





## Article

# Site-Specific Effects of Organic Amendments on Parameters of Tropical Agricultural Soil and Yield: A Field Experiment in Three Countries in Southeast Asia

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**Abstract:** Organic amendments may improve the quality of acidic tropical agricultural soils with low organic carbon contents under conventional management (mineral fertilization and irrigation) in Southeast Asia. We investigated the effect of biochar, compost and their combination on maize growth and yield, soil physical, biological and chemical properties at harvesting time at four sites in three countries: Thailand, Vietnam and Laos. Treatments consisted of 10 t·ha<sup>-1</sup> cow manure compost and 7 t·ha<sup>-1</sup> of Bamboo biochar and their combination. Maize biomass production and cop yields were recorded for two seasons. Elemental content, pH and nutrient availability of soils were analyzed after the first growing season. We also characterized macrofauna abundance and water infiltration. Few changes were noted for maize biomass production and maize cop yield. Soil chemical parameters showed contrasting, site-specific results. Compost and biochar amendments increased soil organic carbon, pH, total K and N, P and K availability especially for sandy soils in Thailand. The combination of both amendments could reduce nutrient availability as compared to compost only treatments. Physical and biological parameters showed no treatment response. We conclude that the addition of compost, biochar and their mixture to tropical soils have site-specific short-term effects on chemical soil parameters. Their short-term effect on plants is thus mainly related to nutrient input. The site-dependent results despite similar crops, fertilization and irrigation practices suggest that inherent soil parameters and optimization of organic amendment application to specific pedoclimatic conditions need future attention.

**Keywords:** compost; biochar; fauna; soil physio-chemical properties; maize growth; tropical soil



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## 1. Introduction

Tropical regions are amongst the most vulnerable to the impact of climate change [1]. At the same time many tropical countries suffer from rapid population growth and relatively poor economic situations [2]. Although 40% of the world population is living in tropical countries [3] and solutions have to be found to maintain food security under the growing consequences of climate change, tropical agricultural systems are understudied.

In Southeast Asia, farmers generally use mineral N, P and K fertilizers to sustain agricultural productivity of highly weathered nutrient poor tropical soils. However, the use of mineral fertilizers may lead to acidification and further degradation of soils [4]. In fact, modern agricultural activities with high use of external (agrochemical) inputs can lead to soil organic matter loss, which increases the threat of soil loss through erosion. Globally, soils have lost 116 Gt of C since the beginning of agriculture [5]. The decline in

soil organic matter is related to loss in many soil functions, such as nutrient availability, water holding capacity, and biodiversity. Most importantly, soil organic carbon (SOC) loss reduces erosion resistance leading to 36 billion tons of soil loss through erosion globally [6]. Therefore, recently there was a call for increasing SOC by the use of sustainable agricultural practices in order to protect soils, increase agricultural productivity, as well as climate change adaptation and mitigation [7]. The use of transformed organic wastes and the development of smart fertilization strategies may be especially useful for this purpose [8,9].

In this context, several studies have already investigated the impact of joint biochar and compost applications on soil properties, biomass production and yields in both temperate and tropical cropping systems, with a range of results depending on biochar type, soil type, climate and time. However, despite the fact that biochar has a positive effect for plant growth in the tropics due to positive effects on pH and nutrients [10], most of the studies have been carried out in developed countries, where soil fertility is not an issue [11]. While biochar is viewed as a soil conditioner due to its low nutrient contents, compost presents a relatively easily available nutrient source in a tropical context [12] and may be lost rapidly by microbial decomposition after soil application [13]. Under temperate climate conditions, the application of compost/biochar mixtures to soil may have synergistic effects in terms of soil nutrient contents and water holding capacity under field conditions [14]. As biochar/compost mixtures were also shown to reduce soil erosion in tropical sloping land [15], and to form aggregates reducing their loss from soil in tropical environment [16], we hypothesized that the combination of compost and biochar may be highly beneficial for soil properties and agricultural production due to additive effects leading to the on-site preservation of both materials.

The aim of our study was to determine the effect of compost, biochar and their combination on soil fertility and plant growth in “monsoon” tropical environments. While many experimental studies were carried out in the greenhouse or at one site in developed countries [11], the originality of our study was the investigation of the effect of the same three organic amendments on plants and soil at four sites in developing countries in Southeast Asia. We set up a randomized field experiment with maize using the same organic materials as amendments in three countries: Thailand, Vietnam and Laos. The same amount of organic amendment and fertilizer were applied to two irrigated maize seasons in each country. We concentrated in this study on the improvement of the quality of tropical agricultural soils in Southeast Asian countries including physical, chemical and biological parameters. We hypothesized that (i) the addition of compost, biochar or their combination in addition to mineral fertilizers would have a positive effect on soil nutrient availability and that (ii) similar plant growth would occur due to equal fertilizer use and irrigation among sites. We analyzed for SOC and total and available N, P and K, because these parameters may directly influence biomass production and yield in the short term. Moreover, we were interested in the amendments’ potential to influence macrofauna abundance and water infiltration.

