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Research Article

Effects of microaerobic fermentation and black soldier fly larvae food scrap processing residues on the growth of corn plants (*Zea mays*)

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Abstract

Solid residues produced by processing food waste via Microaerobic Fermentation (MF) and by Black Soldier Fly larvae (BSFL) have been proposed as soil fertilizers. Yet, little is known about their effects on plant growth. This study compares the growth of corn plants (*Zea mays*) in soil amended with MF or BSFL residue, with effects of aerated compost on corn growth over ten weeks. Corn plants grown in soil amended with MF residues were 109% taller and had 14% more leaves than those grown in traditional aerated compost (Cedar Grove). But plants grown in BSFL residues were stunted, growing 39% shorter and having 19% fewer leaves on average. Only height data was statistically significant. Results indicate that MF produced from food scraps is a suitable soil amendment product, but BSFL solid residue from a similar source is phytotoxic when amended, untreated, into soil in a ratio of one part residue to two parts soil. More research on additional post-processing methods for BSFL solid residue is needed.

Keywords
Soil amendment; compost; plant growth; corn; Microaerobic Fermentation; Bokashi; Black Soldier Fly larvae

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Introduction

The process of composting produces a soil amendment that is rich in fiber, nitrogen (N) and phosphorous (P). Fertilizing efficiency of compost products depends on many factors including feedstock materials and the specifics of the process used (Griffin and Hutchinson, 2007). Aerated composting encourages breakdown of organic material by aerobic micro- and macro-organisms often under thermophilic conditions (BioCycle, 2008). Vermicomposting allows for processing of materials by earthworms and bacterial communities under non-thermophilic conditions (Theunissen *et al.*, 2010). Black Soldier Fly larvae (BSFL) are also used for processing of organic waste, especially manure (Liu *et al.*, 2008; Myers *et al.*, 2008). The larvae live in and feed off of organic matter, decreasing its volume and pathogen load (*E. coli* and *Salmonella*) (Erickson *et al.*, 2004; Liu *et al.*, 2008), but little is known about the effects of BSFL solid residues from food scrap processing on plant growth.

Microaerobic Fermentation (MF; also known as Bokashi), another process for controlled degradation of organic waste, is a lactic fermentation akin to silaging, and is routinely done in enclosed fermenters with liquid drainage under microaerobic conditions (about 0.5-2.0% O_2) (Fig. 1). When processing vegetal materials; such as food waste, leaves and wheat bran; the MF process takes about two to five weeks (Bhattarai and Bhudhathoki, 2006; Masó and Blasi, 2008). During fermentation, a compost leachate rich in carboxylic acids, alcohols and amines, is produced and should be continuously drained. Liquid, in the form of water or leachate pre-treated by aeration, must be added to the system periodically to maintain moisture levels, which also enhances the extraction of more nutrients from the solid phase into the liquid phase (Alattar *et al.*, 2012). MF processing is unlike conventional composting, where most nutrients remain locked in the solid phase and salinity, especially sodium and chloride (an undesirable portion of post-consumer food and manure composts), cannot be decreased (Tester and Parr, 1982; Turan, 2008). Unlike conventional compost (which is stable from molds and can be added directly on top of the soil) MF solid residues are buried for a second phase of degradation and stabilization before the soil is ready for planting (Green and Popa, 2011).

