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Pecan (*Carya illinoinensis*) and Dairy Waste Stream Utilization: Properties and Economics of On-Farm Windrow Systems

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Abstract: Improper management of organic waste can lead to unnecessary carbon dioxide and methane emissions, and groundwater contamination. In this study, organic waste materials from two of New Mexico's (U.S.A.) top agricultural industries, pecan (*Carya illinoinensis*) and dairy cattle dairy manure, were used to evaluate the feasibility of an on-farm compost program. Pecan woody residues (P) served as the primary carbon source; regional cattle dairy manure (M) served as the primary nitrogen source. Additional (A) inputs from a compost consulting company (PM/A) and green waste from community landscaping and on-farm harvested legumes (PMG/A) were employed, both of which required additional labor and material inputs. Finished composts were analyzed for selected macro, secondary and micronutrients, pH, sodium adsorption ratio (SAR), electrical conductivity (EC), total carbon (TC) and organic matter (OM) content, bulk density (b_d), and microbial biomass. The PM alone treatment showed similar or significantly higher amounts of macro, secondary and micronutrients compared to the PM/A and PMG/A treatments. Total microbial biomass and total salinity were highest for the PM treatment. The total cost of the PM treatment was around 1/6 of the cost of the lowest-cost addition compost production scheme, indicating that simpler, lower-input production methods may be more advantageous for on-farm compost program development.

Keywords: agricultural sustainability; biomass; compost; compost consulting; cost benefit; landscape; manure; organic materials; organic waste

1. Introduction

New Mexico (NM) is currently the largest US producer of pecans (*Carya illinoinensis*) [1]). Mechanical pruning of pecan trees is a common practice for commercial pecan production, resulting in a large supply of carbon-rich biomass. Historically, woody agricultural waste in NM was burned, infringing upon regulatory and air quality standards [2]). The NM Environment Department (NMED) now limits the amount of agricultural biomass burning based upon daily environmental conditions and emission reductions techniques [3]).

As of 2017, cattle derived dairy was the highest cash receipt agricultural industry in NM, with the greatest production being in Chaves County [4,5]). NM is in the southwestern United States and receives an average of 25 cm of precipitation annually. Water conservation and water quality initiatives are critical in the mostly semi-arid, aquifer-reliant state [6]).

Proper management of nitrogen-rich dairy cattle manure is important to prevent water contamination [6]). The US Food and Drug Administration's (FDA) concerns about the use of untreated manure as a soil amendment in food crop production is related to food safety, as untreated manure has the potential to contain pathogens, including *E. coli* O157:H7 [7]. Proper composting has been shown to kill most E. coli O157:H7 [8–10]).

In the United States, the increase in organic farming has prompted the safe use of soil organic matter and biomass utilization that will not result in soil nutrient immobilization [11]. As compost consulting companies marketing their practices and products are continuing to emerge, identifying the most cost-effective form of compost processing will facilitate compost-processing adoption [12]. Ref. [12] identified a lack of availability of woody biomass, stringent regulations, time and economic investments, and not being adequately informed and knowledgeable on compost practices, as the primary factors inhibiting on-farm composting.

Plants rely on microorganisms to mineralize organic material [13]. Soil-applied compost treatments can provide many nutrients including nitrogen for plant growth and development that is otherwise limited to legumes and nitrogen-fixing symbiotes [14]. While much of the compost-related research highlights the effects of compost application on soil and crop parameters, few studies assess organic waste generator development of safe and effective organic waste-to-resource programs [15]. Identifying the most cost-effective form of compost processing for increased farmer resource maximization is paramount to compost program development and adoption [16].

