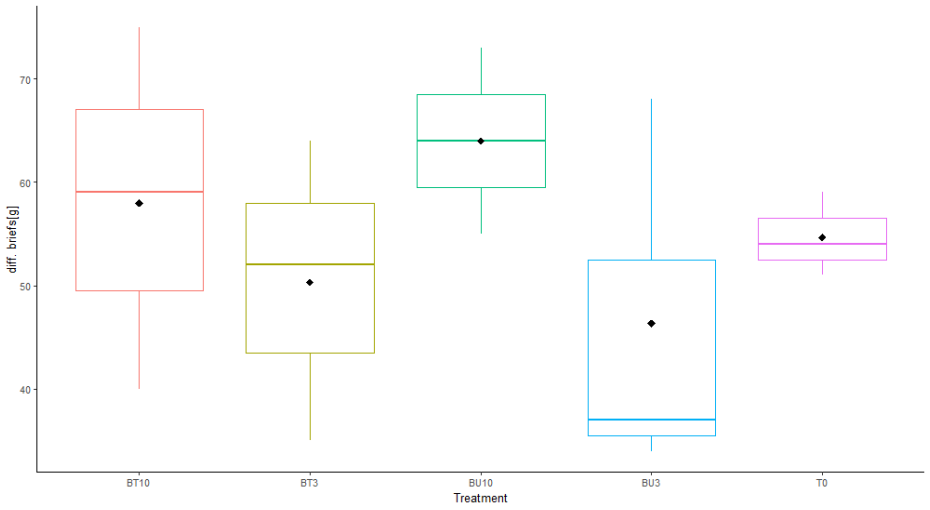


Figure 25 : Weight difference in briefs after 2 months [g]. The black dots represent the specific mean for each treatment.

IV.4 Soil-plant relations

IV.4.1 Nutrient flow

A representation of the nutrient flow between the charged biochar, the soil, and the plant is provided in Figure 26. The available K and exchangeable Ca content of the soil were found to be below the minimum detectable dose. Consequently, these data are not included in the input and central portion. The input section represents the quantity of nutrients applied for each treatment. The output section represents the mean of quantity of nutrients uptake by plant. With the exception of the output section, where nutrients are represented in terms of total uptake, the nutrients in question represent their available form. In order to ascertain the variation of quantities in the output section and the variation of nutrient content in the soil between initial and harvest content, the following equations was employed:

Equation 5

$$Variation = \frac{Nutrient_{plant} - Nutrient_{Treatment}}{Nutrient_{Treatment}} \times 100$$

Equation 6

$$Variation = \frac{Harvest\ content_{soil} - Initial\ content_{soil}}{Initial\ content_{soil}} \times 100$$

The content of BU3 has decreased at a depth of 0-20 cm, with a lower value of -1% and BU10 with a higher value of -20.6% in comparison to the initial content of the soil. The remaining treatments exhibited a value that was approximately equal to the aforementioned values, fluctuating within the range of -10.7 to -11.9%. The trend is the same for depth 20-40 where the NH_4^+ content of BU3 has even increased by 1.3% (Figure 26).

In terms of nutrient uptake, the N uptake of the BU10 plant was 45% below the input level, and that of the BT10 plant 51.6%. For P, the quantity absorbed is very high compared with the quantity applied for BU10 and BU3. It is lower for BT10 and BT3. The BU3 plant has a quantity of K almost 15 times greater than the quantity of K applied. The quantity also increases sharply for the other quantities. Nevertheless, the K uptake for BT3 and BT10 is lower than T0. BU10 uptake is slightly higher than T0. Biochar charged with urine have a higher uptake than BT10 and T0. Finally, all the treatments absorb more or less 90% less than the amount of Mg applied (Figure 26).

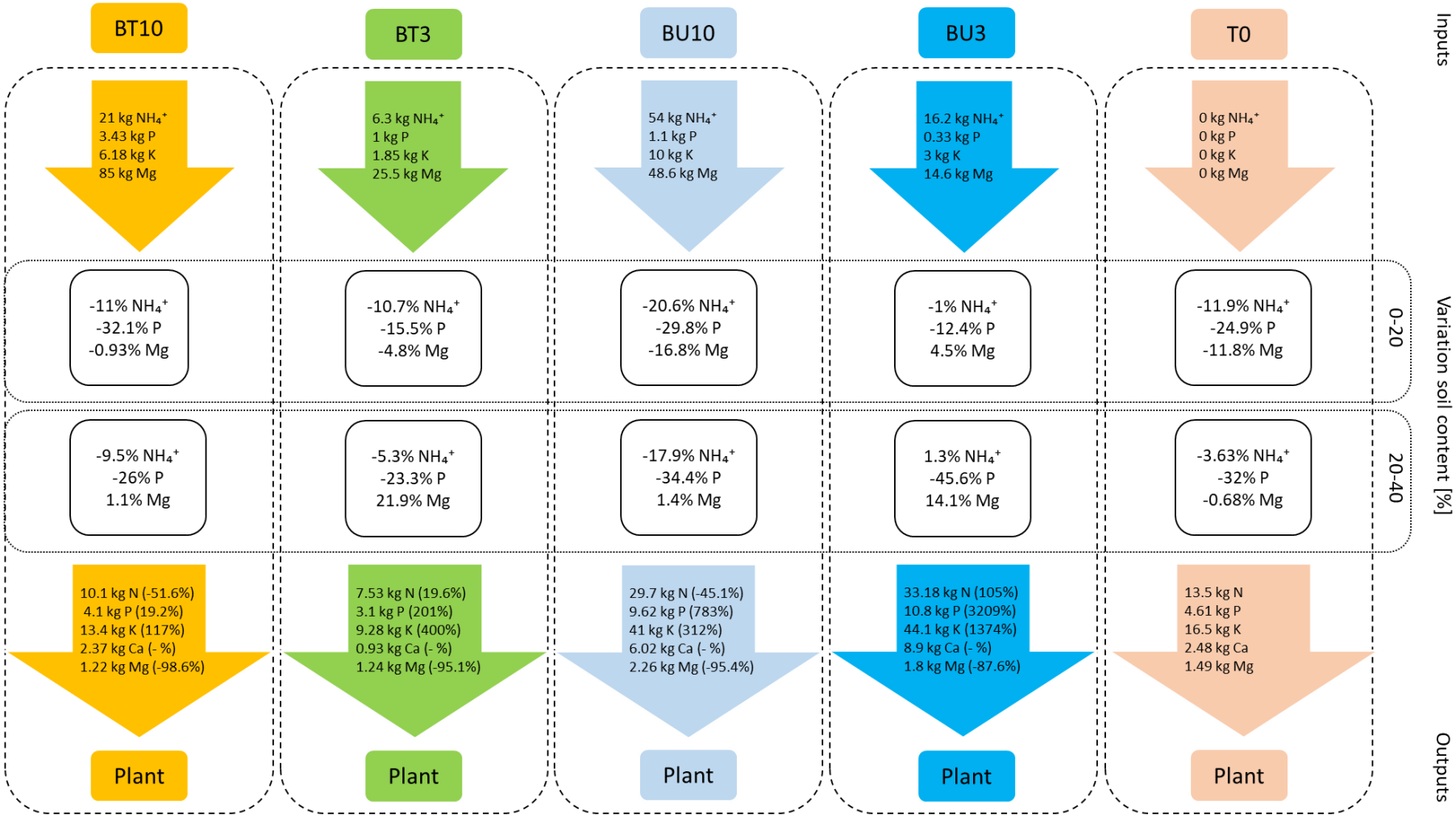


Figure 26: Nutrient flow of the experiment. Both sections utilise the unit "kg/ha" for the nutrients. In the output section, percentage represent the variation of quantities of nutrients compared to the quantity applied for each treatment. The central portion of the figure is constituted of two sections. The first section represents the variation in nutrient content between the soil at depths of 0-20 cm prior to the crop being planted and at the time of harvest. The second section represents the variation for the depth of 20-40 cm.

IV.4.2 Correlations

The initial step entailed an examination of the correlation between each variable for each treatment, utilising the ggpairs function in R Studio (Appendix 10). Subsequently, the significant correlations between the two variables were identified and developed through the use of Pearson's test. The alpha level used for the p-value is 0.05. The objective is to examine the interrelationships between soil parameters, specifically, CEC and pH, and nutrients uptake.

IV.4.2.1 pH KCl

This section examines the relationship between the soil pH KCl at a depth of 0-20 cm in relation to the mean quantity of P uptake by the plant (Figure 27.A) and the mean quantity of Ca uptake by the plant (Figure 27.B). It also examines the relationship between the pH KCl of soil at a depth of 20-40 cm and the mean quantity of Mg uptake by the plant (Figure 27.C). P-values for significant correlations are shown in Table 17.

Table 17 : Correlation coefficient, p-value and meaning for treatments with significant correlation. The designation "S" indicates a significant correlation. The first BU3 in the table is associated with the correlation between the pH KCl of soil at a depth of 0-20 cm and the mean quantity of P uptake by the plant. T0 is associated with the correlation between the pH KCl of soil at a depth of 0-20 cm and the mean quantity of Ca uptake by the plant. The second BU3 in the table is associated with the correlation between the pH KCl of soil at a depth of 20-40 cm and the mean quantity of Mg uptake by the plant.

Figure	Treatment	Correlation	P-value	Meaning
P uptake (A)	BU3	0.999	0.025	S
Ca uptake (B)	T0	-0.999	0.026	S
Mg uptake (C)	BU3	0.999	0.028	S

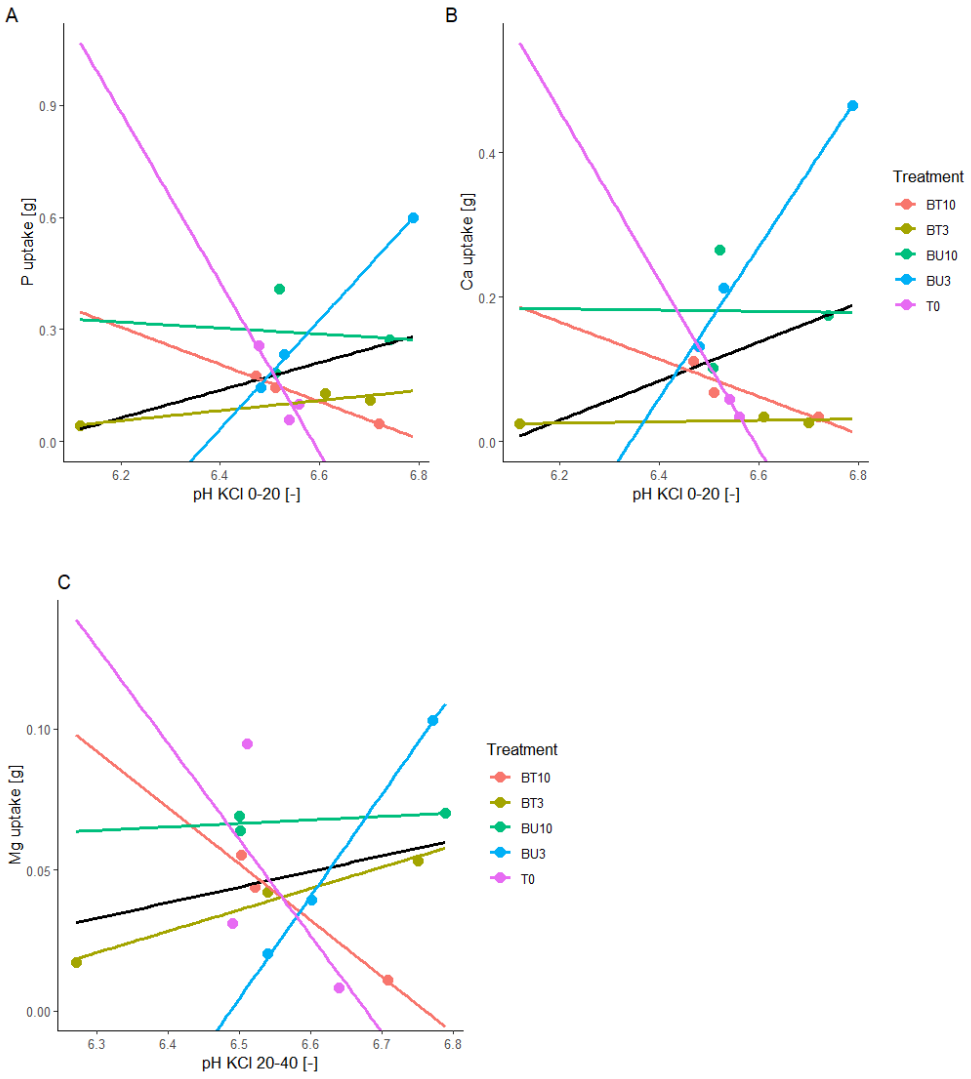


Figure 27 : Distinct regression line for each treatment, with the black line representing the general regression. Figure A illustrates the relationship between the pH KCl in the soil at a depth of 0-20 cm and the mean quantity of P uptake [g] by the plant. Figure B illustrates the relationship between the pH KCl in the soil at a depth of 0-20 cm and the mean quantity of Ca uptake [g] by the plant. Figure C illustrates the relationship between the pH KCl in the soil at a depth of 20-40 cm and the mean quantity of Mg uptake [g] by the plant. The data points represent the individual measurements for each block of permanent bed.