## 2. Materials and Methods

### 2.1. Study Sites

The same agricultural experiment was carried out in Thailand, Vietnam and Laos. In Thailand, the experimental sites (LDD10 and LDD5) were located in the Ratchaburi province (99°51'13" E, 13°41'32" N) and Khon Kaen province (102°50'20" E, 16°26'18" N); in Vietnam, the experimental site was situated west of Hanoi at Dong cao (105°29'10" E, 20°57'40" N); and in Laos, it was located in Nabong (102°47'34" E, 18°7'25" N) next to the town of Vientiane. All four sites experienced monsoon climate with the main precipitation occurring from April to October, and very few rainfall events during the dry season (October–March). Annual rainfall averages were 1226 mm·year<sup>-1</sup> in Ratchaburi, 1246 mm·year<sup>-1</sup> in Khon Kaen (Thailand), 1438 mm·year<sup>-1</sup> in Nabong (Laos), and 1502 mm·year<sup>-1</sup> in Dong Cao (Vietnam). The average annual temperature in the three countries ranged between 24 and 30 °C. Soils at all four sites are highly weathered. They

were characterized by sandy loam texture and classified as Acrisol in Nabong (Laos). In Ratchaburi (Thailand), soils had a sandy-loam texture and were classified as Ultisol, whereas in Khon Kaen (Thailand), soils had a sandy-loam texture and were classified as Entisol. In Dong Cao (Vietnam), dominant soil type is Acrisol with a clay content >50%. General parameters of the soils at the experimental sites are listed in Table 1.

**Table 1.** Surface soil pH, OC, N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O contents (mg·g<sup>-1</sup>) and texture (%) at the beginning of the experiments at all four study sites.

Site	Name	pH	OC	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Sand	Silt	Clay	Texture
Vietnam	Acrisol	4.6	21	2.2	2.6	1.9	17	25	58	Clay
Laos	Acrisol	5.1	9.7	1.5	3.7	3.9	54	21	25	Sandy Loam
Thailand (LDD5)	Ultisol	5.5	3.2	0.3	19	9	79	11	10	Sandy Loam
Thailand (LDD10)	Entisol	5.5	7.9	0.7	11	7.2	63	22	15	Sandy Loam

## 2.2. Organic Amendments

Compost and biochar were produced at the same unit and used at all study sites. Compost was produced from dried cow manure bed in covered window under air temperature for 3-months at the Khao Cha-Ngum Royal Study Center for Land Degradation Development, Land Development Department Regional 10, Ratchaburi province, Thailand. During the composting process, humidity was maintained at 50–60% while temperature increased up to 50–55 °C and thereafter decreased again. Compost was harvested when its temperature was similar to air temperature. After harvest, the compost was air dried for a week. Biochar was produced by GRET in Hanoi, on a farm in Cang village, Xuan Phu commune, Thanh Hoa province, Vietnam by carbonizing pieces of bamboo for 8–10 h at 600 °C in airless brick kilns. The properties of compost and biochar are shown in Table 2.

**Table 2.** Chemical properties of organic amendments (P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O refer to total contents, while P<sub>a</sub> and K<sub>a</sub> are available contents).

Amendment	pH	OC	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	NO <sub>3</sub>	P <sub>a</sub>	K <sub>a</sub>
Cow compost	7.5	216	17.1	1.9	12	0.04	0.02	0.02
Bamboo biochar	8.6	558	7.5	2.8	8	0.01	<0.01	0.01

## 2.3. Experimental Design

To study the impact of different types of organic amendment on soil properties, we established an agricultural experiment using a split plot design (1 m × 1 m and 1 m separated from each other by a walking path) with four replicates and 4 treatments. In total for each site the experiment comprised 24 plots. Soil from the 0–15 cm surface layer was sieved to discard stones and litter residue. Before planting, soils were treated with mineral nutrients, i.e., N in form of urea (35 kg·ha<sup>-1</sup>, CH<sub>4</sub>N<sub>2</sub>O, %N = 45.3%), K in the form of potash (80 kg·ha<sup>-1</sup>, K<sub>2</sub>O, %K = 50%) and P in the form of phosphate rock (400 kg·ha<sup>-1</sup>, P<sub>2</sub>O<sub>5</sub>, %P = 15%). With the exception of the control plots, which only received mineral fertilizers, plots were amended with organic fertilizers with either 1 kg·m<sup>-2</sup> corresponding to a dose of 10 t·ha<sup>-1</sup> air dry compost or biochar (700 g·m<sup>-2</sup> corresponding to a dose of 7 t·ha<sup>-1</sup>) or 1.7 kg·m<sup>-2</sup> corresponding to a dose of 17 t·ha<sup>-1</sup> of their mixture.

The experiment was set up with two maize growing seasons: the dry (January–March) and the rainy (June–September) seasons. Fertilizers and organic amendments were incorporated manually to a depth of 5 cm. Thereafter we planted twelve maize plants per square meter. We used baby corn SG22 variety at a population density of 120,000 plants ha<sup>-1</sup>. In the first maize growing season, phosphate and organic amendments

were mixed together and spread around the plants once as the basal fertilization, while urea and potash were spread around the plants twice: half was fertilized at the 4–5 leaf stage and the other half at the 8–10 leaf stage, as the conditional fertilizer [17]. Chemical fertilizer addition was repeated in the second maize growing season. The soil moisture content was adjusted manually every week to 60–70% of the field capacity at all three sites by controlling soil moisture content with Xiaomi soil moisture sensors.

#### 2.4. Soil Sampling and Analysis

After the first harvest, we determined physical soil properties (water infiltration), biological properties (macrofauna community,) and chemical properties (organic carbon (OC), nitrogen (N), phosphorus (P), potassium (K), and pH).

A simplified infiltration test was performed using a PVC pipe 10 cm in diameter and 10 cm height, which was inserted into the soil. Thereafter, 80 mL of water were poured into the ring. The time required for the water to infiltrate was recorded, and the infiltration rate was calculated.

