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# In-situ biochar application conserves nutrients while simultaneously mitigating runoff and erosion of an Fe-oxide-enriched tropical soil

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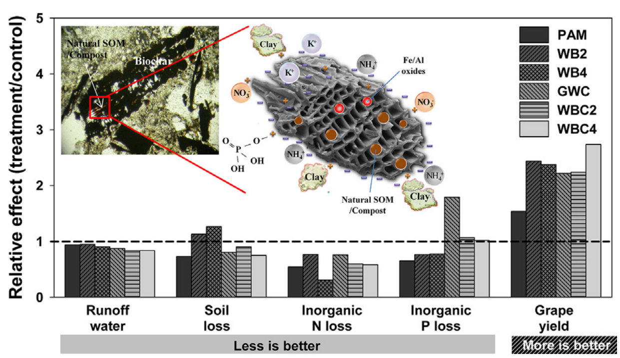
## HIGHLIGHTS

- Co-applying biochar and compost notably reduced runoff and soil loss by 16%–25% in a tropical soil.
- In-situ biochar applying increased inorganic N, available P and K by 1.5–2.5 times in slopelands.
- Crop productivity was enhanced by biochar applying 1.5–2 times at least in a tropical slopeland.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Climate change gives rise to rapid degradation of rural soils in sloping subtropical and tropical areas and might further threaten environmental sustainability. In this study, we conducted an integrated evaluation of the effects of wood biochar (WB) application mixed with a green waste dreg compost (GWC) on runoff quality, soil losses, and agricultural productivity for a highly weathered tropical soil. A conventional agriculture method, in which soils are treated with anionic polyacrylamide (PAM), was also conducted for comparison. The amounts of runoff and soil loss, and nutrient retention were evaluated a year after WB application. Soil fertility was also investigated through a year pot experiment with rape (*Brassica campestris* L.) cultivation. Our results showed that the WB application not only effectively increased soil pH, soil organic carbon (SOC) and exchangeable $K^+$ but also increased the production of rape plants. Significant reduction of runoff and the increases of inorganic nitrogen (IN) and total phosphorus (TP) were found in the WB-treated soil. Compared to the control, the co-application of WB and GWC, particularly for the WB at 4%, decreased runoff by 16.8%, soil loss by 25%, and IN loss (via runoff) by 41.8%. Meanwhile, compared to the control and PAM treatments, the co-application of WB and GWC improved soil acidity and the contents of SOC, IN, TP, and exchangeable $K^+$. The co-application of WB and GWC could be

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an alternative agricultural strategy to obtain benefits to agricultural productivity and environmental sustainability.



## 1. Introduction

Over 73% of areas in Taiwan consist of slopelands, and most slopelands are used for agricultural purposes. Most of the rural soils of slopelands in Taiwan include colluvial sediments (Entisols and Inceptisols) and highly weathering soils (Ultisols and Oxisols) that commonly indicate poor soil fertility and quality. In humid subtropical or tropical climates, intensively cultivated slopeland soils are generally very acidic (pH ≤ 5.0), with low contents of soil organic carbon (SOC) (≤1%), cation exchange capacity (CEC), and base saturation percentage (BSP) (Hseu et al., 2014; Jien and Wang, 2013; Jien et al., 2015, 2017).

Farmers are mostly not aware of the vulnerability of their soils to degradation, especially in mountainous or slopeland areas, where unpredictable erosion causes irreversible damage to soil and environmental sustainability. Excess nutrients supplied to crops in those degraded rural soils can be released into water bodies through surface runoff and eroded sediment or leaching, also known as non-point source pollution, thereby reducing surface water and groundwater quality (Mailapalli and Thompson, 2011).

Losses of soil particles and nutrients via erosion from slopeland rural soils not only obviously depletes soil fertility, accelerates soil acidification, and increases fertilizer costs, but also adversely affects the quality of surface water and groundwater (Martínez-Mena et al., 2012; Otero et al., 2011). Pärn et al. (2012) mentioned that N and P are lost because of erosion by around 10–270 and 0.8–14.5 kg $ha^{-1}$ $y^{-1}$, respectively, from slopeland areas under temperate climate, and these losses might be higher under subtropical/tropical climate. Soil and nutrient losses vary substantially depending on both rainfall intensity and soil properties, particularly of soil organic matter (SOM) and aggregate stability (Laird et al., 2010). Thus, the effective maintenance of SOM in slopeland soils can help preserve soil fertility and decrease susceptibility to erosion by enhancing aggregate stability and hydraulic characteristics (Auerswald et al., 2003; Tejada and Gonzalez, 2007).