This study was designed to test three hypotheses:

1. All three treatments—PM (pecan and manure), PM/A (pecan, manure, and additions), and PMG/A (pecan, manure, "green chop", and additions)—will result in the same quality of compost due to similar compost quality indicators based on selected physical, chemical and microbial properties of the finished compost product. Additions (A) were prescribed by the compost consulting company and included proprietary unknown inoculants; clay; unfinished compost from a past windrow processing; and community landscape material. The use of "green-chop" was also prescribed by the consulting company which included on-farm produced and harvested legumes.
2. The increased treatment turning/aeration and moisture inputs of the Additions (A) treatments will result in more rapid compost completion times because of faster decomposition kinetics. Treatment temperature thermodynamics will be positively impacted by treatment turning and moisture levels due to increased microbial activity. Treatment carbon dioxide rates will increase due to increased microbial respiration rates. The clay addition input will increase available moisture, resulting in higher microbial biomass [17].
3. The higher relative amount of treatment manure in the PM treatment will result in both higher EC and overall microbial biomass because of the higher salt content and initial microorganisms present in the cattle dairy manure. More nitrate-N will be present in treatments higher in initial dairy manure [18]. More P and K values will be present in treatments with higher manure input treatments. The treatments with A inputs will be higher in secondary and micronutrients due to the additional nutrients in the substrate materials.

2. Materials and Methods

2.1. Windrow Site, Primary Substrate Descriptions, and Economic Analyses

This study was performed at a pecan farm in Roswell, NM (Chaves County) with a total farm area of 486 hectares. The average temperature of the primary research site is 16 °C. The annual average high temperature is 24 °C and the annual average low temperature is 8 °C, respectively [19]. The average annual precipitation is 33 cm [19]. As a standard practice, the farmer trims every other hectare every other year; 122 hectares are trimmed yearly. Three on-farm windrows were constructed beginning on 16 June 2017. The primary carbon source for the windrow systems were on-farm produced pecan shredded trimmings (P) and the primary nitrogen source was dairy cattle manure (M). Pecan biomass included pecan tree pruning's shredded to 5 cm minus (≤5 cm). Dairy manure sourced locally in Chaves County was collected from multiple dairies, stockpiled and dried for several months, and transported to the farm research site by a local farming and transportation company. Each windrow, corresponding to different treatments, employed various combinations of organic material substrates and practices (Table 1) and was approximately 91 m in length and 1.2 m in height.

Table 1. Windrow substrate quantities and maintenance procedures.

Treatment	Substrates and Quantities	Windrow Maintenance Procedures
PM	Pecan tree biomass (P): 129 m^3 (83%) Manure (M): 27 m^3 (17%)	Weekly turning and watering
PM/A	Pecan tree biomass (P): 126 m^3 (50%) Manure (M): 38 m^3 (15%) Landscaping material (Addition "A"): 38 m^3 (15%) Compost, unfinished (A): 25 m^3 (10%) Clay (A): 25 m^3 (10%)	One-time clay and unfinished compost applications Daily turning and watering Weekly combining Daily edge cleaning
PMG/A	Pecan tree biomass (P): 61 m^3 (31%) Manure (M): 15 m^3 (8%) Compost, unfinished (Addition "A"): 15 m^3 (8%) Clay (A): 15 m^3 (8%) Green-chop (G): 90 m^3 (46%)	One-time clay and unfinished compost applications One-time green-chop application Daily turning and watering Weekly combining Daily edge cleaning

Each of the three treatments comprised pecan and manure substrates at various rates. The PM treatment was 83% pecan biomass (P) and 17% manure (M). The PM/A treatment comprised 50% pecan biomass (P) and 15% manure (M). The PMG/A treatment was made up of 31% pecan biomass and 8% manure. Two of the three treatments (PM/A and PMG/A) comprised additional (A) inputs as prescribed by the compost consulting company. Additions (A) were prescribed by the compost consulting company and included proprietary unknown inoculants; clay; unfinished compost from a past windrow processing; and community landscape material. The use of "green-chop" was also prescribed by the consulting company and included on-farm produced and harvested legumes (Table 1). The green-chop (G) was only utilized in the PMG/A (pecan-manure-green-chop addition) treatment.

Economic analyses were conducted via compost windrow enterprise budget assessments, comparing costs associated with total substrate volumes, inputs, maintenance, and labor and potential finished compost product revenue, on an annual and hourly (per use) basis. Land and associated taxes were not factored into fixed costs, as this was not a new on-farm acquisition. The finished compost amendments can translate to economic benefits as a potential supplement for synthetic fertilizers [19]). The farmer estimated finished compost in Chaves County NM, without transportation, would be valued at $100–300/tonne.