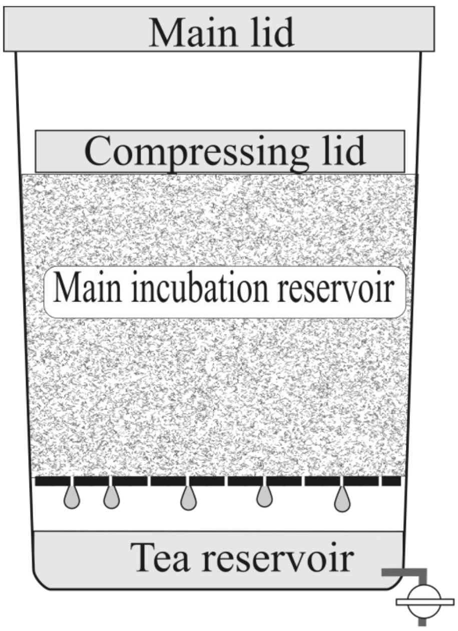

Figure 1. Basic scheme and functioning of a Microaerobic Fermentation (MF; a.k.a. Bokashi) fermenter. Compost leachate is continuously or frequently drained and liquid (water or treated leachate) is periodically added on top to maintain a high moisture level (>60%) and to reintroduce mineral nutrients. Conditions inside the fermenter are microaerobic, moist, and should evolve toward acidic (pH approximately 3.4-3.8) due to buildup of organic acids (mainly lactic and acetic). (Alattar *et al.*, 2012).

Optimal proportions of compost amendment to soil range from 8% to 75% depending on the soil properties, the type of compost and the crop being grown (Atiyeh *et al.*, 2000; Hicklenton *et al.*, 2001; Herrera *et al.*, 2008; Kalantari *et al.*, 2011). Herrera *et al.* (2008) reports optimal growth of tomato seedlings in soil amended with 30% municipal solid waste (MSW) aerated compost. Kalantari *et al.* (2011) reported optimal growth in corn plants grown in soil amended with 3% vermicompost (yard leaf and manure origin) and even higher growth when Fe sulfate supplements were also added. Atiyeh *et al.* (2000) reported increased growth of tomato plants grown in 10% and 20% pig manure vermicompost, or 10% vermicomposted food waste. The Oregon Department of Environmental Quality (DEQ) suggests a 20% compost portion for most plants (Oregon DEQ, 2003).

Amending soil with compost has extensive short and long term effects on soil quality and plant growth. These include increased sequestration of organic C, increased N content, increased soil microbial biodiversity, decreased bulk density and increased crop quality and yield (Marchesini *et al.*, 1988; Meier-Ploeger *et al.*, 1989; Ros *et al.*, 2006; Diacono and Montemurro, 2010). Carbonell *et al.* (2011), Akanbi and Togum (2002), Sullivan *et al.* (2002) and others have shown that compost amendment instead of, or in combination with, nitrogen fertilizer amendment increases both crop productivity and profit margins.

The objective of this study was to evaluate the effects of MF and BSFL solid residues on the early (ten weeks) growth of corn plants (*Zea mays*) relative to traditional compost.

Materials and Methods

All organic materials for corn plant experiments originated from kitchen scraps. These included food waste from fruits, vegetables, bread, coffee grounds, rice, grains and dairy products. The source material was mixed in a bin and distributed between three composting units: a Garden Plus 115 gallon aerobic compost bin, a cylindrical 19 L MF fermenter made from a drinking thermos (Rubbermaid), and a BSFL unit made from a plastic 68 L container with air-holes drilled into the sides, lid and bottom (Rubbermaid, Roughneck).

A bag made from DuPont WeedFree ProFabric filled with rocks was laid on the bottom of both the MF fermenter and BSFL unit. In the MF fermenter, the Pro Fabric bag functioned as a particulate matter filter to avoid clogging when leachate was drained. In the BSFL processing unit, it allowed for simultaneous aeration of larvae and insulation of the container from the bottom.

Organics were collected and processed over three months for aerated compost and MF, and for 1.5 months for BSFL processing (due to increased processing rate). The MF process should not be allowed to evolve toward alkalinization and the production of ammonia. Compost stability was determined through visual and olfactory characteristics. Material was collected from the bottom of the aerated bin when it resembled soil visually and in odor and its origin could not be recognized. Some lignocellulosic material, small twigs and straw, were still recognizable in the material. BSFL residues were collected when fully processed, from areas with little larval activity, which indicates lack of nutrients and complete degradation in that area. MF materials were considered completely processed material, because they were incubated for 3 months, which is significantly longer than the two to five week processing time common for MF. Leachate was lightly squeezed from the residue before the MF residue was used.