In Taiwan, the application of anionic polyacrylamide (PAM) has been used as an effective method for reducing water turbidity and soil erosion. Application of PAM improves soil aggregation, infiltration rate, and water retention as well as reduces water turbidity and soil erosion (Busscher et al., 2007). However, its effectiveness can be limited depending on the soil properties, such as calcium level, clay content, electrolyte level, and SOM (Lee et al., 2010; Wu et al., 2012). The efficacy of PAM in fields has also been considered to be short-term. Therefore, an alternative application method in terms of the ecological aspect and sustainability should be developed for effective soil erosion control.

Biochar is a by-product derived from pyrolysis of organic wastes, serves as a pool of chemically/biologically stable carbon (Lehmann et al., 2009). Numerous studies have reported that biochar is an effective resource for improving the physicochemical properties of soils, including their SOM, aggregate stability, nutrient efficiency, and crop productivity, particularly in long-term cultivated soils under subtropical and tropical climates (Chan et al., 2007; Deenik et al., 2011; Jien and Wang, 2013). Furthermore, the application of biochar to soils has been considered a practical method for the long-term maintenance of SOC and fertility.

Yuan and Xu (2011) demonstrated that fertilizer-use efficiency and crop yield increase following biochar incorporation. The employment of biochar in highly weathered tropical soils has been determined to effectively enhance soil quality and physical properties (Jien and Wang, 2013; Laird et al., 2010). Jien and Wang (2013) and Hseu et al. (2014) reported that biochar application could effectively reduce soil loss by >40% in a highly weathered soil and a mudstone soil in Taiwan, respectively.

Recently, co-composting or co-application of biochar and other organic amendments has been identified as an excellent management practice by compensating for the limitation of each amendment (Awad et al., 2012, 2013; Rogovska et al., 2011; Sanchez-Monedero et al., 2017).

The objectives of this study were to investigate the effects of PAM, biochar, compost, or various mixtures of such on the physical and chemical properties of highly weathered slopeland soils and to evaluate the effects of PAM and organic amendments on plant growth, runoff, soil loss, and nutrient retention under natural rainfall conditions.

## 2. Materials and methods

### 2.1. Study site

The experiment was conducted in the international standard soil erosion plot having a slope of 9% near the National Pingtung University of Science and Technology in Southern Taiwan (E 120° 36′ 22.38″, N 22° 38′ 41.43″) for a year (July, 2014 to June, 2015). For this region, the average annual temperature and precipitation are 24 °C and 2847 mm $y^{-1}$, respectively, and ~90% of annual precipitation occurs from May to September. The soil is classified as Typic Paleudults (Soil Survey Staff, 2014).

### 2.2. Treatments

A series of field subplots (1 m by 4 m) were used in this study, either without treatment (control) or with six soil treatments including: 1 kg $ha^{-1}$ PAM (PAM), 2% wood biochar (WB; WB2), 4% wood biochar (WB4), 1% compost (GWC), 1% compost + WB2 (WBC2), and 1% compost + WB4 (WBC4). The relevant application levels are given as percentages (w $w^{-1}$ on dry weight basis) of the bulk topsoil (20-cm deep). The subplots were vertically arranged on the slope with a randomized complete block design (RCBD). Before the experiment was performed, the subplots' initial vegetation was completely removed, and the topsoil was tilled, after which water was sprayed to reach the water holding capacity of the soil. The soil was then covered with canvas for a month, after which the treatments were administered.

For the PAM treatments, commercially available granular anionic PAM, having a high molecular weight of 12 mg $mol^{-1}$, was dissolved in deionized water to a concentration of 10 mg $L^{-1}$. The pH of the PAM solution was approximately 8.0. A 40-L PAM solution was then evenly sprayed on the soil surface of each PAM subplot, which equaled an application rate of 100 mg PAM $m^{-2}$ (or 1 kg PAM $ha^{-1}$). The biochar used in this study was produced from driftwood, mainly zelkova, under anaerobic conditions at the pyrolysis temperature of 400 °C in the Industrial Technology Research Institute of Taiwan, as recommended by Lehmann (2007). The biochar was ground to pass through a 5-mm sieve and then well mixed. The compost used in this study was a commercial product, produced mainly from soybean meal, rice husks, fish bone meal, and green waste ash. After the amendments were well mixed with the topsoils, all the subplots including the control were covered with canvas and preincubated at their water holding capacity for a month.