Sierra Vista Growers (Anthony, NM, USA) sells bulk horse manure-derived compost for approximately $110/tonne [20]. Detailed economic parameters are included in the Appendix A (Tables A1–A4).

2.2. Fixed Costs

The John Deere 6120R tractor, powering the compost turner, was purchased for $98,000, with an economic life of 15 years at approximately 400 h/year [21]. The JD TC54H Front End Loader was attached to the tractor and was used to form the compost windrows. The front-end loader was purchased for $60,000 with a life of 15 years. The Bob Cat Skid Steer was purchased for $38,000, with an approximate life span of 15 years, and was used to integrate the windrow substrates and to "clean" the windrow edges by reincorporating loose windrow material back into the windrow [21]. The horizontal grinder was purchased for $90,000, with a 15 year life span. The windrow compost turner (Aeromaster PT-130, Midwest Bio-Systems, Tampico, IL, USA), was purchased for $47,940, with a lifespan of approximately 15 years, and was affixed with a 1893 L Aeromaster WT-3000 water drum wagon with a purchase price of $23,905 and approximate 15 year life span. Water and energy costs were not factored into the analysis due to existing on-farm water rights and solar-powered water pumping; the approximate cost for the hydraulic pump and miscellaneous equipment was $3470, with a 15 year life span. Depreciation costs assume wear, obsolescence, and the age of the machinery and equipment [21].

2.3. Variable Costs: Pecan Biomass

A total of 122 hectares with 125 trees per hectare are trimmed annually on the farm and this corresponds to approximately 117 kg of dry tree mass removed per tree yearly [2]. Average pecan biomass bulk density was based on provided data (Table A4). A total of 713,700 kg of trimmings are produced on farm per year. Once the tree limbs were cut, a tractor (John Deere TC54H 180 horsepower diesel) loader and a brush fork was used to gather and transport the trimmings to the windrow site. Based on an estimated tractor purchase price of $200,000, total cost (overhead + fuel + labor) would be $90.54/hour [22]). Cut tree limbs were shredded to 5 cm minus by a horizontal grinder (Bandit Model 3680 Beast Recycler, Bandit Industries, Inc., Remus, MI, USA). The limb horizontal grinder rental cost was $15,000 per year, resulting in a limb shredding cost of $21 per metric tonne, if all on-farm biomass was shredded. All equipment fuel, depreciation, labor, and overhead costs were calculated on a yearly basis [21,22]). Windrow incorporation of pecan trimmings was estimated at approximately 1.5 h per windrow; total windrow establishment was approximately 2 h per windrow.

The PM treatment required 126 tonnes of shredded biomass per windrow. If the operation was scaled up to 714 tonnes of shredded pecan biomass (~5.6 windrows possible; 5 windrows were assumed), the total windrow processing labor time would be approximately 17 h at $15/hour ($255).

The PM/A treatment required 123 tonnes of shredded pecan biomass per windrow. Five windrows were again assumed for a full-scale scenario. Total labor for in-field pecan limb to windrow shredding incorporation for 125 tonnes of shredded pecan biomass was 3 h, therefore, 15 h was assumed for five windrows at $15/hour pecan shredding labor ($225 for five PM/A windrows).

The PMG/A treatment was comprised of 59.6 tonnes of shredded pecan biomass per windrow. For a full-scale scenario under this treatment, 11 PMG/A windrows can be constructed, using 655.6 tonnes of shredded pecan biomass and 17 h of labor at $15/hour labor hourly wage ($255).