Soil monoliths (25 cm × 25 cm × 30 cm) were excavated following the standard Tropical Soil Biology and Fertility Program (TSBF) sampling protocol. The excavated soil was placed in plastic trays and large clods gently broken to enable hand picking of earthworms, termites and ants. The abundance of earthworms, termites and ants was calculated as number of individuals per square meter.

Surface soil samples (0–10 cm depth) were collected from experimental plots, sieved at <2 mm and ground for chemical analyses. The percentage of OC was determined using the Walkley-Black method (TCVN 4050-85). Total N and N extractable with 1 M KCl (1:2.5 w/vol) were determined using the Kjeldahl method (ISO 11251-95). Total K content was determined in water extracts after reduction of nitrate with Devarda's alloy (ISO 5553-84). The pH was measured in a soil/water suspension (ISO 10390-2005). The NO<sub>3</sub>–N contents were determined after Kjeldahl digestion procedure with H<sub>2</sub>SO<sub>4</sub> and HClO<sub>4</sub> with a Flame photometer (TCVN 4053-81). Available K was extracted with 1 M ammonium acetate (1:10 w/vol) for 30 min and determined by atomic adsorption spectroscopy after filtration. Total P content was determined colorimetrically after digestion with H<sub>2</sub>SO<sub>4</sub> and HClO<sub>4</sub> for 2.5 h at 300 °C.

#### 2.5. Maize Growth and Yield

Maize yield was recorded as the total weight of de-husked baby cob per hectare. Aboveground plant biomass of maize was determined at the end of each cultivation cycle as dry matter after oven-drying for 10 days at 60 °C.

#### 2.6. Statistical Analyses

For each study site, ANOVA was used to test the amendment effects on soil physical, chemical and biological parameters and maize yield. For maize yields, season was not included in the statistical model and separate ANOVA has been carried out for each season. Prior to running ANOVA, data were tested for homogeneity of variances and normality and log-transformed when required. LSD post hoc multiple comparison tests were used if the effects were significant. Differences among treatments were declared significant at the 0.05 probability level. We also performed principal component analyses (PCA) to visually summarize the information of soil fertility parameters and maize yield. All statistical analyses and plots were carried out with R software using “car”, “agricolae” and “ade4” packages [18].

### 3. Results

#### 3.1. Soil Characteristics

Physicochemical parameters of the four surface soils before the experiment are presented in Table 1. The pH<sub>H2O</sub> of the air-dried soils ranged from 4.5 to 5.5 with an average of 5.1. This is characteristic for highly weathered tropical soils. The content of sand, silt

and clay fractions varied between sites, resulting in soil texture ranging from clay to sandy loam. The Acrisol in Vietnam was characterized by the highest clay content, whereas all other soils had higher sand contributions ranging from 54 to 79%. The OC content before the experiment was highest for the clayey soil in Vietnam and lowest for the sandy loam soil in Laos (Table 1).

### 3.2. Organic Amendments

Table 2 shows the chemical parameters of compost and biochar used for the experiments. Biochar had a higher pH, higher OC (2.6-fold), total P (1.5-fold) and available K (1.2-fold) than compost. However, the contents of total N (2-fold), K (1.5-fold), NO<sub>3</sub> (8-fold) and available P (7.5-fold) were lower than in the cow manure compost. The C:N ratio of 13:1 of compost may allow for its rapid mineralization after soil application.

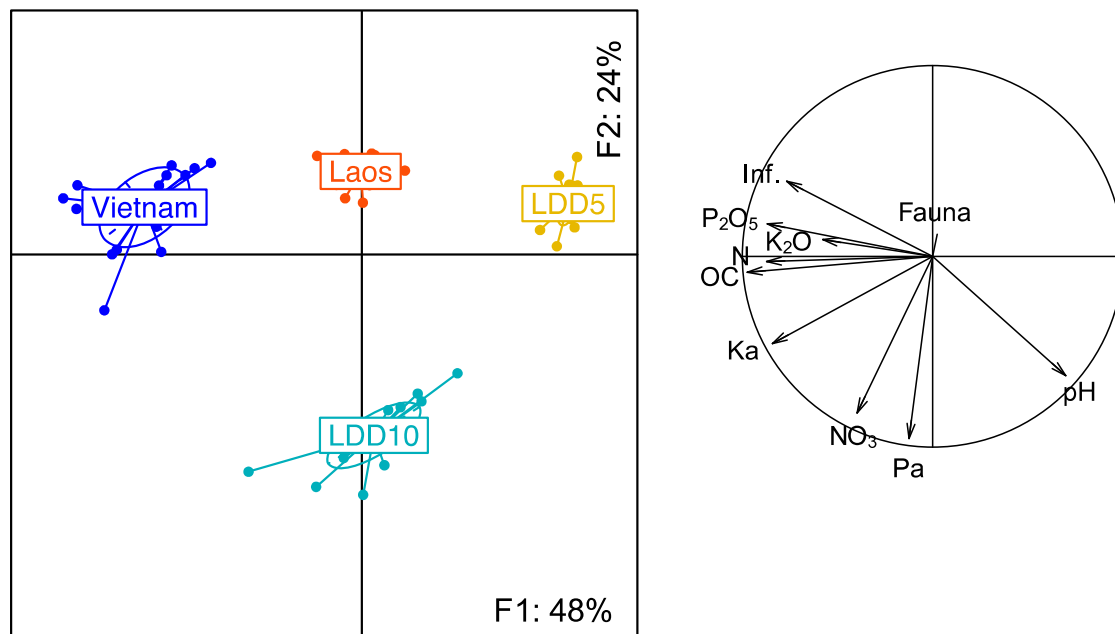
### 3.3. Soil Parameters at the End of the Experiment