Residue-soil mixtures were prepared in 1:2 residue to soil ratios (w/w). A clay loam collected from the study location was used; the soil collection area had not recently been fertilized, nor did it have significant plant growth. BSFL and aerated composts were mixed into the soil, whereas MF residues were layered between two to five cm of soil on the bottom and 15 cm of soil on top. This is consistent with the second phase of MF, burying residues to allow for soil stabilization (Bokashicycle, 2010; Green and Popa, 2011). The mixtures were allowed to set and stabilize for three days before planting. Each treatment was tested in triplicate using three separate pots with one corn plant in each. Two controls were used in the experiment, an un-amended, no compost control and a store-bought aerated compost control (Cedar Grove, WA). Both were mixed in the same ratios as the compost treatments and allowed to stabilize for the same period of time.

About one hundred Sweet Corn plants (Ed Hume Seeds, WA) were started in three ounce (89 ml) paper cups (Dixie, GA), from seed, using commercial seedling soil mix (Black Gold, WA). After one week, fifteen similar sized seedlings were chosen for experimentation and randomly assigned to a treatment.

Plants were transferred to 2.6 L pots (ProCal, OH). Their location in the experimental plot was randomized each week for the first six weeks. After this point, randomization was stopped because of increased risk of damaging the plants. All plants were watered for 15 minutes, one to two times daily using an automatic sprinkling system. The height and number of leaves for each plant were analyzed weekly. After ten weeks the plants were removed from their pots, and the roots and leaves were checked for deformities, abrasions or evidence of illness.

Ammonium content of unmixed compost, initial compost/soil mixtures and final compost/soil mixtures were measured using the Nessler ammonium assay (Popa and Green, 2012) and initial pH was measured on aqueous slurries.

Results and Discussion

Aerated compost residue resembled soil with some twigs and straw evident in the mix. MF processed materials resembled pickled organics. BSFL solid residue was dense, grey in color and had the consistency of thick, moist clay. Once mixed with soil, mixtures had more uniform characteristics. Although, mixtures from the BSFL residue were slightly more moist and grey in color and mixtures from the Cedar Grove control were drier and darker brown in color then the other soil mixtures. The pH, measured from aqueous slurries, was similar in all initial compost/soil mixtures, ranging between 6.2 and 7.4.

For the first three weeks of experimentation plants from all treatments and controls, except for BSFL, grew an average of 30 cm in height (4.5 times the initial height). Even in these early stages, BSFL treatments showed more depressed growth at 11 cm average after three weeks. Thereafter, MF and Aerobic (produced on-site) treatments grew rapidly compared to BSFL treatments. Eventually MF and Aerobic treatments reached average heights three times the average for the BSFL treatments. At final measurements plants ranged from 31.5 cm to 160.3 cm and had a range of 5 to 8 leaves.

Corn plants in both the Cedar Grove (industrially produced compost control) and Aerated compost produced on-site had significantly increased height compared to the no compost control (18% and 144% taller respectively; $p < 0.05$). Aerated compost produced on-site lead to increased growth above the Cedar Grove compost treatment. This is likely due to the increased maturity of the store-bought compost compared to that produced on-site (Barrena, Font, Gabarrell, & Sánchez, 2014).

Corn plants grown in MF (average height: 152.1 cm) were more than two times taller on average ($p < 0.05$) and had 14% more leaves (however $p > 0.05$) than the control (Cedar Grove) compost treatment (average height: 72.8 cm, average leaf number: 7.3) (Fig. 2). BSFL treatment average plant height (45.2 cm) was 39% shorter than the control ($p < 0.05$); leaf growth was 19% less than the control (however $p > 0.05$). The increased plant growth resulting from MF treatment builds on recent research showing that MF soil amendment increases available N and soil fertility (Boechat, Santos, & Accioly, 2013). Also, Suthamathy and Seran (2013) found increased radish growth in MF of manure compared to both inorganic fertilizer and no fertilizer treatments.