2.4. Variable Costs: Dairy Manure

Dairy manure is available locally at an assumptive unlimited amount. Average dairy manure bulk density was based on provided data (Table A4). Manure was delivered for $6.62/tonne, unloaded next to the windrow site, and incorporated into the windrows by a tractor (John Deere TC54H 180 horsepower diesel). Dairy manure at a rate of 27 tonnes was incorporated into the PM treatment, which accounted for 17% of the total PM windrow volume (Table 1). Scaled up to use all of the available yearly on-farm pecan biomass (714 tonnes), approximately 135 tonnes of manure would be needed, at a cost of $894, to form five PM windrows. For the PM/A treatment, the pecan biomass-to-manure ratio was 3.32:1; scaled up to five windrows would require 185 tonnes of manure at $1225. For one PMG/A windrow, 14.6 tonnes, and a ratio of 4.07:1 pecan biomass: manure was needed; for 11 PMG/A windrows, this requires 161 tonnes of manure at $1066.

2.5. Pecan and Manure (PM) Windrow Economics

The pecan and manure (PM) windrow was created on 16 June 2017 and completed on 22 August 2017. The PM windrow was turned (aerated) and watered once per week

(Table 1) for a total of 11 h processing time. Economic evaluation included all materials and equipment depreciation costs. Scaling up to five windrows, 55 h of windrow processing labor would be needed ($825). Annual machinery, maintenance and insurance was estimated at $3476 (1% of the capital cost of $347,559 annually). Diesel fuel was estimated at $939 (51.48 L per hour of machine use, diesel fuel price at $0.66 per L, in 2019) [22].

2.6. PM/A and PMG/A Windrows: Additional Windrow Input Economics

The PM/A and PMG/A windrows included additional procedures: daily windrow uncovering and covering, cleaning of windrow edges using a tractor to reincorporate all loose composting material. Separated material from the windrows were reincorporated. Each (A) windrow required approximately 2 h per weekday (5 days/week) (Table 1).

The PM/A windrow had specific additions (A): proprietary unknown inoculants; clay; unfinished compost from a past windrow processing; and community landscape material (Table 1). The PM/A treatment comprised approximately 50% shredded pecan biomass, 15% manure, and 15% landscape material. Landscape material was provided at no cost with an on-farm residential landscape waste drop-off program. Local residents dropped-off bagged or bulk landscape material (e.g., grass, bush, and tree trimmings). Approximately 10% unfinished compost (from a previous windrow) and 10% clay were the remaining inputs (Table 1). The PM/A windrow was created on 9 June 2017 and was completed on 28 July 2017. With 35 days of processing for the PM/A windrow, each PM/A windrow required 70 h of total labor. Scaled up to five PM/A windrows, total processing labor would be 350 h.

The PMG/A windrow was created on 4 September 2017 and was completed on 6 November 2017. The PMG/A treatment included shredded pecan biomass (31%), manure (8%), on-farm grown and harvested "green-chop" leguminous plant material (G, 46%), proprietary unknown inoculants, clay (8%), and unfinished compost from a past windrow (8%) (Table 1). Assuming use of on-farm equipment, costs for the "green-chop" for one PMG/A windrow included a variety of leguminous seeds at $1200 and 38 h of labor ($380) for cultivation, harvest, and transportation. Scaled up to 11 PMG/A windrows, "green-chop" seed would be $13,200 and labor would be $4180 (Table 2). With two hours of windrow processing per day (after establishment), total labor for one PMG/A windrow was 90 h. If scaled up to 11 PMG/A windrows, 990 h would be needed.

The compost consulting company additions included an "N-Converter" (1.12 L over 30 m of windrow and 10 applications, a "humifier" (3.79 L over 30 m and 5 applications), a "finisher" (0.45 kg over 30 m and 3 applications), and clay. The proprietary "inoculant combination pack" (humifier and finisher) was $719.49 and N-converter was $128.16 per application. The windrow (A) clay product was applied once; clay was 8–10% by volume in the (A) windrows and each clay application cost approximately $725.67/tonne.

Table 2. Pecan, manure, green-chop, and additions (PMG/A) windrow enterprise budget.