IV.4.2.2 Cation-exchange capacity at 0-20 cm

This section examines the relationship between the CEC at a depth of 0-20 cm in relation to the mean quantity of N uptake by the plant (Figure 28.A) and the mean quantity of K uptake by the plant (Figure 28.B). It also examines the relationship between the CEC and the mean quantity of Mg uptake by the plant (Figure 28.C). P-values for significant correlations are shown in Table 18.

Table 18 : Correlation coefficient, p-value and meaning for treatments with significant correlation. The designation "S" indicates a significant correlation. The BT10 values in the table are associated with the correlation between the CEC at a depth of 0-20 cm and the mean quantity of N, K, and Mg uptake by the plant.

Figure	Treatment	Correlation	P-value	Meaning
N uptake (A)	BT10	-1	0.012	S
K uptake (B)	BT10	-0.998	0.037	S
Mg uptake (C)	BT10	-0.998	0.038	S
	BU10	1	0.007	HS

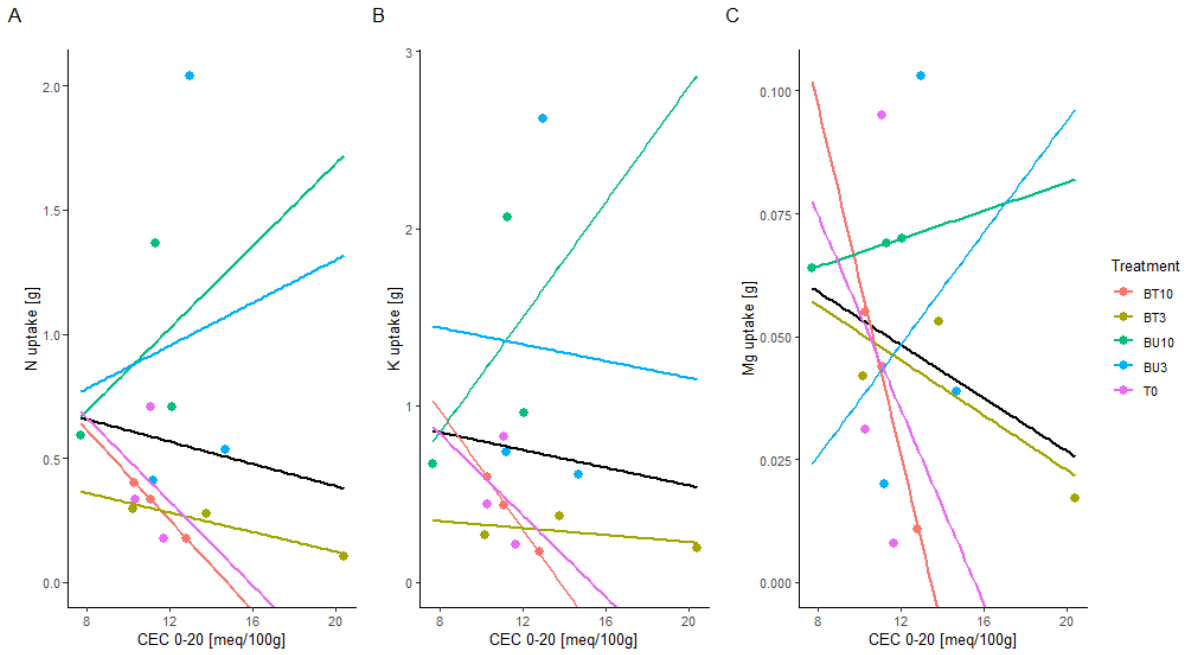


Figure 28 : Distinct regression line for each treatment, with the black line representing the general regression. Figure A depicts the correlation between CEC in the soil at a depth of 0-20 cm [meq/100g] and the quantity of N uptake by the plant[g]. Figure B illustrates the relationship between CEC and K uptake, Figure C between CEC. The data points represent the individual measurements for each block of permanent bed.

IV.4.2.3 Cation-exchange capacity at 20-40 cm

This section examines the relationship between the CEC at a depth of 20-40 cm in relation to the mean quantity of Ca uptake by the plant (Figure 29). P-values for significant correlations are shown in Table 19.

Table 19 : Correlation coefficient, P-value and meaning for treatments with significant correlation. The designation "S" indicates a significant correlation, while "HS" denotes a highly significant correlation. The BU10 is associated with the correlation between the CEC and the mean quantity of Ca uptake by the plant.

Figure	Treatment	Correlation	P-value	Meaning
Ca uptake	BU10	0.998	0.037	S

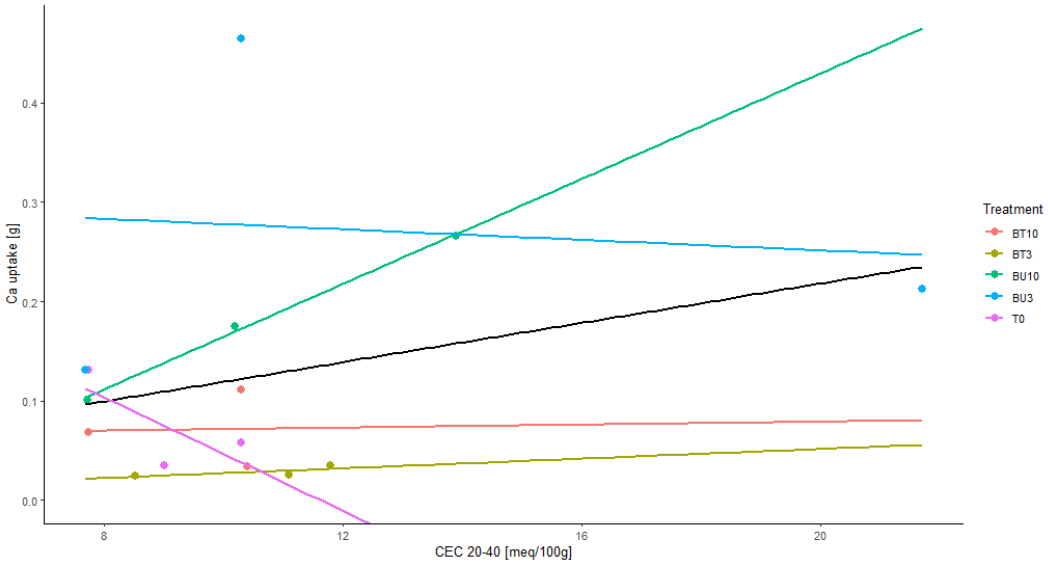


Figure 29 : Distinct regression line for each treatment, with the black line representing the general regression. This figure depicts the correlation between CEC in the soil at a depth of 20-40 cm [meq/100g] and the quantity of Ca uptake by the plant [g].

IV.4.3 Principal component analysis

The subsequent graphs illustrate the individual data points of principal component analysis (PCA) and the variables that contribute to the variance between treatments (Figure 30 and Figure 31). The eigenvalues graph demonstrated that the three initial dimensions of ACP were sufficient to elucidate the total variance. The nutrient uptake data were not used to create graphs, as the objective was to evaluate the differences without the potential confounding influence of nutrient uptake data. The insufficient number of observations for each treatment precluded the creation of ellipses. With the exception of T0, the points for each treatment are not in close proximity to one another. The original variables exhibit disparate values. Upon examination of the centroid for each treatment, it becomes evident that the centroid of BT10 is the most proximate to that of T0. With regard to biomass variables, BU10 and BT3 display a centroid that is markedly disparate from the others (Figure 30). With respect to soil characteristic variables, BU10 evinces characteristics that diverge from those of BU3. BT10, BT3, and T0 exhibit a centroid that is in close proximity to one another (Figure 31).

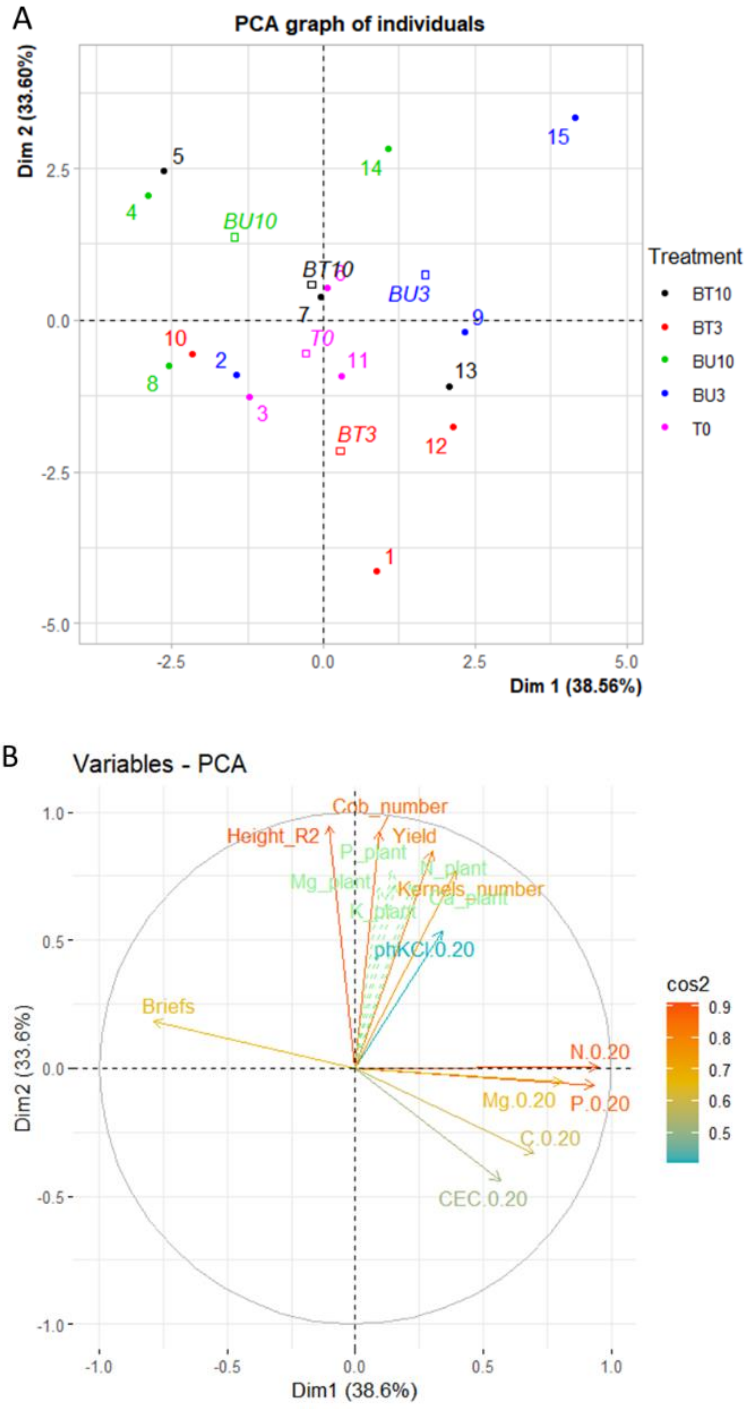


Figure 30 : (A) PCA graph of individuals and (B) variables in dimension 1 and 2. In the B graph, variables with a light green colour are not involved in the construction of the axes. The colour of each variable represents the quality of the representation of that variable. The greater the degree of red in the vector representation in the B graph, the greater the proportion of the observed variance that can be attributed to the underlying components.

