Treatment of Vegetable Residues

Emily Austin, Richard G. Zytner, Sheng Chang
School of Engineering, University of Guelph, Guelph, ON, Canada
eaustin@uoguelph.ca

Abstract
Research was completed on treating peelings from a small scale processor of fresh cut vegetables so that the waste could be used for land application. Composting and anaerobic digestion were both used successfully and showed that both methods are technically feasible. The amount of methane produced from anaerobic digestion was approximately 100 L/kg dry mass. This amount is lower than that produced by other wastes that typically produce around 150L/kg dry mass

Introduction
Fresh cut vegetable processing is water intensive as it consists of four main steps before the vegetables can be shipped to stores. After arriving at the processing facility, the first step is washing to remove soil and rocks, followed by peeling or trimming based on the vegetable. During the peeling or trimming stage, a significant amount of water is used depending on the method used, with the peels and trimmings ending up in the water stream. Next, the vegetables are cut to the appropriate size which results in additional vegetable solids in the wash water stream. Finally the vegetables are packaged for sale.
The challenges facing all processors is the large quantity of water used in the washing and peeling, and the significant quantity of vegetable solids produced. Research is needed on both water use and solids handling to keep processing facilities cost effective and environmentally responsible. The emphasis of this project is the effective treatment and disposal of the solids removed from the wash water, which consists of vegetable solids and soil.

Small scale vegetable processors would like to apply the solids back to the land, while larger industrial type operations dispose of the residue in the municipal wastewater, an expensive option or send the residue off site for treatment. Ultimately, the goal is for all processors to operate under the regulations promulgated for non-agricultural source material (NASM) [1]. That is, the application of wash-water and related residues to the land in compliance with the legislation. For this work, composting and anaerobic digestion are being studied as a way to treat the solid residue.

Composting is a very old and simple way to treat organic waste and the conditions that need to be met are well established [2]. The moisture content must be between 50 and 70%, the initial C:N ratio must be between 20:1 and 40:1, particle size should be less than 7.6 cm, and there must be adequate air flow. If the pile is large enough it will produce enough heat to maintain the pile at 55°C, which is ideal for composting. Composting is a cost effective way to treat organic waste if land is available.

Anaerobic digestion is a more complex way to stabilize the organic waste. However, it has the advantage of methane production which can be used to produce heat and electricity and can offset the costs of operation. Most anaerobic digestion at this time is co-digestion with manure or sewage sludge. Solid waste needs to be reduced in size to 10-40mm before digestion for biological accessibility. [3] The C:N ratio in an anaerobic digester is between 20:1 and 30:1 [4], and the alkalinity tends to be in the range of 2000-4000 mg/L. Mesophilic temperatures provide greater VS reduction compared to thermophilic temperatures at the same SRTs, while thermophilic temperatures provide better disinfection, improved dewaterability of the sludge, and better reduction of organic nitrogen. [5]

For this study, vegetable waste was taken from two processors, covering a variety of vegetables. The residue collected was then treated in laboratory scale reactors simulating composting and anaerobic digestion. The objective of the study was to identify the ideal operating conditions for treating the vegetable residue. For ease of comparison, the results for carrots have been highlighted.

Materials and Methods

Composting

Composting was simulated with three 4 L glass jars. These were heated using a water bath kept at a constant temperature of 55°C. The optimum type and amount of bulking agent was studied, with straw, wood chips, and wood shavings being used as bulking agents. The amount of time the compost takes to reach maturity, reduction in fecal coliform levels, cost, and nutrient content and availability are the factors on which the composting will be evaluated.

Anaerobic Digestion

Two digesters were used which were constructed of aluminum and had a working volume of approximately 3.5 L, and were constantly stirred. The temperature was maintained using heating tape and controllers, and an initial purge of air using nitrogen gas ensured anaerobic conditions. Gas from the reactors was collected in Tedlar® bags, with a feed tube inserted 50 mm below the liquid surface to feed the reactors. Digestion was started with seed microorganisms from an anaerobic digestion process at a municipal waste water treatment plant. The reactors were fed once per day with vegetable solids and also sodium bicarbonate to maintain a proper pH.

The variables tested were temperature and retention time. The effluent was tested for its phytotoxicity, pathogen levels, and carbon to nitrogen ratio to evaluate its suitability for land application or need for further treatment. The amount of methane produced was measured as it can help offset treatment costs.