	Quantity	Unit	Price ($)	Total ($)
Revenue ($)	517	tonnes	110.00	56,870.00
Variable costs ($/quantity)				
Pecan shredding's, labor ($/hour)	17	hour	15.00	255
Pecan limb grinder for shreddings production	17	hour	62.37	1060.29
Manure	161	tonnes	6.62	1065.82
A (Additions inputs)				
"Inoculant combination pack" (/application)	11	application	719.49	7914.39
"N-Converter"	11	application	128.16	1409.76
Green-chop	11	application	1200.00	13,200.00
Clay ($/application)	11	application	725.67	7982.37
Compost (unfinished)	11	application	895.44	9849.84
Windrow management				
John Deere tractor 6120R	17	hour	18.37	312.29
John Deere frontend loader	17	hour	29.00	493
Bobcat skid steer	17	hour	6.58	111.86

Table 2. *Cont.*

	Quantity	Unit	Price ($)	Total ($)
Windrow establishment labor ($/hour labor)	17	hour	15.00	255.00
Windrow processing (turning and watering)	990	hour	15.00	14,850
Variable costs total ($)				58,759.62
Fixed costs ($/hour/year)				
John Deere tractor 6120R (windrow processing)	990	hour	18.37	18,186.30
Aeromaster PT-130 compost turner (windrow processing)	990	hour	0.41	405.90
Aeromaster WT-3000 water wagon (windrow processing)	990	hour	0.21	207.90
Hydraulic pump & miscellaneous equipment (windrow processing)	990	hour	0.03	29.70
Fixed costs total ($)				18,829.80
Total cost ($)				77,589.42
Breakeven price ($)				150.00
Contribution margin (net return) ($)				−20,719.42

714 tonnes of shredded pecan biomass produced yearly on farm. Pecan tree biomass (P): 61 m^3 (31%); Manure (M): 15 m^3 (8%); Compost, unfinished (Addition "A"): 15 m^3 (8%); Clay (A): 15 m^3 (8%); Green-chop (G): 90 m^3 (46%).

2.7. Compost Characterization

Following an approximate 2–4 month windrow curation time, windrow sub-samples were taken at each of the three treatment windrows on 15 January 2018 following US Composting Council compost sampling procedures [23]. Each of the three windrows were divided into three equal sections, with five samples per section randomly generated per windrow. A shovel was used to dig an approximate 0.3 m by 0.3-m depth at each of the sampling points and then a 2.5 cm soil core sampler was used to collect seven random sub-samples. The sub-samples were then composited into three samples per windrow.

Finished compost samples were air-dried and analyzed for: total Kjeldahl N (TKN); nitrate-N (NO_3-N); available P, K, Ca, Mg, Fe, Mn, Zn, Cu, and Na; electrical conductivity (EC); sodium adsorption ratio (SAR); pH; organic matter (OM); and organic carbon (OC). TKN was employed to determine the total sample concentration of organic nitrogen, NH_3 and NH_4 [24]. Due to the relatively high N content of the compost samples, only 0.5 g was analyzed using a dilution factor of 50 for TKN analysis (1 mL sample and 49 mL deionized water); samples were digested using a Technicon Block Digestor (Technicon Industrial Systems, Tarrytown, NY, USA) and were analyzed using a Technicon Autoanalyzer II (Technicon Industrial Systems, Tarrytown, NY, USA), according to manufacturer guidelines [25].

Available NO_3-N and K were analyzed using a 1:5 deionized water extraction. Available P was measured according to the Olsen method [25]. Fe, Cu, Mn, and Zn was assessed by Diethylene triamine penta-acetic acid (DTPA) extraction and metal quantification using an Optima 4300 DV ICP-OES. For the DTPA analysis: the sample was extracted via solution containing DTPA; the extract was analyzed for metals by an inductively coupled atomic emission spectrometry (ICP); calcium chloride was added to the DTPA solution to prevent dissolution of zinc in calcium carbonate; triethanolamine was added to buffer the DTPA solution to prevent dissolution of pH dependent trace metals (PerkinElmer Instrument, Norwalk, CT, USA) [26]. Extracted metal ions were quantified using the Optima 4300 DV ICP-OES. Saturated paste or 1:5 deionized water extract was used for pH, EC, Mg, Ca, and Na. An Oakton pH/CON 510 series probe was used to measure pH and EC. Compost sample total carbon and organic matter content was determined according to the Walkley-Black method [25].

