Mineral Nutrient Recovery in Pyrolysis Co-products for Varied Feedstocks

Jatara Wise[1], **Don Vietor**[1], Sergio Capareda[2], Tony Provin[1], Derek Husmoen[1], Ronnie Schnell[1] & Clyde Munster [2]

(1) Soil & Crop Sciences & (2) Biological & Agricultural Engineering, College Station, TX

Abstract

Plant biomass can be pyrolyzed under oxygen-free conditions and high temperature to produce fuel, bio-oil and synthesis gas, leaving behind a charcoal byproduct commonly termed "bio-char." Sustainable bioenergy systems will require recycling of bio-char to replenish soil nutrients on original fields used to produce biomass for pyrolysis. However, little research is available illustrating the relationship between feedstock properties, bio-char yield, and conservation of plant nutrients under varying pyrolysis temperatures and inert gas flow-rates. Some research suggests limited recovery of key plant nutrients in bio-char indicates that these nutrients are present in the bio-oil or synthesis gas. This research studies the relationship between classic fiber analysis of forages and bio-char yield. In addition, mass balance of plant nutrients was quantified in the bio-char, bio-oil and synthesis gas derived from pyrolysis of three biomass feedstocks (high-energy sorghum, corn stover, and switchgrass) at controlled temperature and gas flow rate. Significant differences in bio-char yield were observed among inert-gas flow rates and feedstocks ($p<0.05$), but bio-char yields were not correlated with feedstock fiber or ash contents. Analysis of bio-char samples indicated poor mass-balance recovery of potassium, phosphorus and other nutrients in the bio-char. For sorghum, less than 60% of pre-pyrolysis biomass potassium and phosphorus was recovered in bio-char. Low recoveries in bio-char were due, in part, to potassium and phosphorus recovery in remaining co-products, including condensed tar and bio-oil and non-condensable synthesis gas. Bio-oil and tar fractions revealed recovery of nearly 15% of biomass potassium, but recovery of less than 1% of biomass phosphorus. The synthesis gas acid trap captured less than 4% of biomass phosphorus and slightly over 35% of the biomass potassium. Filter paper was used remove residue from the acid trap and contained nutrient levels similar to the bio-oil and tar fractions. Low nutrient recovery in recycled bio-char could limit nutrient return to production fields and sustainability of feedstock production.

Introduction

- Pyrolysis is the thermo-chemical decomposition of biomass at high temperatures in the absence of oxygen.
- Pyrolysis is a preferable renewable energy conversion process due to its short conversion time, ease of sample preparation, and there is a system of refineries and processing plants that could easily modified to process the bio-oil co-product.
- It is believed that the majority of mineral nutrients reside in the bio-char.
- The crops analyzed in this study are high-energy sorghum and switchgrass.
- Bio-char can be re-applied back to the production field to:
  - ❑ Supply organic carbon for sequestration
  - ❑ Replenish soil essential mineral nutrient (ex: Potassium and Phosphorus)

Hypothesis and Objectives

- H_0 : Pyrolysis conditions have no effect on the recovery of mineral nutrients.
- H_a : There is some effect.
- The objectives of this study were to:
  - ❑ Relate pyrolysis conditions (temperature and gas flow-rate) to recovery of mineral nutrients
  - ❑ Examine how various pyrolysis conditions effect bio-char yield

Materials and Methods

1) High-energy sorghum and switchgrass was pyrolyzed at temperatures of 500 and 600ºC each and at nitrogen gas flow rates of 1 and 2 liters per minute.
2) The bio-char, bio-oil, and contents of the acid trap (Syngas) were collected and prepared for nutrient analysis.
3) Bio-char and oil were ashed and prepared for Inductively Coupled Plasma (ICP) analysis analyzed for mineral nutrient levels at the Texas A&M Soil Testing laboratory. The acid samples were digested and analyzed via ICP also.