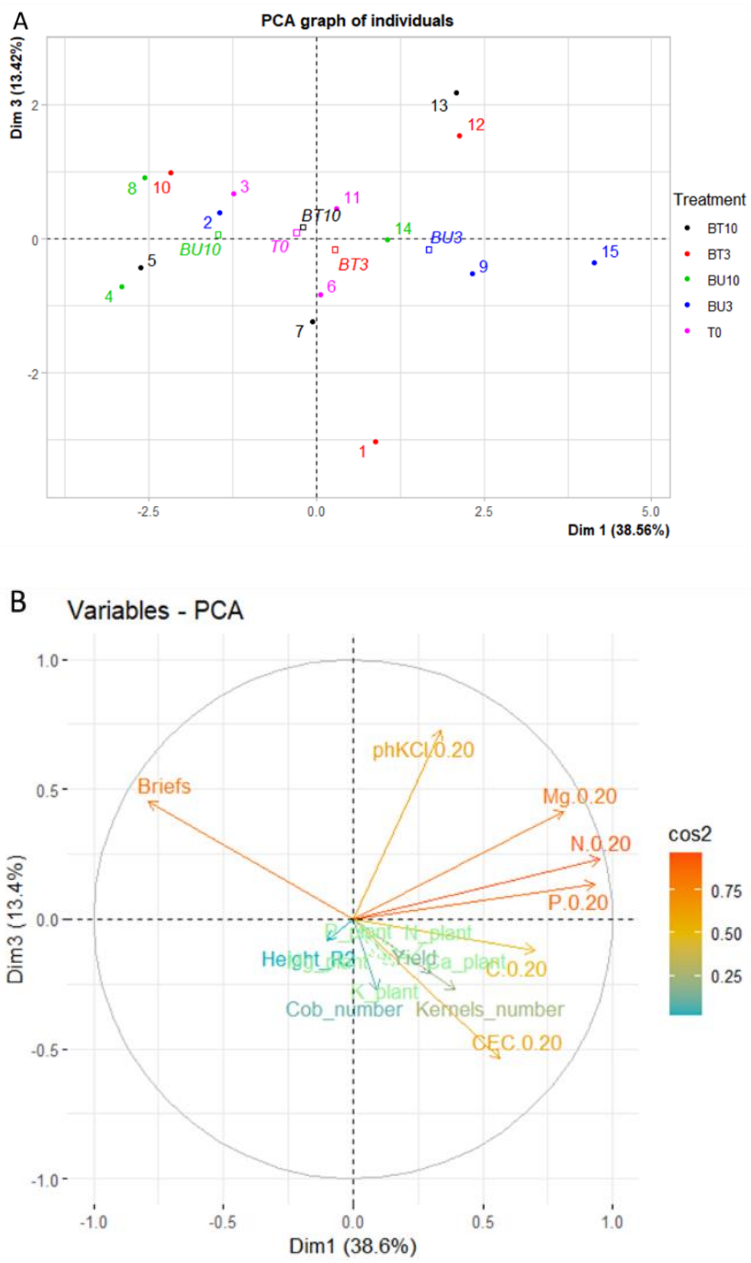


Figure 31 : (A) PCA graph of individuals and (B) variables in dimension 1 and 3. In the B graph, variables with a light green colour are not involved in the construction of the axes. The colour of each variable represents the quality of the representation of that variable. The greater the degree of red in the vector representation in the B graph, the greater the proportion of the observed variance that can be attributed to the underlying components.

V DISCUSSION

V.1 Stress and variability

As evidenced by the nitrogen critical dilution curve and the calculation of harvest index, all plants were subjected to stress during the course of the experiment (K D Subedi et al., 2011; Plenet et al., n.d.). A number of hypotheses can be proposed to explain the multifactorial effect of stress observed in the sweet corn plant. Firstly, the crops were subjected to the negative effects of drought due to irrigation issues. Drought can cause nutrient deficiencies, even in fertilised fields, because the physico-chemical properties of the soil can lead to reduced mobility and absorption of individual nutrients (Amtmann et al., 2009). Furthermore, transpiration is a crucial process in the movement of water and nutrients from the roots to the upper regions of the plant. Drought conditions result in the closure of stomata, which in turn reduces transpiration (Mengel and Kirkby, 2001). Consequently, the transport of nutrients from the roots to the shoot is also constrained by the reduction in transpiration rate (Hu et al., 2007).

Secondly, the effect of drought could have been increased by the mixing of RCW and soil by wild boar. This event reduced the beneficial properties of the mulch, which improves the soil's properties and protects it from extreme temperatures and drought (Dawes, 2010; Wang et al., 2019). The passage of the wild boar could have induced variability due to the fact that the whole unit was not mixed in the same way. Consequently, some units may have been more affected by the high temperatures and dry conditions.

Thirdly, the mixing of soil and RCW resulted in an increased interface between the two materials, thereby rendering RCW more susceptible to degradation by microorganisms. This incident has the potential to induce nitrogen starvation. The application of RCW has the potential to induce nitrogen starvation as a consequence of the competition between the plant for N uptake and the microbial biomass for the mineralisation of RCW (Duchaufour et al., 2020). The rates of mineralisation and immobilisation in soil are dependent upon the availability of C and N pools for microorganisms. As C/N increases, the immobilisation of nitrogen tends to occur, as observed in the present case with RCW (Clough et al., 2013). It can be postulated that incidents involving wild boars have no impact on the level of termite presence. This level

in question is not significantly affected by the RCW mode of application (buried or mulched) (Félix Lancelloti, 2019).

Finally, it is possible that the application of the compost 19 days prior to transplanting, in conjunction with the simultaneous commencement of irrigation, may have resulted in the leaching of nutrients. The leaching of these nutrients may have resulted in nutritional stress. Like explain by Rashmi et al., (2017) leaching occurs when mineralisation and absorption by the plant are not synchronised, and the water flow is sufficient to transport the solute to a depth where it can be transported. The size of biochar particles can also cause nutritional stress. It is possible that the biochar particles were too large and that the liquid was not absorbed efficiently. Indeed, particles was max 40mmx10mm. It has been demonstrated that the physical adsorption capacity of biochar is closely related to its pore diameter. As the surface area of biochar increases, the number of chemical adsorption sites exposed also rises, allowing for greater nutrient absorption (Gong et al., 2019).

The ANOVA test demonstrated a statistically significant difference between treatments for NH_4^+, Ca uptake, cobs number and kernels number of PRB. However, the post-hoc test employed does not permit the creation of distinct groups based on mean values. It can be due to the small sample size of the high variability for treatments (Lee et al., 2018). The high standard deviation of Ca uptake, cobs and kernels number may confirm this hypothesis (Figure 14; Figure 19;Figure 22;Appendix 9).

V.2 Impact of charged biochar on nutrients cycle and soil parameters

The elevated NH_4^+ concentration for BU3 compare to other treatments can be attributed to the hypothesis proposed by Hagemann et al. (2017) and Schmidt et al. (2015). It suggests that the organic molecules present in urine form an "organic coating" on the intra-porous biochar aromatic carbon surfaces and reduce hydrophobicity. This coating subsequently allows for the binding of anions such as nitrate or phosphate, as well as cations like ammonium, through water bridges, resulting in reversible sorption. It can be hypothesised that this organic coating fix also provides nutrients from other sources than biochar, and releases these nutrients at a slower rate. This hypothesis may explain the greater uptake of nutrients by BU3. Another hypothesis may explain this high uptake. The plant with the highest values was on the unit not

modified by wild boar (Appendix 11). The protection provided by the mulch may have helped to maintain a higher level of water in the soil, resulting in better nutrient dynamics in the soil and, consequently, better nutrient uptake.

The hypothesis of organic coating posits that the concentration of other nutrients in BU10 should exceed that of BU3. Furthermore, the soil nutrient content of these two treatments should exceed that of BT10 and BT3. With the exception of the available-P and Mg^{2+} content at depth 0-20, where BU3 exhibits a higher value, this is not the case. The lower NH_4^+ content of BU10 can be attributed to different hypothesis, including the following: microbial activity for the transformation and immobilisation of NH_4^+ is greater than in unit BU3. The hypothesis can be supported by the qualitative analysis of brief degradation, which indicates that BU10 exhibits the highest level of microorganism activity (Figure 25; Appendix 7). Moreover, the low content of N in the BU10 plant compared to the input content (Figure 26) and the ARE value between 0 and 1 can support that a part of the nitrogen has been immobilised.

The comparable NH_4^+ content of BT10, BT3 to T0 may be also attributed to the immobilisation and nitrification by micro-organisms. The presence of BT10 and BT3 with a low N uptake in comparison to BU10 and BU3, their ARE value between -1 and 0 for N lends support that immobilisation was higher than nitrification (Table 16). This hypothesis may be supported by the fact that N uptake is inversely correlated with CEC for BT10. It can be posited that there is a correlation between CEC and microorganisms when biochar is applied, given that biochar has been demonstrated to increase microbial activity and CEC (Clough et al., 2013; Das et al., 2022). This increase in activity can increase immobilisation and reduce the amount of nutrients available to the plant (Dapour et al., 2023; Edenborn et al., 2018). This phenomenon can give rise to issues when a low nitrogen treatment is employed, as microorganisms demonstrate a greater capacity for nitrogen uptake than plants (Moreau et al., 2015). For these two treatments, it can be postulated that the N contents were insufficient to meet the requirements of the microorganisms and the plant.

For available-P, application of biochar enabled more P to be retained in soil and thus increases the availability of this nutrient (Das et al., 2022; Gao et al., 2019; Rashmi et al., 2017). The present study revealed that the quantity of available-P in the soil was not proportional to the quantity of biochar applied. This phenomenon can be attributed to microbiological activity.

The lowest values in 0-20 depth are observed in treatments with the highest doses of biochar, which may indicate that these treatments result in greater microbial activity and greater P immobilization (Baize, 2018). Furthermore, the elevated P uptake observed for urine-charged biochar can be attributed to its comparatively higher pH KCl, in comparison to other samples. This can be explained by the fact that the application of cow manure biochar increases the dynamics of P availability following the increase in soil pH by the biochar (Uzoma et al. 2011). The significant correlation between P uptake and pH KCl at depth 0-20 for BU3 lends support to this hypothesis. The more the biochar raises the pH, the more nutrients are available and the more they can be absorbed by the plant. In the case of BU10, however, the absence of a correlation may be attributed to the limited sample size, which may not have sufficient statistical power to demonstrate a relationship. Finally, the lower values for urine-charged biochar for available P at depth 20-40 can be explained by this elevated P uptake. A larger sample size would have been needed to give more weight to these hypotheses, which are based on trends rather than significant results.

The increase in soil pH, in CEC and in soil organic carbon by biochar could increase the availability of K^+, Mg^{2+} and Ca^{2+} for the plant (Naeem et al., 2017; Randolph et al., 2017). In this study, no treatment increased significantly ph KCl, CEC and organic carbon compare to the base and T0 content. The significant positive correlation between Mg^{2+} uptake and pH KCl for BU3 may be support that biochar increases soil pH and therefore nutrient availability. Due to the size of the samples, it was difficult to assess whether the correlations of the other treatments followed the same trend and whether they are as strong. In terms of nutrient content, the amount of K^+ and Mg^{2+} was higher in the biochar input at 10 t/ha than at 3 t/ha while Ca^{2+} was too low to measure (Figure 26). It can be reasonably assumed that the soil composition for these two treatments would have been greater in quantity than that of the other treatments; however, this is not the case. It can be explained by different hypotheses.

Firstly, the absorption of Mg^{2+} and Ca^{2+} by plants that have undergone the BU10 and BU3 treatments is greater. Moreover, there is a significant correlation between Mg^{2+} uptake and Ca^{2+} uptake and CEC for BU10. This may be attributed to the capacity of BU10 of limiting the leaching of these particles (Naeem et al., 2017; Randolph et al., 2017). In the case of BU3, however, the absence of a correlation may be attributed to the limited sample size, which may not have sufficient statistical power to demonstrate a relationship. As posited by Naeem et al.

(2017), these findings can be attributed to the notable increase in Mg^{2+} content in soil resulting from the addition of cow manure, which in turn enhances Mg^{2+} uptake. Although the values are below the detection limit, it can be estimated that the Ca^{2+} content has also increased.

Secondly, the low Mg^{2+} uptake in plants may be explained by uptake competition between K^{+} and Mg^{2+}. An increased uptake of K^{+} is known to reduce the uptake of Mg^{2+} (Xie et al., 2021). This higher level of K^{+} for urine-charged biochar can be due to the organic coating and the high immobilization level of compost tea-charged biochar.