The addition of compost and biochar or their combination influenced pH, OC, NO<sub>3</sub><sup>-</sup>N, and available K depending on soil types as compared with the control treatment (Table 3). pH ranged between 4.4 and 6.9. It was unaffected or tended to increase after amendment addition. Total OC concentrations ranged between 0.04 and 0.20 mg·g<sup>-1</sup> (Table 1). Total P concentrations ranged between 0.01 and 0.05 mg·g<sup>-1</sup> and total K concentrations varied between non-detectable and 0.42 mg·g<sup>-1</sup>. Treatment effects were variable even for compost addition. Nitrate concentrations ranged between 0.07 and 0.28 mg·g<sup>-1</sup>. They increased at all sites after biochar and compost addition, except in Laos. Available phosphorus concentrations ranged between 0.06 and 0.51 mg·g<sup>-1</sup>. Available potassium concentrations ranged between 0.02–0.13 mg·g<sup>-1</sup> and were little influenced by treatments at all sites. The abundance of macrofauna did not show significant differences. Infiltration rate of water ranged from 0.1 to 2.0 mL·s<sup>-1</sup> and did not change after amendment addition. Addition of organic amendments thus significantly influenced soil chemical properties (pH, OC, K<sub>2</sub>O, NO<sub>3</sub>, P<sub>a</sub> and K) but not soil macrofauna and water infiltration.

**Table 3.** Effect of compost and biochar on soil chemical, physical and biological properties, of soil samples collected after maize harvest. Treatments are represented as follow: (M) NPK fertilizer only, (MB) NPK + biochar; (MC) NPK + compost and (MBC) NPK + compost and biochar. Variables are: pH<sub>H2O</sub>, OC, N, NO<sub>3</sub><sup>-</sup>, K and P total (P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O), available K and P (P<sub>a</sub> and K<sub>a</sub>), macrofauna abundance (Fauna), and infiltration rate of water (Inf). Different letters indicate significant differences among treatments of the same country.