BSFL residue may have stunted plant growth for various reasons including: depletion of some key nutrients, poor drainage in soil leading to anaerobiosis or phytotoxic components when the BSFL:soil ratio is 1:2. These effects were hypothesized based on high ammonium concentrations characteristic of BSFL residues and low residue porosity. Although significant research has been done on conversion of organic

Plant Science Today (2016) 3(1): 57-62

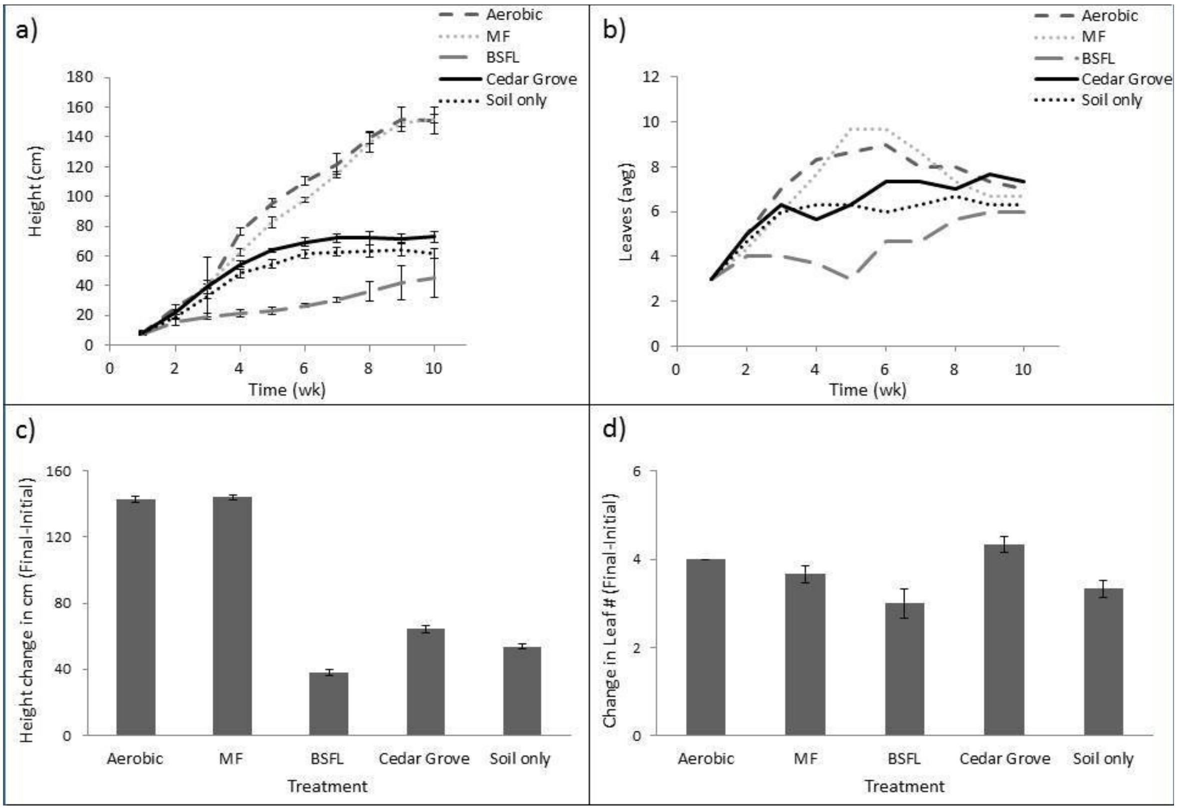

Figure 2: Evolution of height (a) and leaf growth (b) over the duration of the experiment and average change in height (c) and leaf growth (d) after 10 weeks. Compost treatments: Aerobic, Microaerobic Fermentation (MF) and Black Soldier Fly larvae residue (BSFL) compared to Cedar Grove compost and soil only controls.