Thirdly, there are a higher quantity of Mg^{2+} at a depth of 20-40 for the low-dose biochar than for the high-dose biochar. It may be attributed to their reduced capacity to store Mg^{2+} at a depth of 0-20. For all treatments, it can be assumed than one part of Mg^{2+} was leached to 20-40 depth and another was leached totally. Indeed, the important hydrated ionic radius and the correspondingly weak adsorption to soil colloids of Mg^{2+} render them highly susceptible to leaching (Xie et al., 2021).

V.3 Impact of charged biochar on sweet corn characteristics

With the exception of the number of kernels for BT10, which exhibits a comparable value, the remaining parameters demonstrate a higher value for PRB in comparison to PF. A number of hypotheses can be proposed in this context. First, the lower pH value for PF than PRB (Appendix 3). High acid soils, like PF, have a high saturation of cations, including H^{+}, Al^{3+} and Mn^{2+}. These cations have the potential to cause Ca^{2+}, Mg^{2+} and K^{+} deficiency in plants as they can interfere with root uptake of these nutrients (Duchaufour et al., 2020; Xie et al., 2021). Furthermore, such soils have a poor capacity to retain nutrients, which is intensified by the presence of very low mineral reserves and soil organic matter content (Cissé et al., 2021; Duchaufour et al., 2020). Moreover, PRB retains rainfall better, improve soil quality, improve water use efficiency and improve grain yield in corn compared with PF (Govaerts et al., 2005; Parihar et al., 2019).

The significant difference in height and in dry matter for PRB experiment and the significant difference in number of kernels aren't not generally like in other study. Indeed, the enhancement of corn yield is associated with an increase in the rate of biochar application in soil in tropical climates (Lima et al., 2024; Schmidt et al., 2015). Moreover, the application of

biochar to a drought-stressed maize crop resulte in an increase in osmotic potential, transpiration rate, and leaf relative water content (Das et al., 2022).

BU3 has a higher dry matter value because it has a better physiological development due to a better absorption of nutrients (McCauley et al., n.d.). This better development can be explained by the values of the 3 plants on the unit not modified by wild boar, which increase the average BU3 absorption (Appendix 11). Point 15 relating to this unit can support this hypothesis of the two PCA graphs (Figure 30; Figure 31). If the values of BT10 and BU10 are not identical to those of BU3, it may also be attributed to the influence of microbial competition. In fact, their ARE value reinforces this hypothesis (Kumar et al., 2020).

The similarity in height between BU3 and BU10 can be attributed to the superior efficacy in absorbing nutrients when compared to other treatments. Indeed, the application of cow manure biochar increases the dynamics of nutrient availability (Naeem et al., 2017). The similar height of BT10 and these treatments can be attributable to its capacity to enhance water retention (Bako et al., 2021). For PF, the higher amount of P applied for BT10 may be the reason for the higher number of kernels (Bouharmont et al., 2017).

Furthermore, the elevated mean number of cobs and kernels per plant observed for BU10 and BU3 relative to the other treatments can be attributed to their higher P uptake and its impact on their development (Bouharmont et al., 2017; McCauley et al., n.d.).

V.4 Potential of charged biochar for small-scale farmers

One of objectives of the study was to identify solutions that will facilitate the advancement of organic small-scale farming in tropical conditions and encourage the transition away from chemical fertilisers (Alaguraja et al., 2020). It is hypothesised that charged biochar has the capacity to improve this situation.

It is evident that a multitude of alternative liquid organic fertilisers may prove effective for charged biochar. However, as explained above, using urine can be more effective than compost tea. Moreover, the production of effective compost tea can be challenging for small-scale farmers due to the number of ingredients required to produce compost and the necessity

for an optimal aerobic compost tea process (Bako et al., 2021; Kumar et al., 2020; Pant et al., 2012).

In light of the potential for biochar to exacerbate deforestation issues associated with its production and to compete with the use of residues for other purposes, micro-dosing and application to the root zone represents a sustainable use that can help to mitigate these risks (Jones et al., 2012; Kätterer et al., 2022; Schmidt et al., 2015). According to various studies, a large number of field trials have shown that enriching biochar with organic and inorganic nutrients and applying it at low doses (between 0.5 and 2 t/ha) to the root zone of various crops considerably increased crop yields compared with the same fertilization type and amount without biochar (Kätterer et al., 2022; Saba et al., 2023; Schmidt et al., 2017).

VI PERSPECTIVES AND CONCLUSION

It is crucial to identify techniques, or disseminate existing techniques, that can assist small-scale farmers in cultivating crops that are more resilient in the context of climate change. In addition, to improve the sustainability of small farms in tropical countries, it is vital to contemplate strategies enabling producers to assume autonomy in crop fertilisation practices. The utilisation of charged biochar in tropical conditions may offer a promising avenue for enabling farmers to achieve self-sufficiency in fertilisation.

In the case of this study, few analyses and measurements showed significant differences. This may be due to the small number of samples, the high variability and the exceptional events that occurred during the experiment. Due to these events, it was not possible to study the real effects of the various treatments if they had been applied in environments without these disturbances. Despite this, a number of trends emerged. Biochar charged with compost tea and BU10 potentially caused significant immobilisation. This may show that if the soil is poor and other organic fertilisers need to be applied, they should be applied at targeted growth stages of the plant.

In addition, the high BU3 values of the experimental unit less impacted by extreme events may show that RCW applied as mulch can limit the effects of drought on the plant. Apart from this bias, urine-charged biochar appears to be more effective in increasing nutrient availability and yield in sweetcorn. Furthermore, urine-charged biochar seems to be the most realistic combination to use locally, given the complexity of making tea compost. More studies comparing treatments at economically viable doses should be carried out.

It could be interesting to carry out a study to assess the potential of charged biochar for use on small-scale farms in countries with a tropical climate. Part of the study could look at the potential of using a fast-growing plant that is little used in everyday tasks to make biochar. Another part could study the long-term impact on the soil and crop yields to see if this type of practice can be effective on a local scale.

Finally, it may be useful for this type of field experiment to carry out a risk analysis before the start in order to avoid exceptional events biasing the results.

VII PERSONAL CONTRIBUTION

The student participated fully in all aspects of the project. The student achieved to:

- Different meetings with promoters and one of the farm managers to think about it is possible to do and create the project.
- A protocol for carrying out the experiment and programming all manipulations
- The fabrication and the application of charged biochar.
- Different meetings with a laboratory to organise the analysis programme, the sample storage programme.
- A work within a set budget.
- All the crop management operations, such as planting, transplanting and weeding. He also built all the pest control structures, such as the bamboo barrier and the net greenhouse. He also carried out all the research and purchases to combat harmful insects.
- In a manner that sought to minimise disruption to the farm's organisational structure. He also tried to do the work with as little help as possible from volunteers and farm workers.

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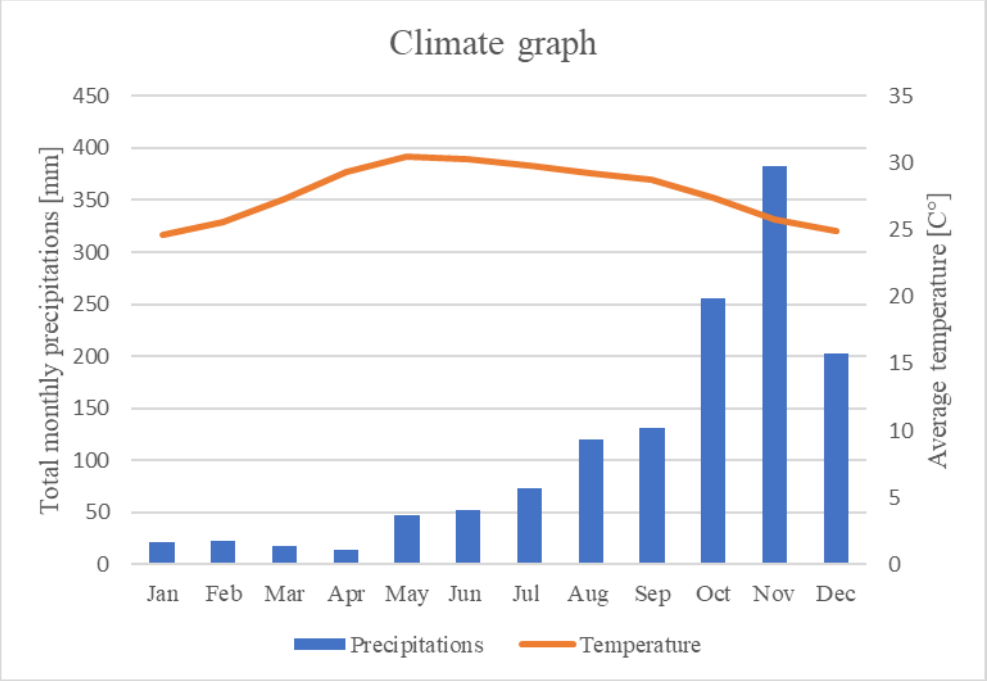
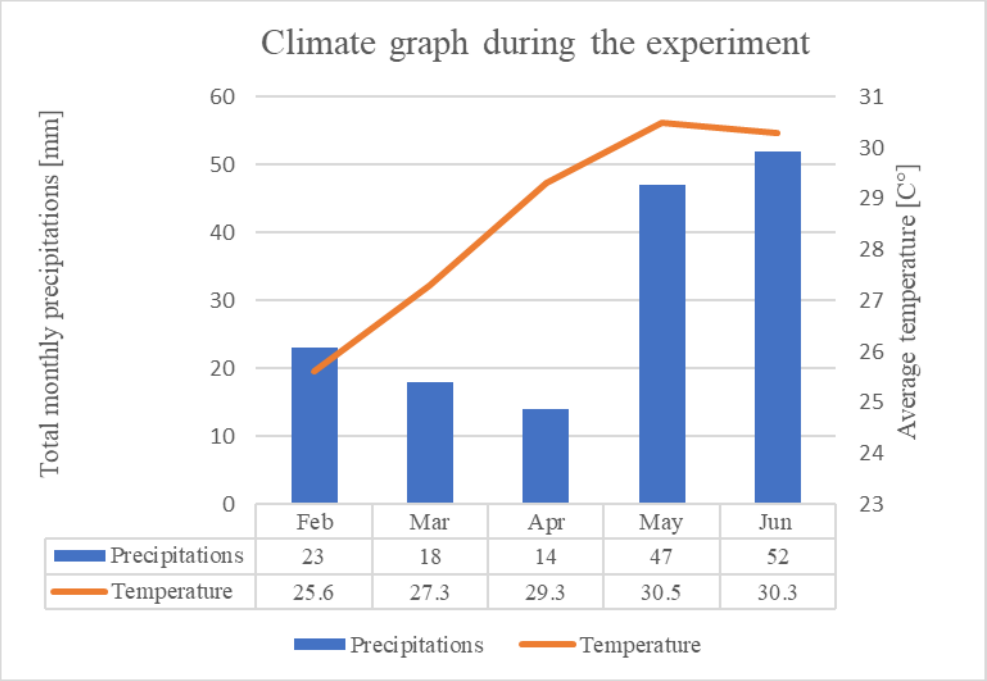
IX APPENDICES

IX.1 Appendix 1

Climate data: Average temperatures measured from 1999 to 2003 (“Auroville climate: Weather Auroville & temperature by month,” May-1-2024) and average precipitations from 1969 to 2023 (“AV Geomatics,” May-3-2024).