Sites	Fertilization	pH	OC	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	NO <sub>3</sub>	P <sub>a</sub>	K <sub>a</sub>	Fauna	Inf
Vietnam	M	4.5 <sub>(0.1)</sub> <sup>a</sup>	17.1 <sub>(0.1)</sub> <sup>b</sup>	2.0 <sub>(0.0)</sub>	2.0 <sub>(0.0)</sub> <sup>a</sup>	2.4 <sub>(0.0)</sub>	1.1 <sub>(0.1)</sub> <sup>c</sup>	15.1 <sub>(0.7)</sub> <sup>a</sup>	8.4 <sub>(1.2)</sub> <sup>b</sup>	516 <sub>(772)</sub>	0.9 <sub>(0.4)</sub>
	MB	4.4 <sub>(0.2)</sub> <sup>b</sup>	20.3 <sub>(0.0)</sub> <sup>a</sup>	2.1 <sub>(0.0)</sub>	1.7 <sub>(0.0)</sub> <sup>a</sup>	2.3 <sub>(0.0)</sub>	2.4 <sub>(0.1)</sub> <sup>a</sup>	14.9 <sub>(1.1)</sub> <sup>a</sup>	9.1 <sub>(0.6)</sub> <sup>b</sup>	60 <sub>(72)</sub>	1.6 <sub>(0.7)</sub>
	MC	4.9 <sub>(0.2)</sub> <sup>a</sup>	20.2 <sub>(0.1)</sub> <sup>a</sup>	2.1 <sub>(0.0)</sub>	1.9 <sub>(0.0)</sub> <sup>a</sup>	2.3 <sub>(0.0)</sub>	1.9 <sub>(0.5)</sub> <sup>b</sup>	16.2 <sub>(0.9)</sub> <sup>a</sup>	13.3 <sub>(0.8)</sub> <sup>a</sup>	184 <sub>(183)</sub>	2.0 <sub>(1.0)</sub>
	MBC	4.9 <sub>(0.1)</sub> <sup>a</sup>	19.6 <sub>(0.1)</sub> <sup>a</sup>	2.1 <sub>(0.0)</sub>	1.8 <sub>(0.0)</sub> <sup>b</sup>	2.3 <sub>(0.0)</sub>	1.2 <sub>(0.0)</sub> <sup>c</sup>	12.0 <sub>(2.8)</sub> <sup>b</sup>	9.5 <sub>(0.9)</sub> <sup>b</sup>	232 <sub>(322)</sub>	1.2 <sub>(0.3)</sub>
Laos	M	4.6 <sub>(0.1)</sub> <sup>b</sup>	9.7 <sub>(0.1)</sub>	1.2 <sub>(0.0)</sub>	0.5 <sub>(0.0)</sub>	3.4 <sub>(0.0)</sub> <sup>b</sup>	1.1 <sub>(0.1)</sub> <sup>b</sup>	9.3 <sub>(1.2)</sub> <sup>bc</sup>	5.9 <sub>(0.9)</sub> <sup>a</sup>	156 <sub>(89)</sub>	0.6 <sub>(0.2)</sub>
	MB	4.7 <sub>(0.1)</sub> <sup>b</sup>	10.4 <sub>(0.1)</sub>	0.9 <sub>(0.0)</sub>	0.5 <sub>(0.0)</sub>	3.8 <sub>(0.0)</sub> <sup>ab</sup>	1.4 <sub>(0.2)</sub> <sup>a</sup>	10.9 <sub>(0.1)</sub> <sup>ab</sup>	5.3 <sub>(0.7)</sub> <sup>a</sup>	100 <sub>(47)</sub>	0.6 <sub>(0.2)</sub>
	MC	5.2 <sub>(0.1)</sub> <sup>a</sup>	10.2 <sub>(0.1)</sub>	1.1 <sub>(0.0)</sub>	0.4 <sub>(0.0)</sub>	4.2 <sub>(0.0)</sub> <sup>a</sup>	0.6 <sub>(0.1)</sub> <sup>c</sup>	11.4 <sub>(1.1)</sub> <sup>a</sup>	5.8 <sub>(0.2)</sub> <sup>a</sup>	164 <sub>(111)</sub>	0.6 <sub>(0.1)</sub>
	MBC	5.2 <sub>(0.1)</sub> <sup>a</sup>	9.6 <sub>(0.1)</sub>	1.0 <sub>(0.0)</sub>	0.4 <sub>(0.0)</sub>	3.9 <sub>(0.0)</sub> <sup>ab</sup>	1.2 <sub>(0.4)</sub> <sup>ab</sup>	8.7 <sub>(1.4)</sub> <sup>c</sup>	4.1 <sub>(0.4)</sub> <sup>b</sup>	80 <sub>(107)</sub>	0.7 <sub>(0.2)</sub>
Thai (LDD5)	M	6.6 <sub>(0.1)</sub> <sup>bc</sup>	3.7 <sub>(0.0)</sub> <sup>b</sup>	0.3 <sub>(0.0)</sub>	0.3 <sub>(0.0)</sub> <sup>a</sup>	0.1 <sub>(0.0)</sub> <sup>a</sup>	0.5 <sub>(0.1)</sub> <sup>b</sup>	10.1 <sub>(0.9)</sub> <sup>a</sup>	1.6 <sub>(0.3)</sub>	76 <sub>(113)</sub>	0.3 <sub>(0.03)</sub>
	MB	6.5 <sub>(0.1)</sub> <sup>c</sup>	4.7 <sub>(0.0)</sub> <sup>a</sup>	0.6 <sub>(0.0)</sub>	0.1 <sub>(0.0)</sub> <sup>b</sup>	<0.1 <sub>(0.0)</sub> <sup>b</sup>	1.1 <sub>(0.2)</sub> <sup>a</sup>	6.1 <sub>(0.5)</sub> <sup>b</sup>	2.1 <sub>(0.2)</sub>	76 <sub>(141)</sub>	0.1 <sub>(0.0)</sub>
	MC	6.9 <sub>(0.1)</sub> <sup>a</sup>	3.7 <sub>(0.1)</sub> <sup>b</sup>	0.4 <sub>(0.0)</sub>	0.3 <sub>(0.0)</sub> <sup>a</sup>	0.1 <sub>(0.0)</sub> <sup>a</sup>	0.7 <sub>(0.4)</sub> <sup>b</sup>	9.2 <sub>(1.1)</sub> <sup>a</sup>	2.3 <sub>(0.4)</sub>	896 <sub>(1542)</sub>	0.1 <sub>(0.0)</sub>
	MBC	6.7 <sub>(0.1)</sub> <sup>b</sup>	3.8 <sub>(0.1)</sub> <sup>b</sup>	0.5 <sub>(0.0)</sub>	0.1 <sub>(0.0)</sub> <sup>b</sup>	<0.1 <sub>(0.0)</sub> <sup>b</sup>	1.1 <sub>(0.1)</sub> <sup>a</sup>	6.0 <sub>(2.8)</sub> <sup>b</sup>	1.7 <sub>(0.3)</sub>	8 <sub>(9.2)</sub>	0.1 <sub>(0.0)</sub>
Thai (LDD10)	M	6.8 <sub>(0.03)</sub>	8.2 <sub>(0.1)</sub> <sup>c</sup>	0.8 <sub>(0.0)</sub>	0.5 <sub>(0.0)</sub>	1.3 <sub>(0.0)</sub> <sup>b</sup>	1.9 <sub>(0.3)</sub> <sup>b</sup>	44.0 <sub>(4.7)</sub> <sup>b</sup>	8.9 <sub>(0.3)</sub> <sup>bc</sup>	116 <sub>(170)</sub>	1.1 <sub>(0.0)</sub>
	MB	6.9 <sub>(0.05)</sub>	12.5 <sub>(0.1)</sub> <sup>ab</sup>	1.1 <sub>(0.0)</sub>	0.5 <sub>(0.0)</sub>	2.3 <sub>(0.0)</sub> <sup>a</sup>	2.4 <sub>(0.3)</sub> <sup>ab</sup>	47.3 <sub>(2.6)</sub> <sup>ab</sup>	9.1 <sub>(0.4)</sub> <sup>b</sup>	92 <sub>(124)</sub>	0.1 <sub>(0.0)</sub>
	MC	6.8 <sub>(0.07)</sub>	11.1 <sub>(0.1)</sub> <sup>b</sup>	0.9 <sub>(0.0)</sub>	0.4 <sub>(0.0)</sub>	2.3 <sub>(0.0)</sub> <sup>a</sup>	2.5 <sub>(0.2)</sub> <sup>a</sup>	41.8 <sub>(2.9)</sub> <sup>b</sup>	8.1 <sub>(0.9)</sub> <sup>c</sup>	160 <sub>(236)</sub>	0.1 <sub>(0.0)</sub>
	MBC	6.9 <sub>(0.12)</sub>	13.4 <sub>(0.1)</sub> <sup>a</sup>	1.7 <sub>(0.2)</sub>	0.5 <sub>(0.0)</sub>	2.3 <sub>(0.0)</sub> <sup>a</sup>	2.8 <sub>(0.3)</sub> <sup>a</sup>	51.1 <sub>(3.3)</sub> <sup>a</sup>	10.2 <sub>(0.9)</sub> <sup>a</sup>	216 <sub>(192)</sub>	0.1 <sub>(0.1)</sub>