Pyrolysis Schematic and Setup

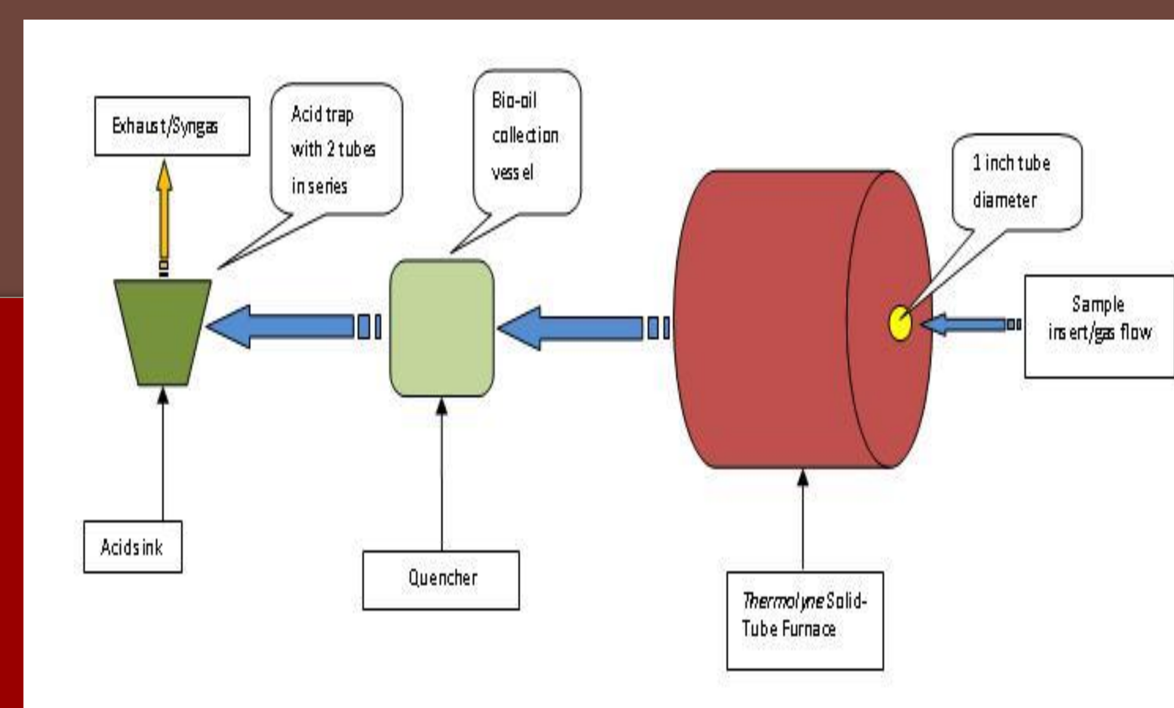

Figure 1. Schematic diagram for mini bench-scale pyrolyzer.

Figure 2. Thermolyne 1" diameter tube furnace.

Figure 3. Bio-oil collection and acid trap setup.

Results

Figure 4. Boat loaded with pre-pyrolysis biomass and post-pyrolysis bio-char.