IX.2 Appendix 2

Soil description of permanent raised bed.The sample was taken from the middle of the central bed on the PRB

a) **Pre-comments**

i) **Location**

- Geographical coordinates: Lat,Long ; 11°59'05.4"N 79°47'25.2"E
- Adress :
  AuroOrchard
  Edayanchavadi Main Road, Junction, Auroville Rd, Thiruchitrambalam, Tamil Nadu 605111

ii) **General climate**

- Savannah climate with dry winters (Aw)
- Average temperature: 28,2°C

iii) **Rainfall**

- 1341 mm/year between 1969-2023 (“AV Geomatics,” March-24-2024).
- The cumulative rainfall recorded during the experiment was 20.39 mm distributed in 53 days

iv) **Parent material (to develop)**

- Acrisol

v) **Slope**

- 0,5-1% (Nearly level ; class 3), NE
- « Plateau »

Horizon from the top to the bottom for PRB

b) **Surface observations**

i) **Vegetation (description, density)**

- MF : Agroforestery

ii) **Land use**

- Sample taken from a permanent butte on a farm that has been practising organic farming since 2012 and practising agroforestry. The sample was taken on an area without any specific treatment.
- row of acacia on one side and two buttes on the other. The buttes are used to grow vegetables.
- Land-use classification :
  - MF : Agroforestery
- Crop code:
  - Ve : Vegetables
  - Ro : Roots and tubers
  - CeMa : Maize
- Human influence :
  - VE : Vegetation strongly disturbed
  - FE : Application of fertilizers
  - ID : Drip irrigation

    - MO : Organic additions
    - MR : Raised beds
- Vegetation classification :
    - WE : Evergreen woodland

iii) Aspect :

- The soil was covered with Ramial Fragmented Wood of *Acacia auriculiformis*
- The soil received a dose of compost at 25,8 t/ha

iv) Weather (Temperature and rainfall) :

- Temperatue: 32 °C
- Wind gusts: 28 km/h
- Humidity: 52 %
- Rainfall: 0 mm
- SU (sunny, clear), (*Guidelines for soil description*, 2006); WC 1 (no rain in the last month)

c) General conclusion (WRB name, USDA)

Depth (cm)	Horizon diagram	H_2O ph test	Texture		Structure (consistency, porosity)	Colors + coloured spots	Macro-Organisms	Other comments
			The Soil Ribbon Test	Proportions of coarse elements				
0-10	A	6,5	Impossible	very soft, crumbly, sand particles clearly visible	small stones	HUE 7.5 YR 4/4	piece of charcoal, 15% quantity composed of micro-roots and 10% quantity composed of micro-roots	presence of roots on the surface (photo attached)
10-25	AB (intermediate text between the 2)	6	straight ribbon broken all over	Less crumbly than A		HUE 5 YR 4/6	10% quantity composed of micro-roots, charcol	
25-50	B	5,5	¼ break	large accumulation of soil after	small transparent stones, one light orange spot	HUE 5 YR 3/6;	<5 % quantity composed of micro-roots	

				spreading on a white sheet of paper		greyish red spot		
50-95	C	5,5	¾ break	The accumulations are larger than in B	Small stones (+- 1 mm) which reflect the colour in sunlight are present in all soil sample, yellow stone (1% quantity composed of micro-roots)	HUE 5 YR 3/6; greyish-black spot => picture		

IX.3 Appendix 3

Soil description of ploughed field part for the experiment. The sample was taken in the middle of the middle bed create for the experiment on PF

Horizon from the top to the bottom for PF part used

a) <u>Pre-comments</u>

i) <u>Location</u>

- <u>Geographical coordinates</u> : Lat,Long ; 11.98496236263801, 79.79034145275718
- <u>Adress :</u>
  AuroOrchard
  Edayanchavadi Main Road, Junction, Auroville Rd, Thiruchitrambalam, Tamil Nadu 605111

ii) General climate

- Savannah climate with dry winters (Aw)
- Average temperature: 28,2°C

iii) Rainfall

- 1341 mm/year between 1969-2023 ("AV Geomatics," March-24-2024).
- During experiment: 20.39 mm

iv) Parent material

- Acrisol

v) Slope

- 1-2% (Very gently sloping ; class 4)

b) Surface observations

i) Vegetation (description, density)

- MF : Agroforestery

ii) Land use

- Crop code:

    - Ve : Vegetables
    - Ro : Roots and tubers
    - CeMa : Maize
- Human influence :
    - VE : Vegetation strongly disturbed
    - FE : Application of fertilizers
    - ID : Drip irrigation (before the beginning of the experiment: IP: flood irrigation)
    - MO : Organic additions
    - MR : Raised beds (before these raised beds were formed, especially for the experiment, the soil was ploughed over 20 cm)
- Vegetation classification :
    - WE : Evergreen woodland

iii) Aspect

- The soil was covered with Ramial Fragmented Wood of *Acacia auriculiformis*

iv) Weather (Temperature and rainfall) :

- Temperatue: 32 °C
- Wind gusts: 28 km/h
- Humidity: 52 %
- Rainfall: 0 mm

c) General conclusion (WRB name, USDA)

Depth (cm)	Horizon diagram	H_2O ph test	Texture		Structure (consistency, porosity)	Colors + coloured spots	Micro-Organisms	Other comments
			The Soil Ribbon Test	Proportions of coarse elements				
0-10	A	6	Impossible	Very soft, crumbly, sandly		HUE 7.5 YR 3/3	10% quantity composed of roots, 5 % quantity composed of charcoal 5 % quantity composed of plant debris	Yellow spot
10-25	AB	4	¼ break	Small sand particles in 50% of the quantity		HUE 5 YR ¾	<1 % of plant debris	
	B	3,5	100 % small break in the middle but the ribbon can be made	Small sand particles in 25% of the quantity		HUE 5 YR 3/6		Boundary between the 2 horizons difficult to measure
55-95	C	3,5	100 % small break in the ¾ but the ribbon can be made	Small sand particles in 10% of the quantity		HUE 5 YR 3/6		

IX.4 Appendix 4

Soil description of ploughed field part unmodified. This description was made on the part of the micro field not used for the experiment.

a) <u>Pre-comments</u>

i) <u>Location</u>

- Geographical coordinates : Lat,Long ; 11.98496236263801, 79.79034145275718
- Adress :
  AuroOrchard
  Edayanchavadi Main Road, Junction, Auroville Rd, Thiruchitrambalam, Tamil Nadu 605111

ii) <u>General climate</u>

- Savannah climate with dry winters (Aw)
- Average temperature: 28,2°C

iii) **Rainfall**

- 1341 mm/year between 1969-2023 (“AV Geomatics,” March-24-2024).
- During experiment : 20.39mm

iv) **Parent material**

- Acrisol

v) **Slope**

- 1-2%

b) **Surface observations (presence of groundwater ?, drainage?)**

i) **Vegetation (description, density)**

- MF : Agroforestery

ii) **Land use :**

- Crop code:
  - Ve : Vegetables
  - Ro : Roots and tubers
  - CeMa : Maize
- Human influence :
  - VE : Vegetation strongly disturbed
  - FE : Application of fertilizers
  - ID : Drip irrigation (before the beginning of the experiment: IP: flood irrigation)
  - MO : Organic additions
- Vegetation classification :
  - WE : Evergreen woodland

iii) **Aspect :**

iv) **Weather (Temperature and rainfall)**

- Temperatue: 32 °C
- Wind gusts: 28 km/h
- Humidity: 52 %
- Rainfall: 0 mm

c) **General conclusion (WRB name, USDA)**

Horizon from the top to the bottom for PF part unused

Depth (cm)	Horizon diagram	H_2O ph test	Texture		Structure (consistency, porosity)	Colors + coloured spots	Micro-Organisms	Other comments
			The Soil Ribbon Test	Proportions of coarse elements				
0-10	A	7	Impossible			HUE 7.5 YR ¾	5% of quantity composed of charcoal, 5 % of plant debrits, 5 % of roots	More difficult to dig
10-25	AB (based on texture)	6	½ break			HUE 5 YR ¾	1% quantity composes of plant debrits	
25-55	B	5,5	100 %		Same stones as AB	HUE 5 YR 3/6	1% quantity composes of plant debrits, charcoal,	
55-95	C	4,5				HUE 2.5 YR 3/6	1% quantity composes of plant debrits, charcoal,roots	

IX.5 Appendix 5

Cultural precedent

BED 1

BED 2

Year	Month	Bed 1	Bed 2	Micro-field
2021	Sep	Cucumber	Bottle Gourd	Sesbania (Green manure)
	1-15 oct	*Bare soil*		
	15 -31 Oct	Cucumber		
	1- 15Nov			
	15-30Nov	*Bare soil*	Cucumber	
	Dec			Brinjal Striped
2022	Jan			
	Feb	Pole bean		
	Mar -Apr		Beanharicot	
	May	*Bare soil*		
	7-31May		*Bare soil*	
	June-July		Cucumber	
	Aug-15 Sep	Sunhemp (Green manure)		
	15-31 Sep	Bottle Gourd	Sunhemp (Green manure)	Cucumber
	Oct		Bottle Gourd	Cucumber/Sweet corn
	Nov		Long bean	Azuki bean bean
	Dec	Brinjal		
2023	Jan-Feb			Long bean
	Mar- May		Cucumber	
	Jun-15 Jul		Brinjal	
	15-31 Jul			Sunhemp (Green manure)
	Aug-Sep	*Bare soil*		
	Oct- Dec			Ladies fingers

2024	Jan-Feb			Sunhemp (Green manure)

IX.6 Appendix 6

1. Composition of the 6-week-old compost

Element used	Quantity	Unit
Acacia auriculiformis RCW	80	%
Cow dung	8	%
Hens litter	8	%
Biochar	4	%

2. Composition of the nursery substrate

Element used	Quantity	Unit
6-week-old compost	49.85	%
Soil	24.92	%
Coco peat	24.92	%
Neem cake	0.28	%
Pseudomonas	0.01	%
Trichoderma	0.01	%

3. Composition of the compost tea

Element used	Quantity	Unit
Water	92.59	%
6-week-old sieved compost	4.63	%
Jaggery	2.78	%
Stone meal	0.69	%
Salt	0.23	%

IX.7 Appendix 7

Soil your Undies protocol

1. Objective:

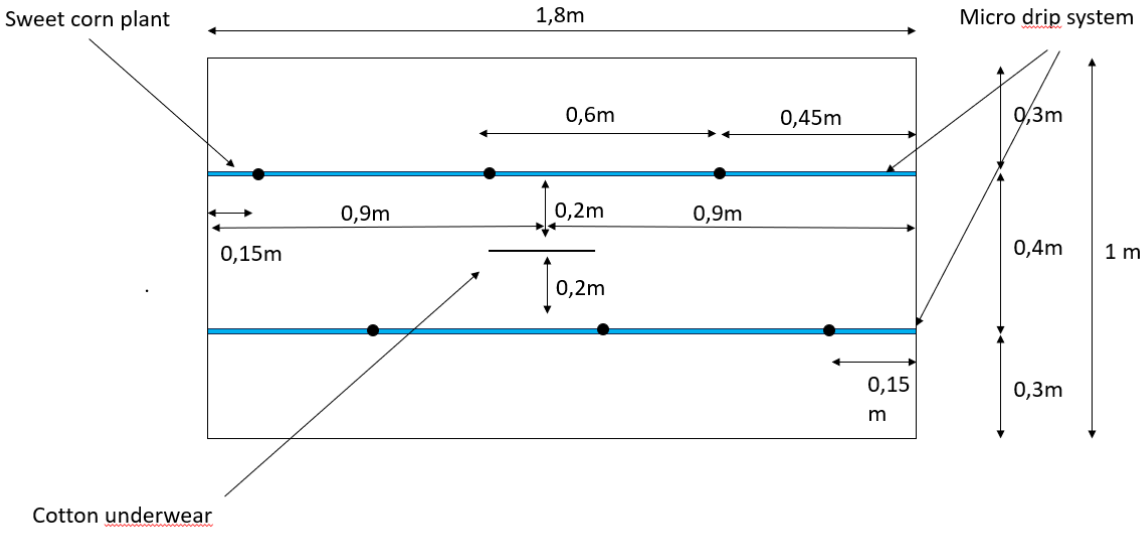
The objective of this test is to have a representation of soil microbial activity. A less precise alternative that laboratory analyses has been found by "Innovative Farmers Association of Ontario": bury a pair of cotton underwear in the soil ("Soil-Your-Undies-protocol-2016.pdf," May-7-2024). In the case of this study, a cotton underwear was buried in each block.

2. Material and methods:

New pairs of white 100% cotton briefs (no dyes, no boxers, no polyester blends) was used. A number of steps were taken to conduct this test:

1. The briefs have been weighed
2. A trench was dug so that the briefs could be placed vertically in the ground. Each layer of soil removed was separated to return the soil to its original depth.
3. The briefs were collected after a period of two months. Remove briefs carefully and rinse with water
4. Subsequently, the specimens were meticulously removed from the ground, washed and air-dried.
5. The final weight of each slip was weighed to compare the differences between each unit.