Principal component analyses showed that all four countries could be differentiated based on the soil properties recorded in the four treatments (Figure 1). However, PCAs performed with the chemical soil properties, which are significantly influenced by amendment types (i.e., pH, OC,  $\text{NO}_3^- \text{N}$ ,  $\text{K}_2\text{O}$  and available K and P) showed clear separation between the different treatments at each of the four study sites (Figure 2). As there was a strong interaction with the location of the experimental fields prevailing, the organization of the different fertilizers in the PCA plan varied greatly between study fields. The first two principal components explained between 66 and 75% of the variability of the chemical soil parameters (Figure 2). Most of the variability was explained for sandy soils in Thailand (LDD 5 and 10).

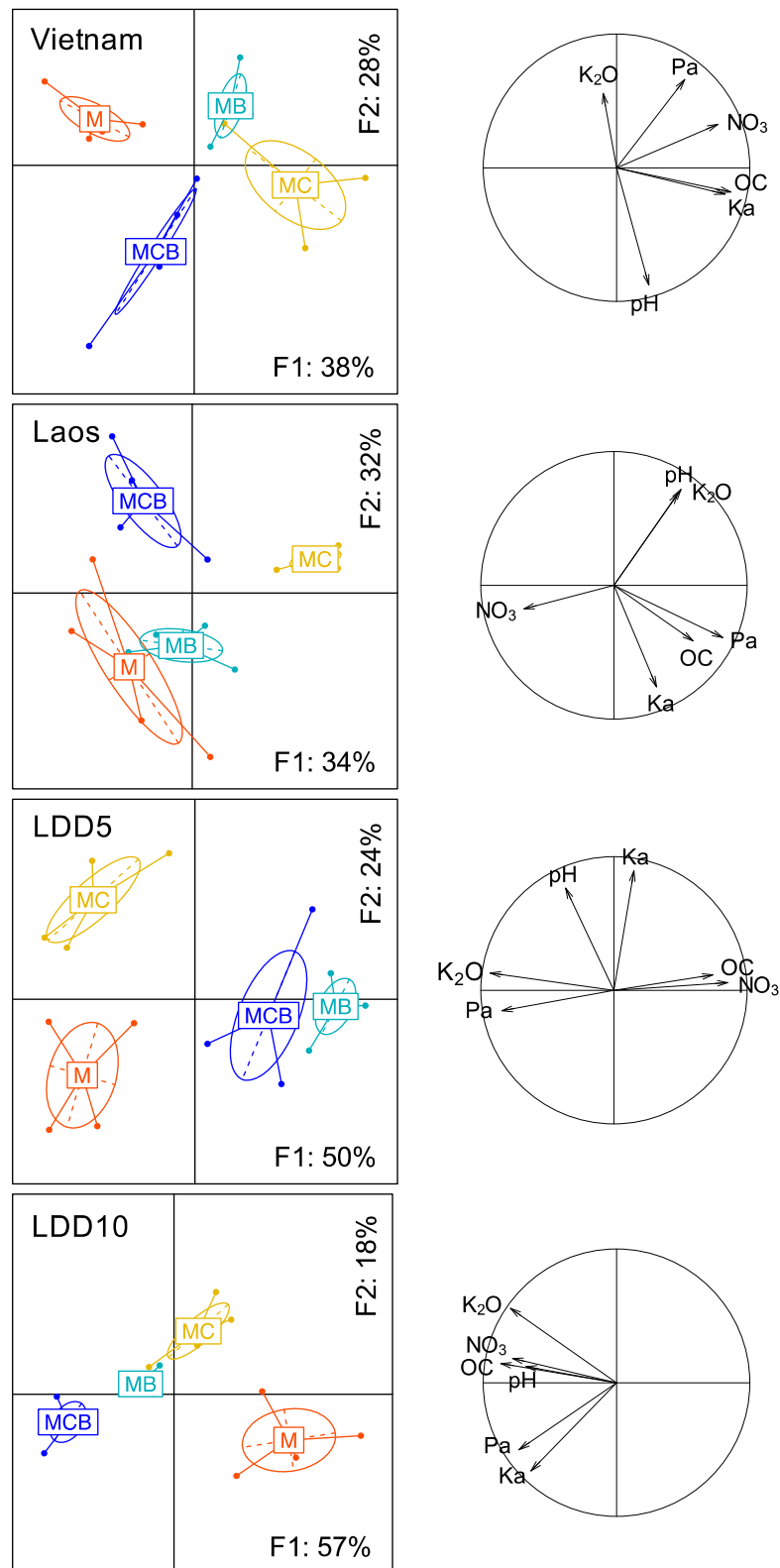


**Figure 1.** Biplot showing of the principal component analysis (PCA) performed on soil properties. Variables are:  $\text{pH}_{\text{H}_2\text{O}}$ , OC, N,  $\text{NO}_3^- \text{N}$ , total K and P ( $\text{P}_2\text{O}_5$ ,  $\text{K}_2\text{O}$ ), available K and P (Pa and Ka), abundance of earthworm, ants and termites (fauna) and infiltration rate (inf).