Phytotoxicity Testing

The method used to evaluate phytotoxicity of the samples was adapted from the method used by Zucconi, 1981[2]. Iceberg lettuce (Lactuca sativa L. capitata) seeds were used as opposed to cress that was used in the Zucconi paper because it has been shown in other papers [6] to be more sensitive to toxicity, though it does not grow as quickly. Each sample was extracted using 10 g water for every gram of compost and was left for 2 h before filtering through a Whatman 934-AH filter. Each petri dish had a piece of filter paper with 1 mL of sample and 6-10 lettuce seeds. The dishes were covered and stored in a drawer to keep away any light. After three days the length of the seeds was measured to find a germination index (GI) which is calculated as follows:

$GI = (Ls*Gs)/(Lsc*Gsc)$

Where Ls is the seed length of the seeds grown in the sample, Lsc is the length grown in the water control, Gs is the percent germination in the sample, and Gsc is the percent germination in the control. Compost is considered not phytotoxic when a 30% solution has a GI greater than 60% [7] and is considered mature when the GI is greater than 80%.[8]

The fecal coliform test (A-1 method), carbon to nitrogen ratio, and all solids tests were conducted in accordance with standard methods. [9]

Results and Discussion

Composition of the vegetable waste and bulking agents

The nutrient levels present in the materials used for composting and anaerobic digestion are presented in Table 1. The carbon to nitrogen ratio in the vegetable residue (carrots) was much higher than expected, which is usually in the range of 15:1 to 35:1. [10] A bulking agent will still be required to increase the void space of the pile for aeration, but this will bring the C:N ratio farther from the range of 20:1-40:1 that is necessary. An additional substrate, such as manure or other vegetable waste, would be needed to address this issue. For the lab trials a slow release fertilizer was used to compensate for this and an initial C:N ratio of 25:1 was used for all trials. The moisture was approximately 70% throughout the trials.

Table 1: Composition of Substrates

	Vegetable Solids	Wood Chips	Wood Shavings	Straw
Moisture (%)	95	8.8	7.9	7.3
Carbon (% of dry solids)	38.8	47.6	45.4	44.0
Nitrogen (% of dry solids)	0.75	0.99	0.24	0.38
C:N	60:1	56:1	221:1	135:1

Composting Results

Initial results show that wood shavings and wood chips are superior bulking agents to straw. Phytotoxicity tests showed that wood shavings and wood chips had a GI of 86 and 64% at a 30% dilution after 21 days of composting at 55°C compared to 21% for straw. This means that the wood shavings and wood chip composts have no phytotoxicity. The C:N ratio at 21 days is 14 for the chips and shavings compared to 29 for straw. Outstanding research is the evaluation of different ratios of bulking agent to vegetable solids. This may result in other bulking agents being found superior based on the fact that less is needed of some substrates to provide the same amount of aeration.

Anaerobic Digestion Results

The experiments conducted at 36 degrees and with a SRT of 21 days have been completed. The major results are shown in Table 2. An additional test to evaluate if adding nitrogen to the feed would help digestion was also completed and is included in Table 2. The nitrogen level for this test was increased so that the C:N ratio was 30:1 rather than 60:1. This is much closer to the 20:1 to 30:1 ratio that is suggested for anaerobic digestion systems. As the table shows the added nutrients do not seem to have improved the digestion of the waste. For the trial with additional nutrients the amount of gas produced was lower and was the reduction of the total solids.

The total biogas production of 260L/kg dry mass is similar to numbers reported from full-scale anaerobic digesters which range from 200-250L/kg dry mass [3], but the quality of the gas is not as good. The gas produced in these trials was approximately 36-43% methane whereas the actual anaerobic digestion plants produce gas which is usually 68% methane. [11] Continuation of the research will help refine the important operating variables.

Feasibility

Operationally, composting can be easier and more economical for the small producer. Limited high-end controls are needed as the producer will just need a flat area where runoff can be controlled to place the windrow. Existing equipment should be able to turn the windrows. Land application post composting according to NASM regulations would reduce fertilizer needs. Overall, capital costs are higher for the digestion system, and probably better suited for the larger producers. However, the methane gas produced can be used to generate both heat and electricity for on-site use from on-site generator. Completion of the research will identify the ideal size of the reactor and peripheral equipment needed.

Table 2: Anaerobic Digestion with a 21 day SRT at 36 degrees Celsius

	60:1	60:1	30:1
pH	6.5	6.6	6.5
biogas produced per kg of dry solids (L)	264.4	257.7	208.6
Amount of methane in biogas (%)	42.4	36.4	38.7
Sodium bicarbonate per gram of dry solids (g)	-	0.263	0.249
TS in feed (g/L)	35	47	43
TVSS in effluent (g/L)	-	8.9	6.94
TS in effluent (g/L)	21	24	24

- not measured

Conclusions

Research completed to date has shown that both composting and anaerobic digestion works for the vegetable residue sampled during the project. Wood shavings and wood chips appear to work best with the carrot residue, resulting in a stable compost that has no phytotoxicity. The C:N ratio in the finished compost is 14:1, making it suitable for land application. The digestion process produces approximately 260 L/kg of methane even at a C:N ratio of 60:1 for the carrot residue. This makes it a potential treatment option for large scale operation.

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