3. Experimental unit:



4. Result

	T0	BT3	BU3	BT10	BU10
% degradation	41.8	46.5	48.6	38.3	31.9
Photo of briefs after 2 months					
					

					
Control					

IX.8 Appendix 8

Test methods in laboratory :

1. **Soil parameters**
   a) **Total Nitrogen Ammonical form %**

      This test is based on IS 14684 (1999): Determination of Nitrogen and Nitrogenous Compounds in Soils [FAD 7: Soil Quality and Fertilizers]

      Procedure:

      1) The Kjeldahl procedure
      2) Calculate total nitrogen in ammonical form, percent by mass of soil taken for the test by using the following formula: 1 ml of 0.1 N standard sulphuric acid= 0.0014 g of nitrogen.

   b) **Available Phosphorous as P**

      This test is based on Manual of Soil Testing in India, Department of Agriculture and Cooperation, Ministry of Agriculture, GOI, 2011. The method used is the Bray's method N°1 for acid soils.

   c) **Available Potassium as K (FAO method)**

      This test is based on Bashour I.I. & Sayegh A.H., 2007. *Methods of analysis for soils of arid and semi-arid regions*, Rome: Food and Agriculture Organization of the United Nations. It is generally accepted that routine laboratory tests for determining plant-available potassium do not accurately reflect the true situation under field conditions, due to the inherent variability in soil clay mineralogy.

      Procedure:

      1) Weigh accurately 5 g of soil and transfer into a 50 ml centrifuge tube.
      2) Add 20 ml of 1.0 M ammonium acetate solution to the tube; stopper and shake in a reciprocal shaker for 5 minutes.
      3) Centrifuge at 2000 rpm for 5 minutes or until the supernatant is clear.
      4) Decant the supernatant into a 100 ml volumetric flask.
      5) Repeat steps 2 – 4 three more times.

6) Make up the supernatant volume to 100 ml by adding ammonium acetate solution.
7) Prepare a series of working K standard solutions in the range of 0 – 2 meq/l of K from stock solution of 0.02 M KCl already prepared. For better results, add LiCl in each standard to yield a final concentration of about 5 meq/l of LiCl.
8) Determine K concentration in the extract by flame photometer as in section 6.3.2 and 8.1.

d) Exchangeable Calcium as Ca and Mg

This test is based on Reeuwijk L.P. van, 2002. Procedures for soil analysis, Technical paper / International Soil Reference an Information Centre, Wageningen: International Soil Reference and Information Centre. They used "ammonium acetate method".

9-5.1 Principle

Exchangeable Ca and Mg are measured by flame atomic absorption spectrophotometry (AAS) and exchangeable K and Na by flame emission spectrophotometry (FES) in ***percolate A***. The CEC is measured through Na by FES in ***percolate B***. For Ca and Mg measurement La (5000 mg/l or 0.5%) is introduced to prevent formation of refractory compounds of Ca and Mg in the flame. For Na and K measurement Cs (1000 mg/l or 0.1%) is introduced to overcome ionization interference.

9-5.3 Procedure

9-5.3.1 Exchangeable Ca and Mg

Standard series

1. Dilute the 1000 mg/l Ca standard solution to 250 mg/l: pipette 50 ml into a 200 ml volumetric flask, make to volume with water.
2. Dilute the 1000 mg/l Mg standard solution to 25 mg/l: pipette 25 ml into a 1 l volumetric flask, make to volume with water.
3. Of the 250 mg/l Ca solution and the 25 mg/l Mg solution pipette a series of 0-5-10-15-20-25 ml into 250 ml volumetric flasks respectively.
4. To each flask add 25 ml NH_4OAc 1 *M* solution and 125 ml 1% La solution. Make to volume with water. The standard series are then: 0-5-10-15-20-25 mg/l Ca and 0-0.5-1.0-1.5-2.0-2.5 mg/l Mg.

Measurement

Pipette 1 ml of ***percolate A*** (see 9-4.2.2) and 9 ml of the 0.55% La suppressant solution into a test tube, homogenize and measure Ca and Mg in this solution by AAS at wavelengths of 422.7 and 285.2 nm respectively.

e) pH KCl and pH H_2O

These tests are based on ISO 10390: 2021.
Procedure:

1) Preparation of the suspension. A suspension of a test portion is made up in five times its volume with one of the following solutions:
   - water
   - a solution of KCl in water, concentration = 1 mol/l
2) Calibration of the pH-meter
3) Measurement of the pH

g) CEC (FAO method)

This test is based on Bashour I.I. & Sayegh A.H., 2007. *Methods of analysis for soils of arid and semi-arid regions*, Rome: Food and Agriculture Organization of the United Nations.

1) Weigh accurately about 5 g soil and transfer the sample to a 50 ml centrifuge tube.
2) Add 30 ml of 1.0 M sodium acetate solution to the tube, stopper and shake in a mechanical shaker for 5 minutes.
3) Centrifuge at 2000 rpm for 5 minutes or until the supernatant liquid is clear.
4) Decant the liquid completely and repeat the extraction three more times. Discard the decants.
5) Repeat steps 2 – 4 with ethanol or isopropyl alcohol until the EC of the decant reads less than 40 mS/cm (usually it takes 4 to 5 washings).
6) To displace the adsorbed Na, repeat steps 2 – 4 using the ammonium acetate solution. Collect the decants in 100 ml volumetric flask fitted with a funnel and filter paper. Make up to volume with ammonium acetate solution.
7) To determine sodium concentration by flame photometry (see section 6.3.2), prepare a series of Na standard solutions in the range of 0 – 4 meq/l of Na. For better results, add LiCl in each standard to yield a final concentration of about 5 meq/l of LiCl.

f) Organic carbon (IS method)

This test is based on "IS 2720 (Part 22) :1972.

6. PROCEDURE

6.1 The sample shall be placed in a glass weighing bottle and weighed to 0·001 g. A small quantity, from 5 g to 0·2 g depending on the organic content (*see* Note) shall be transferred to a dry 500-ml conical flask, the weighing bottle reweighed and the equivalent weight on oven-dry basis of soil specimen removed (W_3) calculated by difference and allowing for the moisture content of the soil.

NOTE — The size of the specimen for chemical analysis will vary with the amount of organic matter present in the soil. As much as 5 g may be required for soil low in organic matter and as little as 0·2 g with a very peaty soil. After a number of determinations have been made, experience will indicate the most suitable size of specimen to be taken. In unfamiliar types of soil it is suggested that a series of specimens of varying sizes should be weighed out and tested. The determination giving a total of 5 to 8 ml dichromate solution reduced should be taken as the correct result.

6.2 Ten millilitres of N potassium dichromate solution shall be run into the conical flask from a burette, and add 20 ml of concentrated sulphuric acid very carefully from a measuring cylinder. The mixture shall be thoroughly swirled for about one minute and allowed to stand on a heat insulating surface, such as asbestos, or wood, for 30 min to allow oxidation of the organic matter to proceed. During this period the flask shall be protected from draughts. Distilled water, 200 ml, shall then be added along with 10 ml of orthophosphoric acid and one ml of the indicator (*see* Note). The mixture shall be shaken vigorously. If the indicator is absorbed by the soil, a further 1 ml of the solution shall be added. Ferrous sulphate solution shall then be added from the second burette in 0·5 ml increments, the contents of the flask being swirled, until the colour of the solution changes from blue to green. A further 0·5 ml of potassium dichromate shall then be added, changing the colour of the solution back to blue. Ferrous sulphate solution shall then be added drop by drop with continued swirling until the colour of the solution changes from blue to green after the addition of a single drop. The total volume of the ferrous sulphate solution used (Y) shall be noted to the nearest 0·05 ml.

NOTE — If complex ferric ions which interfere with the end point are present in the soil, after the addition of 10 ml of orthophosphoric acid, 0·2 g of sodium fluoride may be added before the addition of the indicator.

7. CALCULATIONS

7.1 The total volume (V ml) of potassium dichromate used to oxidize the organic matter in the soil is given by the following formula:

$$V = 10{\cdot}5\ (1 - Y/X)$$

where

Y = total volume of ferrous sulphate used in this test, and

X = total volume of ferrous sulphate used in the standardization test (*see* **4.1**).

7.2 The percentage of organic matter (OM) present in the oven-dried sample shall be calculated from the following formula:

$$\text{OM, percent by weight} = \frac{0{\cdot}67\ W_2\ V}{W_1\ W_3}\ (\textit{see}\ \text{Note})$$

where

W_2 = weight on oven-dry basis of the soil sample passing 10-mm IS Sieve,

V = total volume of potassium dichromate used to oxidize the organic matter (as in **7.1**),

W_1 = weight on oven-dry basis of the total soil sample taken for the test before sieving, and

W_3 = weight on oven-dry basis of the soil specimen used in the test.

2. Nutrients in plant

a) Total Nitrogen

This test is based on IS 14684 (1999): Determination of Nitrogen and Nitrogenous Compounds in Soils [FAD 7: Soil Quality and Fertilizers]. The Kjeldahl procedure was used

b) Total Phosphorus

This test is based on Manual of Soil Testing in India, Department of Agriculture and Cooperation, Ministry of Agriculture, GOI, 2011. They used "Olsen's method".

c) Total Potassium

This test is based on FCO: 1985 (Part D). The method used is "Flmae photometry method":

Procedure:

1) Take 5g sample in a porcelain crucible and ignite the material to ash at650-700 C in a muffle furnace.
2) Cool it and dissolve in 5 ml concentrated hydrochloric acid, transferin a 250 ml beaker with several washing of distilled water and heat it.
3) Again, transfer it to a 100 ml volumetric flask and make up the volume.
4) Filter the solution and dilute the filtrate with distilled water so that theconcentration of K in the working solution remains in the range of 0to20 ppm, if required.
5) Determine K by flame photometer using the K- filter after necessarysetting and calibration of the instrument.
6) Read similarly the different concentration of K of the standardsolution in flame photometer and prepare the standard curve by plottingthe reading against the different concentration of the K.
7) Calculation: Potash (K) %by weight = R X 20 X diluting factor, whereR= ppm of K in the sample solution (obtained by extra plotting from standard curve)

d) Total Calcium and Total Magnesium

This test is based on Manual of Soil Testing in India, Department of Agriculture and Cooperation, Ministry of Agriculture, GOI, 2011. They used Versenate (EDTA) method. Procedure :

1) Take 5 g air dried soil sample in 150 ml conical flask and add 25 ml of neutral normal ammonium acetate. Shake on mechanical shaker for 5 minutes and filter through Whatman filter paper No.1.
2) Take a suitable aliquot (5 or 10 ml) and add 2-3 crystals of carbamate and 5 ml of 16% NaOH solution.
3) Add 40-50 mg of the indicator powder. Titrate it with 0.01N EDTA solution till the colour gradually changes from orange red to reddish violet (purple). It is advised to add a drop of EDTA solution at an interval of 5 to 10 seconds, as the change of colour is not instantaneous.
4) The end point must be compared with a blank reading. If the solution is over titrated, it should be back titrated with standard calcium solution and exact volume used is thus found.
5) Note the volume of EDTA used for titration.

IX.9 Appendix 9

The following table presents the mean and standard deviation of soil parameters for the 0-20 depth for PRB.

	0-20									
							Available		Exchangeable	
	pH-H_2O	pH-KCl	Total NH_4^+	CEC	Organic C	diff. weight Brief	P	K	Ca	Mg
Treatment	-	-	mg/kg	meq/100g	%	g	mg/kg	meq/100g		
T0	6.68 ±0.170	6.53 ±0.0416	1502 ±143	11 ±0.702	1.77 ± 0.0577	54.7 ±4.040	72.6 ±11.9	<0.5	<0.5	12.9 ±1.12
BT3	6.69 ±0.449	6.48 ±0.312	1523 ±218	14.8 ±5.17	1.61 ±0.329	50.3 ±14.6	81.7 ±20.3	<0.5	<0.5	14 ±2.40
BU3	6.71 ±0.234	6.6 ±0.166	1687 ±229	13 ±1.75	1.79 ±0.0693	46.3 ±18.8	84.7 ±26.4	<0.5	<0.5	15.3 ±2.72
BT10	6.79 ±0.0781	6.57 ±0.134	1517 ±316	11.4 ±1.28	1.65 ±0.350	58 ±17.5	65.7 ±21.6	<0.5	<0.5	14.5 ±3.74
BU10	6.81 ±0.172	6.59 ±0.130	1354 ±234	10.4 ±2.34	1.34 ±0.182	64 ±9	67.9 ±14.9	<0.5	<0.5	12.2 ±1.71
p-value	*0.948*	*0.91*	*0.022*	*0.345*	*0.21*	*0.597*	*0.709*	/	/	*0.583*
Meaning	NS	NS	S	NS	NS	NS	NS	/	/	NS
			=							

The following table presents the mean and standard deviation of soil parameters for the 20-40 depth for PRB.