### 3.4. Plant Parameters at the End of the Experiment

Table 4 shows the influence of the treatments on aboveground plant biomass and cob yield for the two maize growing seasons. In the first growing season, plant biomass ranged from 19–106  $\text{t}\cdot\text{ha}^{-1}$  and the yield ranged from 2.8–5.4  $\text{t}\cdot\text{ha}^{-1}$ . In the second growing season, the plant biomass ranged from 23–81  $\text{t}\cdot\text{ha}^{-1}$  and the yield from 1.7–5.6  $\text{t}\cdot\text{ha}^{-1}$ . We tested for amendment effects within each growing season and country.

Few significant differences were found for biomass production and yields following the different soil amendment strategies (Table 4). In the first growing season, the only significant difference was noted for LDD5 in Thailand, where mineral fertilization induced the lowest biomass production and cop yields. In the second growing season, biomass was significantly lower with mineral fertilization than with organic amendments in Vietnam and Laos, while cop yields were lower in plots receiving mineral fertilizer in Vietnam only (Table 4).



**Figure 2.** Biplot showing the principal component analysis (PCA) performed on soil chemical properties presenting statistically significant differences between treatments: (M) only NPK, (MB) NPK + biochar; (MC) NPK + compost and (MCB) NPK + compost and biochar. Variables are:  $\text{pH}_{\text{H}_2\text{O}}$ , OC, N,  $\text{NO}_3^-$ -N, K and P total ( $\text{P}_2\text{O}_5$ ,  $\text{K}_2\text{O}$ ), K and P available (Pa and Ka).

**Table 4.** Effect of compost and biochar on biomass production of the whole aboveground plant material (plant biomass) and on fresh baby corn yield without husk (Cob Yield) at the maize harvest of two growing seasons. Treatments are represented as follow: (M) mineral fertilizer (NPK) only, (MB) NPK + biochar; (MC) NPK + compost and (MCB) NPK + compost and biochar. Different letter within each country indicate significant differences between treatments.

Sites	Fertilization	Plant Biomass (t·ha <sup>-1</sup> )		Cob Yield (t·ha <sup>-1</sup> )	
		1st Season	2nd Season	1st Season	2nd Season
Vietnam	M	63.1 <sub>(0.1)</sub>	56.8 <sub>(0.1)</sub> <sup>b</sup>	4.1 <sub>(0.8)</sub>	3.7 <sub>(0.2)</sub> <sup>c</sup>
	MB	60.8 <sub>(0.0)</sub>	72.3 <sub>(0.0)</sub> <sup>ab</sup>	3.5 <sub>(0.8)</sub>	4.6 <sub>(0.1)</sub> <sup>ab</sup>
	MC	72.1 <sub>(0.0)</sub>	81.5 <sub>(0.1)</sub> <sup>a</sup>	3.8 <sub>(0.3)</sub>	4.4 <sub>(0.2)</sub> <sup>b</sup>
	MCB	63.3 <sub>(0.1)</sub>	81.0 <sub>(0.0)</sub> <sup>a</sup>	4.7 <sub>(0.0)</sub>	4.8 <sub>(0.2)</sub> <sup>a</sup>
Laos	M	57.9 <sub>(0.3)</sub>	43.1 <sub>(0.1)</sub> <sup>b</sup>	4.3 <sub>(1.3)</sub>	1.7 <sub>(0.4)</sub>
	MB	93.6 <sub>(0.3)</sub>	64.7 <sub>(0.1)</sub> <sup>a</sup>	6.4 <sub>(1.5)</sub>	2.5 <sub>(0.9)</sub>
	MC	106.5 <sub>(0.5)</sub>	67.3 <sub>(0.1)</sub> <sup>a</sup>	4.2 <sub>(1.6)</sub>	1.7 <sub>(0.6)</sub>
	MCB	86.4 <sub>(0.5)</sub>	64.0 <sub>(0.0)</sub> <sup>a</sup>	5.4 <sub>(1.5)</sub>	2.5 <sub>(0.7)</sub>
Thai (LDD5)	M	19.2 <sub>(0.3)</sub> <sup>b</sup>	39.4 <sub>(0.0)</sub>	2.7 <sub>(0.4)</sub> <sup>b</sup>	2.7 <sub>(1.1)</sub>
	MB	24.2 <sub>(0.6)</sub> <sup>a</sup>	49.4 <sub>(0.1)</sub>	4.2 <sub>(0.6)</sub> <sup>a</sup>	2.7 <sub>(0.1)</sub>
	MC	25.9 <sub>(0.4)</sub> <sup>a</sup>	48.8 <sub>(0.2)</sub>	4.4 <sub>(0.2)</sub> <sup>a</sup>	2.2 <sub>(0.9)</sub>
	MCB	22.9 <sub>(0.3)</sub> <sup>a</sup>	43.7 <sub>(0.2)</sub>	4.5 <sub>(0.7)</sub> <sup>a</sup>	3.3 <sub>(1.1)</sub>
Thai (LDD10)	M	39.2 <sub>(0.0)</sub>	26.8 <sub>(0.08)</sub>	3.3 <sub>(0.01)</sub>	5.9 <sub>(2.34)</sub>
	MB	41.3 <sub>(0.0)</sub>	28.0 <sub>(0.04)</sub>	3.2 <sub>(0.03)</sub>	5.8 <sub>(0.70)</sub>
	MC	38.0 <sub>(0.0)</sub>	26.3 <sub>(0.0)</sub>	3.0 <sub>(0.68)</sub>	5.5 <sub>(1.70)</sub>
	MCB	40.2 <sub>(0.1)</sub>	26.8 <sub>(0.1)</sub>	2.8 <sub>(0.26)</sub>	5.2 <sub>(1.02)</sub>