All windrow carbon dioxide levels (Figure 1) and temperatures (Figure 2) were monitored over a 64 day period. To assess windrow moisture, carbon dioxide and temperature levels, three sub-sampled readings per windrow were taken using a Fieldpiece SOX_3 Combustion Check probe (Fieldpiece Instruments, Inc., Orange, CA, USA). Compost bulk densities were determined via a weight per volume analysis using a 2291 cm^3 cylinder. The treatment samples dried in a 65 °C oven for 5 days to determine moisture content and dry compost weight. Compost samples were analyzed for phospholipid fatty acid (PLFA) by WARD Laboratories as an assessment of overall bacterial and fungal microbial communities. As described by WARD Laboratories, "PLFA gives a representation of living soil microbial biomass and allows us to identify the presence or absence of various functional groups of interest through known PLFA biomarkers" [27].

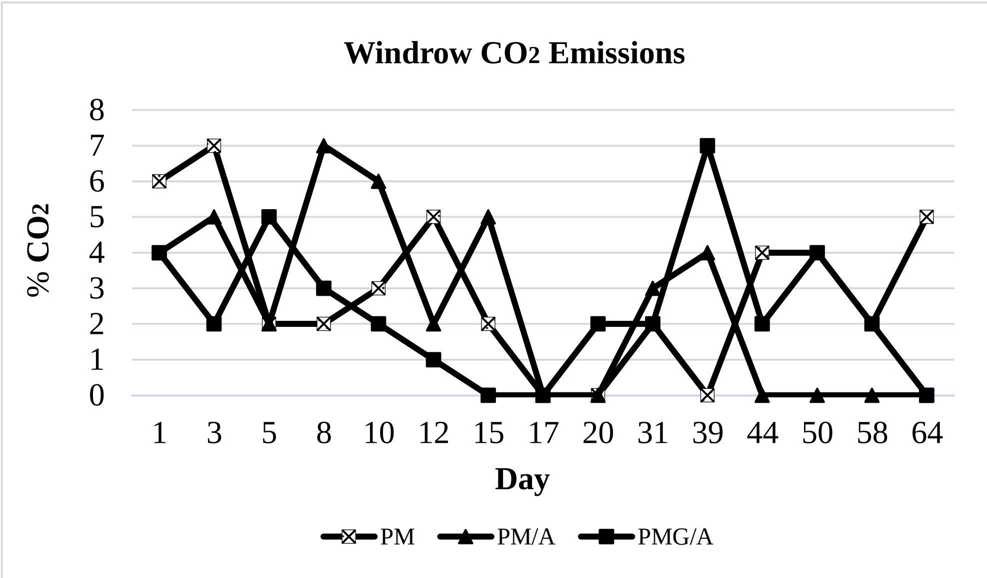

Figure 1. Windrow CO_2 levels over 64 days.