	20-40								
						Available		Exchangeable	
	pH-H_2O	pH-KCl	Total NH_4^+	CEC	Organic C	P	K	Ca	Mg
Treatment	-	-	mg/kg	meq/100g	%	mg/kg		meq/100g	
T0	6.78 ±0.121	6.55 ±0.0814	823 ±138	9.02 ±1.28	0.877 ±0.136	52 ±9.24	<0.5	<0.5	8.31 ±1.11
BT3	6.76 ±0.304	6.52 ±0.241	808 ±160	10.5 ±1.73	0.857 ±0.114	58.6 ±25.5	<0.5	<0.5	10.2 ±2.28
BU3	6.83 ±0.203	6.64 ±0.119	865 ±123	9.02 ±1.28	0.833 ±0.102	41.6 ±15	<0.5	<0.5	9.55 ±0.942
BT10	6.89 ±0.106	6.58 ±0.116	773 ±150	9.48 ±1.51	0.807 ±0.103	56.6 ±10.0	<0.5	<0.5	8.46 ±0.197
BU10	6.84 ±0.159	6.6 ±0.167	701 ±110	10.6 ±3.11	0.78 ±0.0721	50.2 ±7.68	<0.5	<0.5	8.49 ±1.55
p-value	*0.926*	*0.901*	*0.67*	*0.699*	*0.813*	*0.677*	/	/	*0.423*
Meaning	NS	NS	NS	NS	NS	NS	/	/	NS

The following table presents the mean and standard deviation of biomass parameters for PRB.

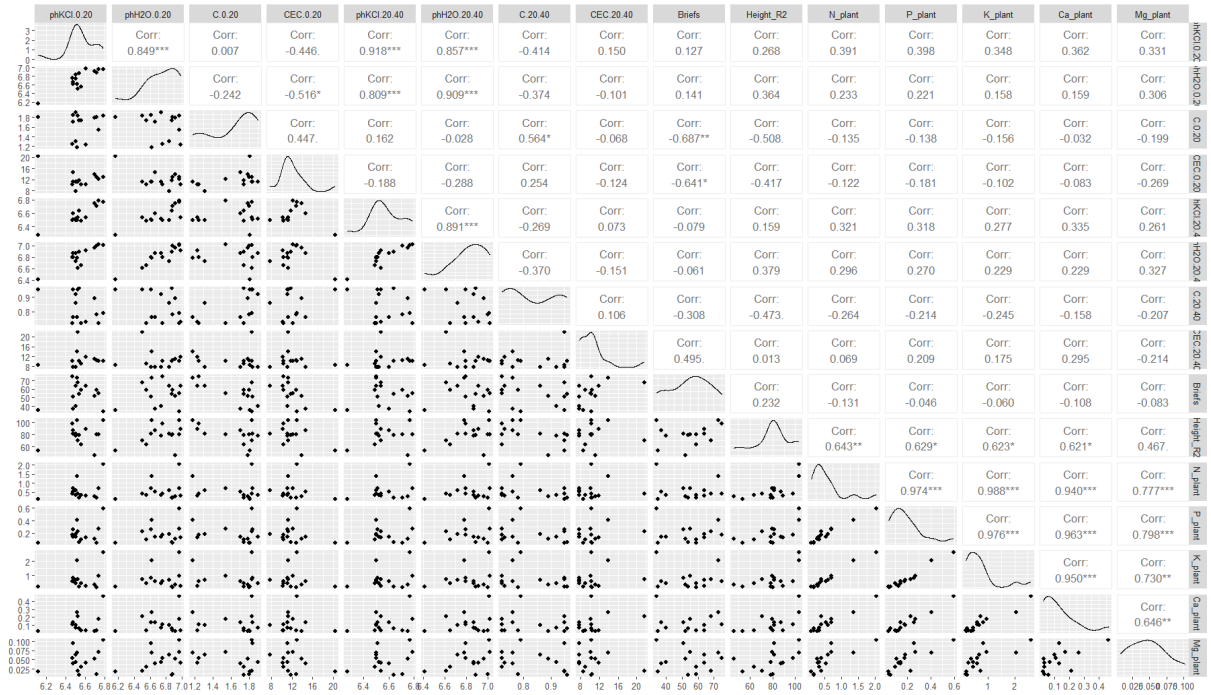
	Permanent Raised BEDS (PRB)								
	N	P	K	Ca	Mg	Height R2	Dry matter	Cobs num.	Kernels num.
Treatment			g			cm	g	-	-
T0	0.406 ±0.271	0.138 ±0.106	0.494 ±0.309	0.0743 (a) ±0.0505	0.0447 ±0.0451	78.5 (b) ±11.1	54.2 (ab) ± 50	0.56 ±0.726	0.56 ±1.67
BT3	0.226 ±0.105	0.093 ±0.045	0.278 ±0.089	0.028 (a) ±0.0053	0.0373 ±0.0184	56.1 (a) ±18.0	15.9 (a) ± 9.45	0.22 ±0.441	0
BU3	0.995 ±0.909	0.325 ±0.241	1.32 ±1.13	0.269 (a) ±0.174	0.054 ±0.0435	87.9 (ab) ±11.0	152 (b) ± 110	1.11 ±1.05	1.44 ±2.70
BT10	0.304 ±0.116	0.123 ±0.066	0.403 ± 0.214	0.071 (a) ±0.0386	0.0367 ± 0.0229	86.4 (ab) ±22.0	113 (ab) ± 157	1.11 ±0.928	0.78 ±1.72
BU10	0.889 ±0.418	0.289 ±0.113	1.23 ±0.734	0.181 (a) ±0.083	0.0677 ±0.00321	87.1 (ab) ±21.4	106 (ab) ±93.2	1.44 ±1.01	1.33 ±2.83
p-value	*0.225*	*0.19*	*0.196*	*0.048*	*0.718*	*0.049*	*0.255*	*0.096*	*0.964*
Meaning	NS	NS	NS	S	NS	HS	S	NS	NS
						BT3 ≠ T0 ≠ (BT10,BU10,BU3)	BT3 ≠ (T0,BT10,BU10) ≠ BU3		

The following table presents the mean and standard deviation of biomass parameters for PF.

	Ploughed Field (PF)			
	Height R2	Dry matter	Cobs num.	Kernels num.
Treatment	cm	g	-	-
T0	53.3 ±36.8	20.2 ±18.9	0.556 ±0.705	0.056 (b) ±0.236
BT10	67.2 ±27.3	29.3 ±21.0	0.722 ±0.752	0.889 (a) ±1.75
BU10	63.6 ±20.2	27.8 ±22.8	0.889 ±0.963	0.169 (ab) ±0.383
p-value	*0.316*	*0.255*	*0.681*	*0.023*
Meaning	NS	NS	NS	S
				T0≠BT10≠BU10

IX.10 Appendix 10

1. General



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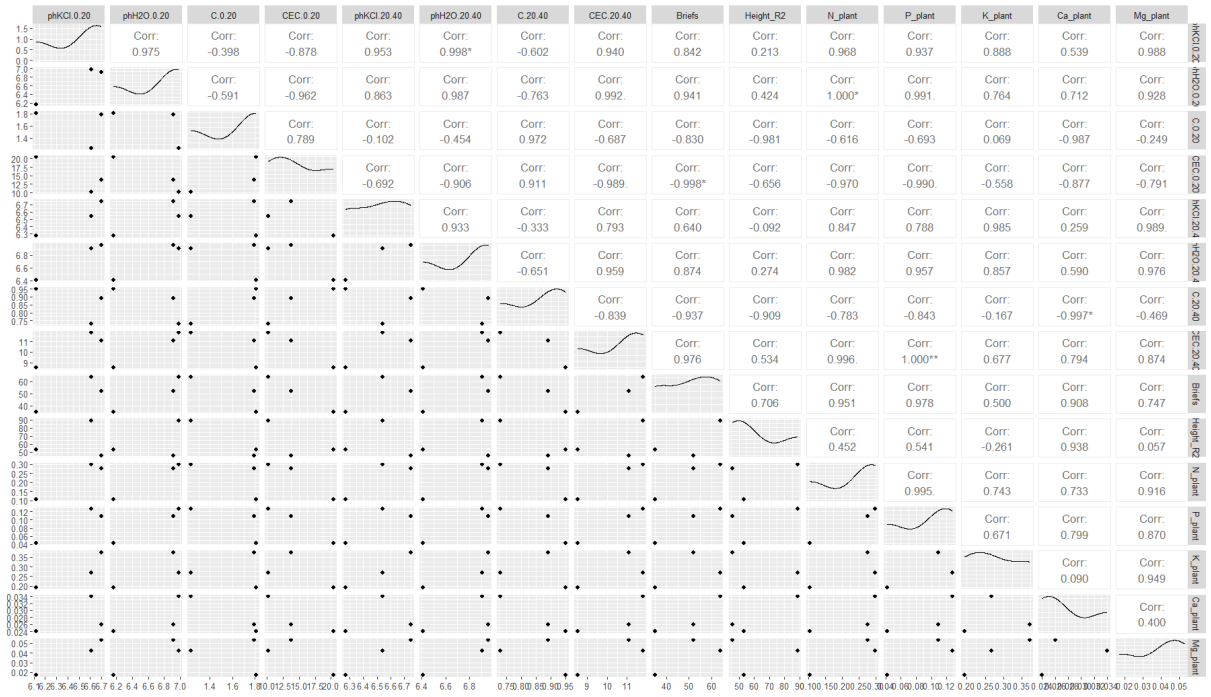
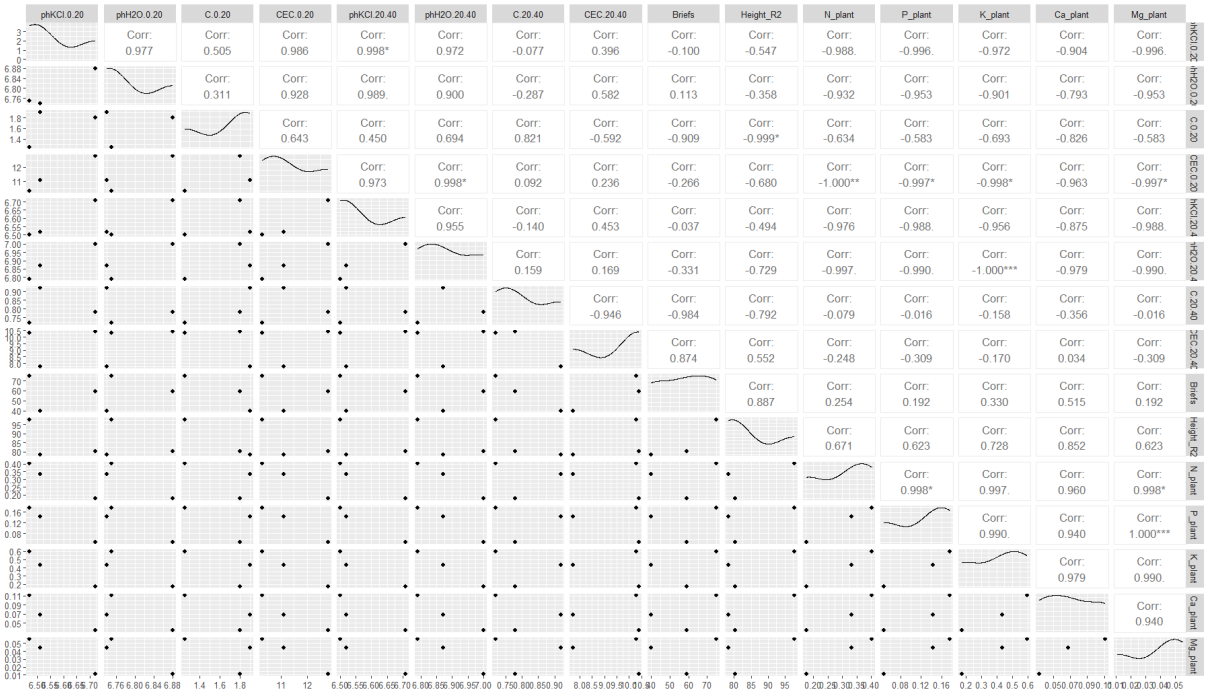
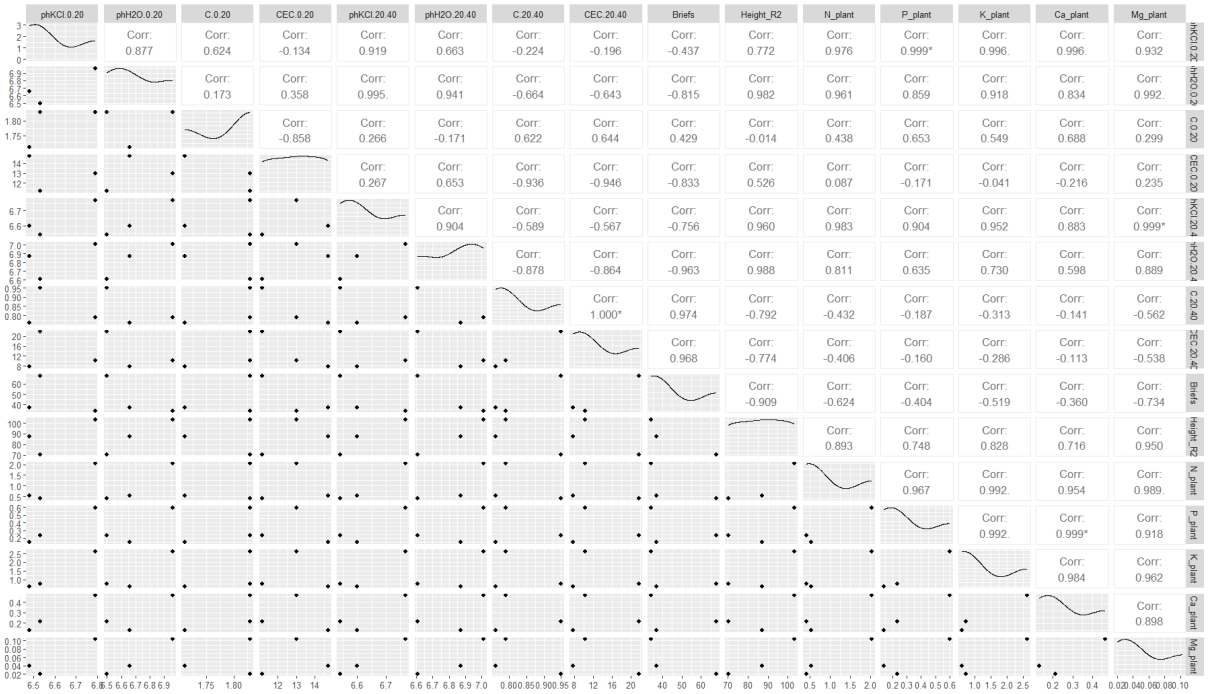