#### 4. Discussion

##### 4.1. Effect of Compost and Biochar Addition on Plant Growth and Yield

Our study indicated very little significant effects on biomass production and/or maize cob yield. No differences were detected among treatments receiving organic amendments. Differences between treatments with and without organic amendments were evident only in Vietnam and Thailand (LDD5). Although compost addition to tropical agricultural soils has been found to improve soil quality by providing labile organic matter, which may be rapidly mineralized after soil addition [19], it does however not necessarily result in the better plant growth under tropical conditions [20,21]. This might be related to the high amount of available nitrogen and salts provided by compost [22] and biochar/compost mixtures [23], which could adversely affect plant growth. However, in sandy soil under tropical conditions, compost addition alone and in mixture with biochar has been found to significantly increase plant growth as compared to mineral fertilizer treatment [24], which is similar to the results observed in our study.

##### 4.2. Effect of Compost and Biochar Addition on Soil Fertility

Our data showed that the addition of compost and biochar impacted soil pH, OC, total K and available N, P and K concentrations after the first maize season. Organic fertilization in general significantly increased these parameters. This is an important change, as these soils are characterized by low N availability, and organic matter amendments may thus decrease the plants' susceptibility to soil N deficiency during growth.

The combination of biochar and compost as compared to compost amendments alone resulted in decreased contents of available K, P and NO<sub>3</sub><sup>-</sup>N in all soils except for available K in sandy soil in Thailand (LDD10) and NO<sub>3</sub><sup>-</sup>N for clayey soil in Vietnam. Biochar is characterized by a high adsorption capacity, which could result in reduced risks of nutrient losses through leaching, as they may occur in tropical soil after compost addition and mineral fertilization [17,21]. However, adsorption of nutrients by biochar may also reduce their availability to plants and thus reduce biomass production.



Acid soils in Southeast Asia are characterized by low soil organic carbon contents and high risk for carbon losses due to intense microbial activity and/or water erosion [25]. Some recent studies have indicated that the simultaneous application of biochar and compost may induce a synergistic effect leading to increased SOC sequestration potential in low fertility soils under tropical climate conditions [24,26]. On the other hand, compost and biochar-composts mixtures were demonstrated to be potential drivers to sustain and enhance soil biological activity [27], and water holding capacity [28]. Therefore it was hypothesized that the positive effects of the amendments on soil properties could improve biomass production and maize cob yield as compared to mineral fertilization only. However, this hypothesis is little supported by the results of our study, which indicated higher biomass production by combination of organic and mineral fertilization only in few cases (one growing season and two countries). Our study was addressing short-term effects, while compost and biochar properties are likely to evolve after soil application [23], which could in the longer term ameliorate physicochemical soil parameters and thus the conditions for plant growth. In addition, biochar/compost mixtures may even shortly after soil exposure prevent erosion or mineralization losses of SOM under high rainfall conditions [15–17].

The impact of the amendments on soil physicochemical parameters was found to be site dependent (Figure 2), i.e., cannot exclusively be related to soil type and/or soil physico-chemical characteristics. This shows that soil-inherent conditions may play a pivotal role in the response to organic matter inputs, supporting the conclusions of recent studies, which suggest that site-specific soil communities may play an important role in biogeochemical cycling [29]. Therefore, it may be necessary to adapt organic amendments to site-specific pedoclimatic conditions [24] and to elaborate soil-specific management strategies [30]. Moreover, the results of our study also indicate, that the beneficial effects of organic amendments are in the short-term most likely related to their nutrient input rather than their impact on physical and/or biological soil characteristics.

## 5. Conclusions

We investigated the short-term effect of biochar and compost and their combination on chemical, physical and biological parameters of tropical soils in three Southeast Asian countries and also analyzed their effect on agricultural production. Our results indicated that biomass and maize cob yields depended on the pedoclimatic context in the three Southeast Asian countries, despite similar use of mineral fertilizers and irrigation. Addition of organic amendments had very little significant effects on biomass and cob yield in the two growing seasons. In the short term, addition of organic amendments showed significant effects on soil parameters, such as pH, OC, K<sub>2</sub>O and available (NO<sub>3</sub><sup>-</sup>N, P and K), while no effect was noted for total nitrogen, total phosphorus, macro fauna and water infiltration. Although positive effects of organic amendments and biomass production and/or yield in a tropical context have often been reported, we conclude that these effects were not as large as expected. Moreover, due to the strong site-specific responses to the organic amendments, future studies should focus on optimizing their application in combination with mineral fertilizers to pedoclimatic conditions, especially in tropical environment. The long-term effect of such amendment strategies on soil properties and agricultural production also needs to be investigated.

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