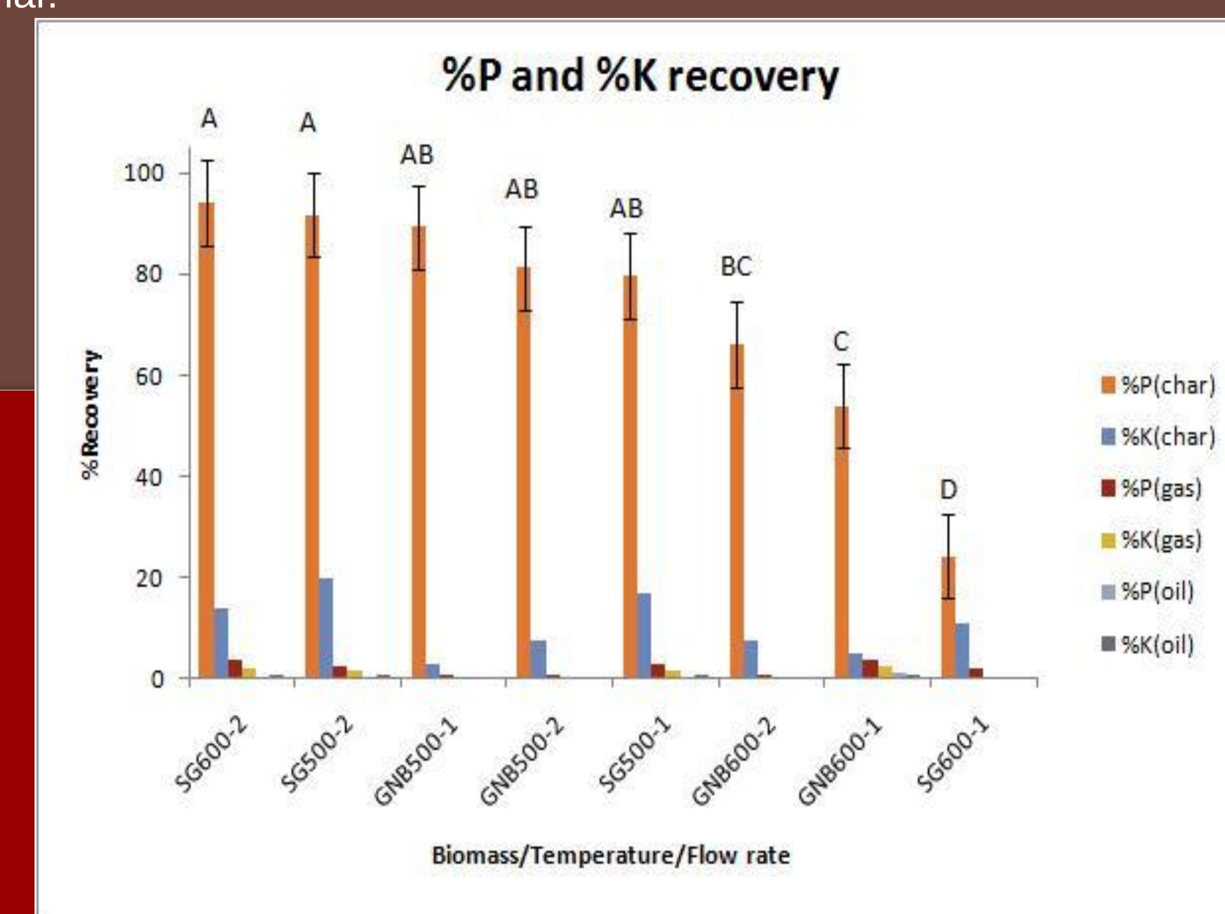

Figure 5. Phosphorus and potassium recoveries from bio-char, acid (gas) trap, and bio-oil. Switchgrass and sorghum was pyrolyzed at two different temperatures (500 C and 600 C) with two separate gas flow rates (1 and 2 liters per minute).

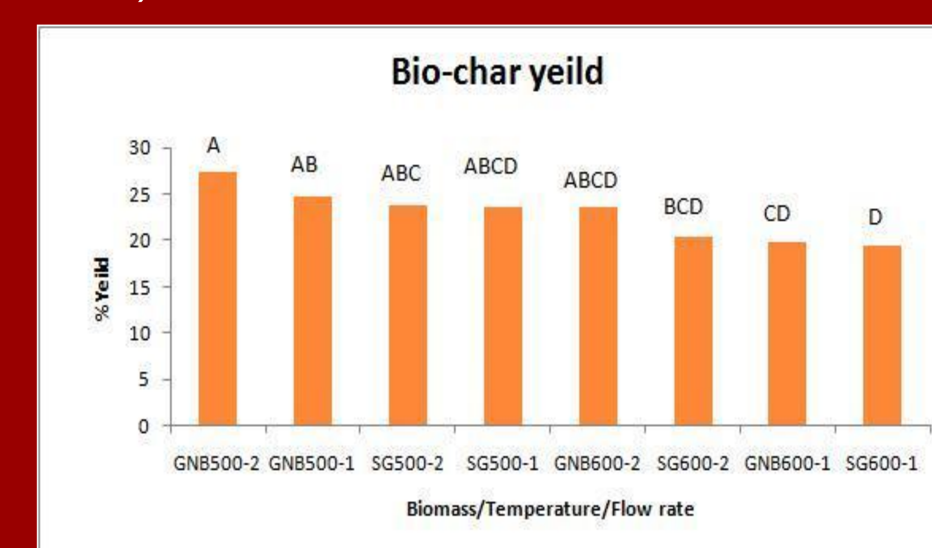

Figure 6. Bio-char yield, expressed as a percent of biomass.

Discussion and Conclusion

- Recovery of phosphorus and potassium in bio-char was impacted by cultivar, temperature, and inert gas flow rate ($p=0.05$).
- Significant losses of potassium were observed, most likely due to the inability of the acid (gas) trap to capture potassium aerosols. This lack of potassium recovery is consistent with other studies conducted at Texas A&M University.
- Additional research is underway to define the impact of each of these parameters and other plant nutrients.

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