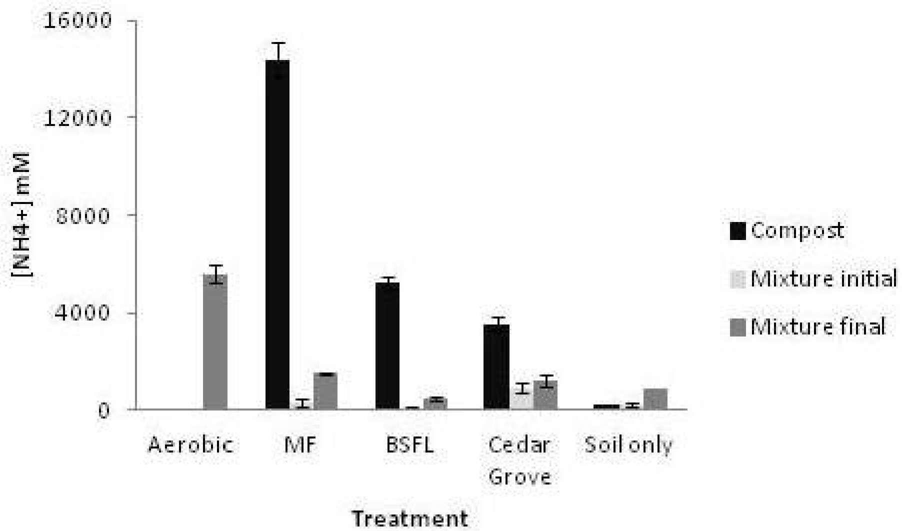

Figure 3: Ammonium concentrations in unmixed compost (Compost), initial compost/dirt mixtures (Mixture initial) and final compost/dirt mixtures (Mixture final) from different treatments and controls: Aerobic, Microaerobic Fermentation (MF) and Black Soldier Fly larvae (BSFL) residues compared to Cedar Grove compost and soil only controls. Compost and initial mixture data were not available for Aerobic compost treatments. Error presented as standard deviation.

waste into BSFL biomass for animal feed, research has not explored the use of BSFL solid residues from food scrap feedstocks for soil amendment (Diener *et al*. 2011; Makkar *et al*. 2014). Further research into stabilization of BSFL solid residue for soil amendment is necessary.

Although ammonium was present in the unmixed BSFL residue, once it was mixed with the soil, very little ammonium was detectable (Fig. 3). MF residue actually had higher ammonium concentrations than BSFL both before (about 5,233 mM ammonium) and after (about 10 mM ammonium) mixing with soil. Initial data was not

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available for aerobic treatments. Results suggest that ammonium was not the direct cause of stunted plant growth in soil amended with BSFL residue. Further research is required to fully understand this effect. Some data suggests that air-drying the BSFL solid residues before amending them into soil eliminates the inhibitory effects on plants (Popa and Green, unpublished).

Conclusion

The effects of MF and BSFL compost residues, generated from food scraps, on corn plant growth over ten weeks were analyzed. MF solid residues increased corn plant growth, but BSFL residues stunted growth, compared to controls. Although it was hypothesized that stunted growth may have been the result of toxic ammonium levels in the BSFL residue, this is not supported by ammonium content measurements which were lower in BSFL residues than in other residues. Results indicate that MF solid residues are beneficial for corn plant growth when amended in soil at a ratio of 1:2 compost to soil, but untreated BSFL residues are not (under similar conditions). Pre-drying of the BSFL residue may be needed before it can be used as fertilizer in 1:2 residue:soil ratio. Further research on methods to post-process BSFL residue and amendment abundance in soil is needed before this material can be used as corn fertilizer.

Competing interests

The authors declare that they have no competing interests.

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