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SUMMARY OF DOCTORAL THESIS

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Title: STUDY ON SUSTAINABLE BANANA WASTE MANAGEMENT THROUGH COMPOST AND BIOCHAR PRODUCTION FOR SOIL AMELIORATION AND ENVIRONMENT PRESERVATION

(土壌改良と環境保全のための堆肥化，炭化処理によるバナナ廃棄物の持続的管理に関する研究)

Soil fertility depletion through erosion and "low in-put agriculture" is the major obstacle to increased crop production and productivity, and household incomes in Sub-Saharan Africa. Chemical fertilizer usage for soil fertility enhancement is quite low due to social-economic constraints. Meanwhile, a large volume of banana, and therefore banana wastes is produced in Uganda (20th World-leading banana producer). The wastes could be processed into potentially beneficial products for soil amendment and carbon sequestration. This work evaluated two concepts (i.e. compost and biochar production) with potential for sustainable and profitable management of banana wastes. Evaluation encompassed compositional analysis of the products for soil additive potential, and recalcitrance for carbon sequestration. The first study aimed to evaluate the efficacy of aerobic and anaerobic composting methods for banana peels and the effect of poultry litter, cow dung and earthworm as starter inoculums on composting, as well as to determine the dominant mineral nutrient components of banana residue-based compost. 5 kg aliquots of withered banana peels (60%MC) were placed in two different sets of compost boxes (aerobic and anaerobic). These were then inoculated and thoroughly mixed with 0.5 kg of cow dung, poultry litter or earthworm at 1.6 kg m^{-3} density to obtain various formulations. For the aerobic setup, boxes were fitted with a vent pipe at the top and an air-supply tube connected to a 1.5 L. min^{-1} air pump at the bottom, while the boxes under anaerobic composting were completely sealed. The experiment was set and left to run in an incubation room (40°C) for a 12-weeks period. Bi-weekly monitoring of the physiochemical characteristics of compost samples revealed that inoculation and aeration are essential for an enhanced composting process. Effect of inoculation was in the order: poultry litter > cow dung > plain peels. Earthworm inoculation was unsuccessful, as earthworms died two days into composting, likely due to unfavourable environmental conditions (temperatures > 40°C, pH >7 and moisture content > 45%. Accelerated composting under inoculated conditions was likely due to additional mineral nutrients N and P in the inoculum formulations; these are believed to enhance composting of organic compounds. Higher decomposition rate under aerobic as compared to anaerobic conditions was likely due to increased bio-oxidative activity (Bernal et al. 2008). The final compost formulations were especially rich in N and K mineral nutrient concentrations ranging 2.04 – 2.18% and 12.2 – 13.9% under aerobic and 1.84 – 2.09 and 10.44 – 11.86% under anaerobic composting conditions respectively; thus suggesting potential for use as N and K fertilizers. Pot cultivation trials however, revealed a risk of alkalinity toxicity when compost is used to supply N. The composts were also highly alkaline (pH > 9), indicating their potential usability in liming in some of Uganda's highly weathered/acidic soils. This

result constitutes the core of this study's novelty, as no other had reported on the physiochemical characterization and potential utilization of banana waste-based compost. Summarily, although composting under aerobic was generally more efficient than that under anaerobic conditions, nitrification was largely inhibited in both setups; there was massive loss of N through NH_3 volatilization likely caused by the high composting pH. The compost is also low in other useful nutrients, such as P, Ca and Mg; thus the need for supplementary supply of deficient nutrients.

Despite its high potential agro-ecological value, composting poses some challenges; such as the long composting period (> 10 weeks), and composts' easy decomposability (low stability). A second study was therefore undertaken to assess biochar production as a second value-added approach for sustainable and profitable management of banana wastes. The study aimed to characterize and compare physiochemical properties (mineral nutrient content, pH, EC, CEC, humification) of banana peel biochar produced under different biomass feedstock moisture content (MC), pyrolysis holding time (HT) and temperature conditions. Biochar was made from banana peels of 0, 50 and 80% MC by heating at 200, 400 and 600°C for 1, 2, 3 and 4 hours of HT. Resultant biochars varied widely in physiochemical properties, with 200°C producing the least transformed biochar, and in some cases (high MC/short HT such as: 80%MC/1-4hrs HT, 50%MC/1-2hrs HT, 0%MC/1hr), the conditions were insufficient for carbonization (no biochar formed). Moisture content affected physiochemical characteristics (mineral nutrient content, pH, EC) in the order: 0 > 50 > 80 % MC; humification and CEC however, behaved differently, with presence of moisture (50 and 80%MC) appearing to enhance humification and CEC build-up as compared to no-moisture conditions (0%). This suggested that presence moisture might be essential for enhanced humification and CEC build-up during charring. This work is the first to delve into the effect of initial feedstock biomass moisture content on physiochemical properties of produced chars; further studies are required to confirm these findings, and understand the mode of action. Temperature generally affected biochar properties in the order: 600 > 400 > 200°C, except for yield, which was highest at 200°C. At 600°C, biochars were the most humified, containing the highest degree of condensation, thus likely the most stable. Effect of HT on charring was similar, but of less significance as compared to temperature. The key nutrient contents and characteristics (P, K, pH, CEC) of produced biochars were moderate and in some cases slightly less at 400°C as compared to 600°C; however, factoring in the biochar yield, which was significantly higher at 400°C would result in more or less the same and in some cases higher nutrient content and quality characteristics. This, coupled with the lower energy requirement would favour 400°C as the ideal temperature for production of agricultural-use biochar, while 600°C is recommended for carbon sequestration. From the agronomic view point, the biochars were rich in K (~ 205g kg^{-1} - water extractable); suggesting that banana peel biochar could potentially readily supply K for plant uptake. Biochars produced at 400/600°C were phenomenally alkaline (pH > 10) likely due to high K enrichment during charring, and these could be used aid in soil liming.

The two products have common and special attributes, suggesting that choice needs to be guided by the ultimate goal. For instance, composting retains relatively higher N, while charring literally loses most it. Conversely, other mineral nutrient contents are more enriched in biochar as compared to compost. Due to high energy and equipment requirements, biochar production may be unsuitable for the poor rural farmers, who instead should employ composting. For large scale banana waste management, especially in urban centers, charring is recommended as the waste volume reduction is higher as compared to composting. The produced biochars are cheaper to transport back to the rural production areas and easier to apply in the field.