3. BT10


phKCl.0.20
phH2O.0.20
C.0.20
CEC.0.20
phKCl.20.40
phH2O.20.40
C.20.40
CEC.20.40
Briefs
Height_R2
N_plant
P_plant
K_plant
Ca_plant
Mg_plant

4. BU3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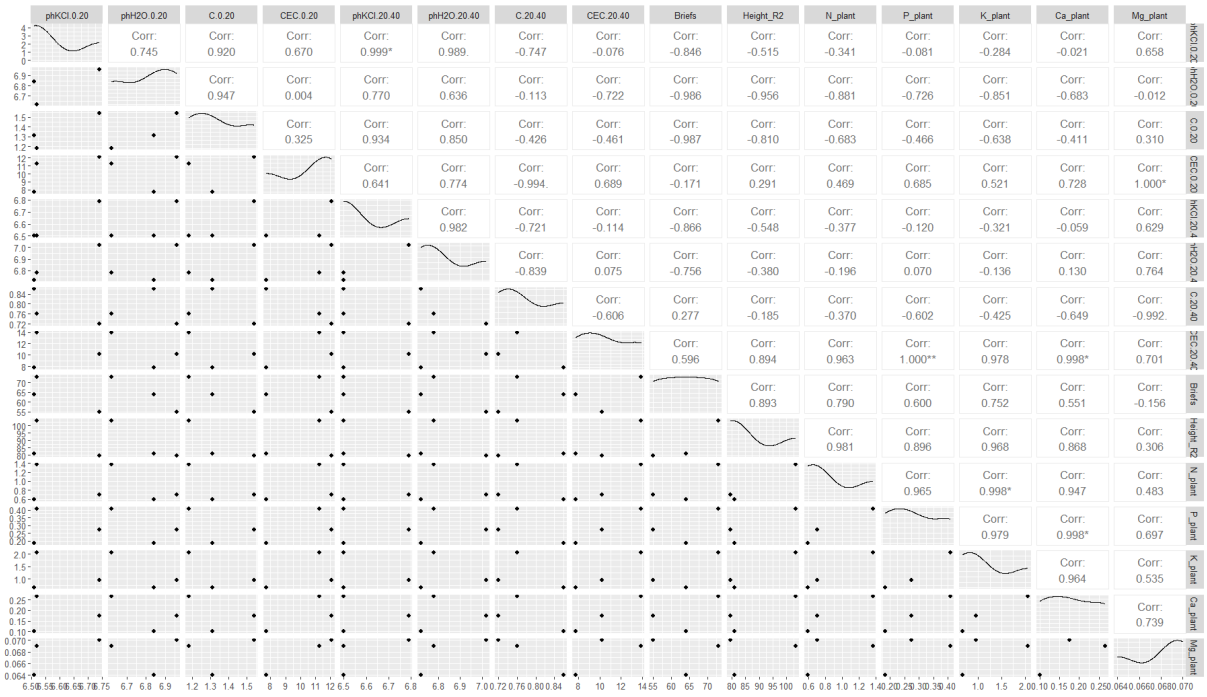
phH2O.0.20
C.0.20
CEC.0.20
phKCl.20.40
phH2O.20.40
C.20.40
CEC.20.40
Briefs
Height_R2
N_plant
P_plant
K_plant
Ca_plant
Mg_plant

5. BU10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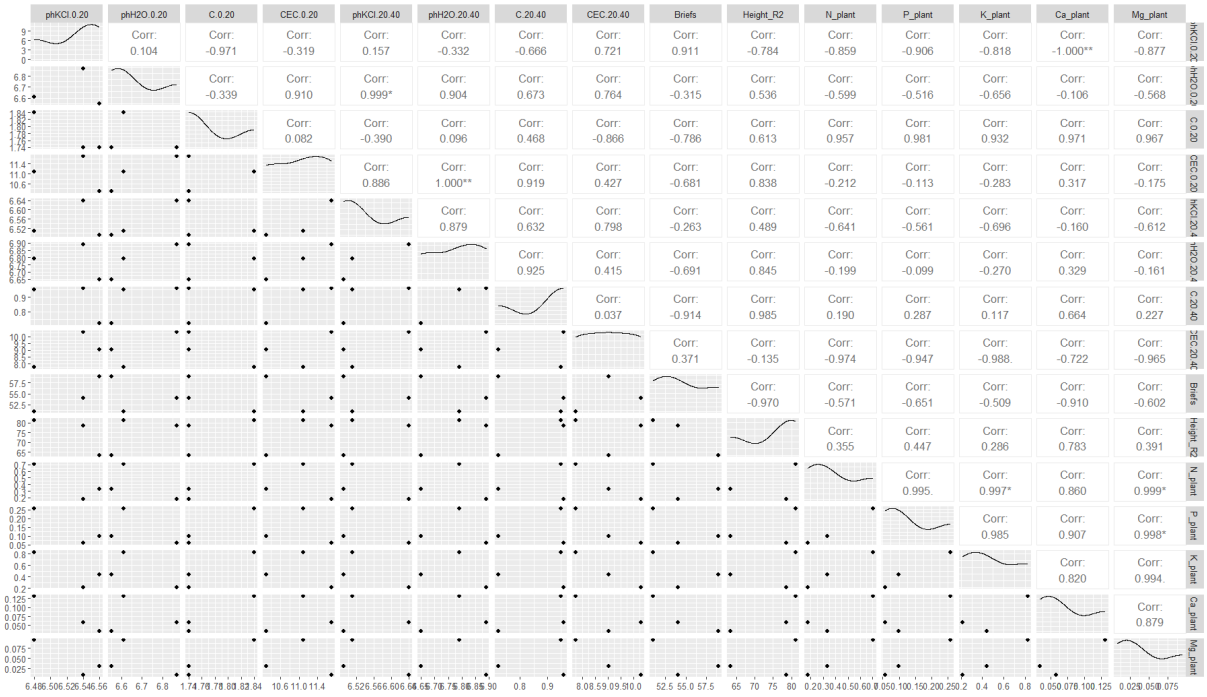
pHH2O.0.20
C.0.20
CEC.0.20
pHKCl.20.40
pHH2O.20.40
C.20.40
CEC.20.40
Briefs
Height_R2
N_plant
P_plant
K_plant
Ca_plant
Mg_plant

6. T0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pHH2O.0.20
C.0.20
CEC.0.20
pHKCl.20.40
pHH2O.20.40
C.20.40
CEC.20.40
Briefs
Height_R2
N_plant
P_plant
K_plant
Ca_plant
Mg_plant

IX.11 Appendix 11

Numeric values of nutrient uptake. The line in yellow was on the unit not modified by wild boar.

Block	Treatment	N	P	K	Ca	Mg
Part 1. bed1	BT3	0.105	0.042	0.194	0.024	0.017
Part 1. bed1	BU3	0.408	0.233	0.737	0.212	0.02
Part 1. bed1	T0	0.335	0.099	0.439	0.034	0.031
Part 1. bed1	BU10	1.368	0.409	2.062	0.266	0.069
Part 1. bed1	BT10	0.403	0.176	0.598	0.111	0.055
Part 2. bed 1	T0	0.705	0.258	0.826	0.131	0.095
Part 2. bed 1	BT10	0.333	0.144	0.437	0.068	0.044
Part 2. bed 1	BU10	0.593	0.184	0.672	0.101	0.064
Part 2. bed 1	BU3	0.536	0.143	0.607	0.131	0.039
Part 2. bed 1	BT3	0.298	0.128	0.268	0.034	0.042
Bed 2	T0	0.177	0.058	0.216	0.058	0.008
Bed 2	BT3	0.275	0.109	0.373	0.026	0.053
Bed 2	BT10	0.176	0.048	0.174	0.034	0.011
Bed 2	BU10	0.707	0.273	0.959	0.175	0.07
Bed 2	BU3	2.042	0.598	2.623	0.465	0.103

Numeric values of Dry matter content. Lines in yellow were on the unit not modified by wild boar.

Block	Number plant	Treatment	Dry matter [g]
Part 1. bed1	A2	BT3	4
Part 1. bed1	A3	BT3	3
Part 1. bed1	A4	BT3	10
Part 1. bed1	B1	BU3	18
Part 1. bed1	B3	BU3	19
Part 1. bed1	B5	BU3	53
Part 1. bed1	C1	T0	35
Part 1. bed1	C5	T0	21
Part 1. bed1	C6	T0	26
Part 1. bed1	D1	BU10	65
Part 1. bed1	D3	BU10	134
Part 1. bed1	D6	BU10	95
Part 1. bed1	E4	BT10	522
Part 1. bed1	E5	BT10	98
Part 1. bed1	E6	BT10	65
Part 2. bed 1	F2	T0	57
Part 2. bed 1	F3	T0	87
Part 2. bed 1	F4	T0	172
Part 2. bed 1	G3	BT10	30
Part 2. bed 1	G4	BT10	114
Part 2. bed 1	G6	BT10	45
Part 2. bed 1	H4	BU10	14
Part 2. bed 1	H5	BU10	16
Part 2. bed 1	H6	BU10	46
Part 2. bed 1	I1	BU3	205
Part 2. bed 1	I3	BU3	187
Part 2. bed 1	I6	BU3	119
Part 2. bed 1	J1	BT3	26
Part 2. bed 1	J2	BT3	20
Part 2. bed 1	J4	BT3	20
Bed 2	K4	T0	55
Bed 2	K5	T0	12
Bed 2	K6	T0	23
Bed 2	L1	BT3	31
Bed 2	L5	BT3	13
Bed 2	L6	BT3	16
Bed 2	M1	BT10	104
Bed 2	M2	BT10	22
Bed 2	M5	BT10	20
Bed 2	N4	BU10	278
Bed 2	N5	BU10	232
Bed 2	N6	BU10	70
Bed 2	O3	BU3	325
Bed 2	O4	BU3	280
Bed 2	O6	BU3	166