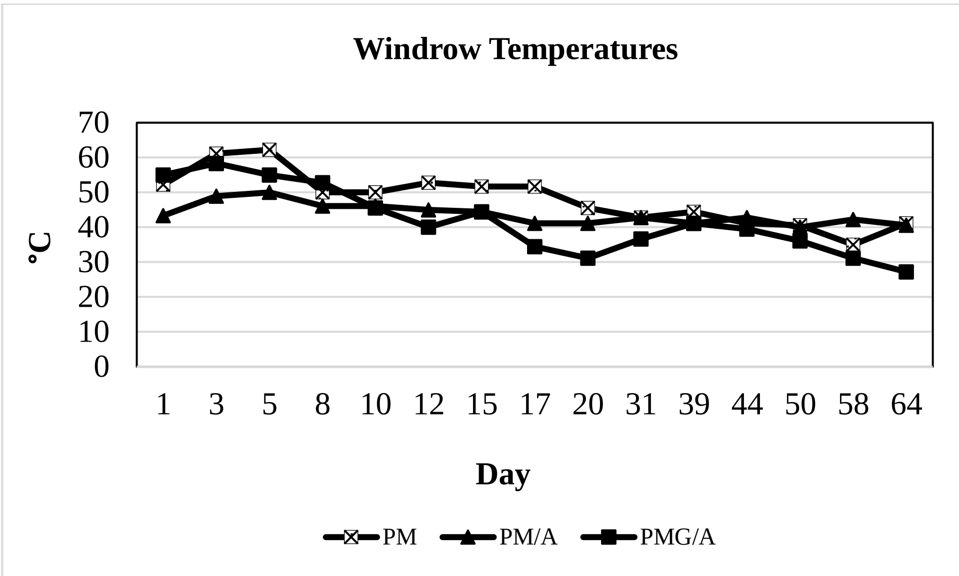

Figure 2. Windrow temperatures over 64 days.

Microbial biomass was assessed as a measure of the bacterial and fungal mass of each of the finished compost treatments [15].

2.8. Treatment Statistical Analysis

For treatment characterization, each response variable was analyzed using a two-way ANOVA with factor sectional locations (Southeast, Central, and Southwest) and treatments (PM, PM/A, PMG/A). F-protected LSD was used for pairwise comparisons. Locations were treated as block effect. Significance was defined for p-value ≤ 0.05. Data were analyzed using SAS version 9.4 software (SAS Institute Inc., Cary, NC, USA. 2016).

3. Results and Discussion

3.1. Economic Windrow Comparisons

The finished compost amendments can translate to economic benefits as a potential supplement for synthetic fertilizers [19]. Finished compost product, in tonnes, was determined by 50% degradation rate of total primary substrate materials; the finished compost products were half of the total substrate materials, in tonnes [28]. The farmer estimated finished compost in Chaves County, NM, without transportation, would be valued at $100–300/tonne. Sierra Vista Growers (Anthony, NM, USA) sells bulk horse manure-derived compost for $110/tonne [20]. Equipment, substrate, labor and processing costs were determined for all three compost treatments [21]). For the PMG/A treatment the total costs far exceeded the potential finished treatment revenue (Table 2).

The PM windrow total cost was $4687, the breakeven price was determined to be $7, and the contribution margin (net return) was $68,023 (Table 3). The PM/A windrow total cost was calculated as $27,368, with a breakeven price of $65, and contribution margin (net return) of $18,832 (Table 4). The PMG/A windrow total cost was $77,589, with a $150 breakeven price, and $−20,719 contribution margin (net return) (Table 2). The farmer used the same amount of inoculant on each of the addition windrows. This greatly increased the production costs of both "addition" windrows. Furthermore, the green-chop production for the PMG/A windrow included significantly more costs, with no return value or associated increased compost biological, chemical, or physical attributes. With more inputs, including the compost consulting company prescribed proprietary inoculants, clay, and percent unfinished compost, both addition windrows showed little potential increased benefits per cost, as compared to the PM windrow.

Table 3. Pecan and manure (PM) windrow enterprise budget.

	Quantity	Unit	Price ($)	Total ($)
Revenue ($)	660	tonnes	110.00	72,600
	Variable costs ($/quantity)			
Pecan shredding's ($/hr of labor)	17	hour	15.00	255.00
Pecan limb horizontal grinder for shedding's production $/hr	15	hour	62.37	935.55
Manure ($/quantity)	135	tonnes	6.62	893.70
	Windrow management			
Windrow establishment labor	15	hour	15.00	225.00
John Deere tractor 6120R (establishment)	10	hour	18.37	183.70
John Deere front end loader (used for establishment only)	10	hour	29.00	290.00
Bobcat skid steer (used for establishment only)	5	hour	6.58	32.90
Windrow processing (turning and watering) $/hr	55	hour	15.00	825.00
Variable costs total ($)				3640.85
	Fixed cost ($/hour/year)			
John Deere tractor 6120R (windrow processing)	55	hour	18.37	1010.35
Aeromaster PT-130 compost turner	55	hour	0.41	22.55
Aeromaster WT-3000 water wagon	55	hour	0.21	11.55
Hydraulic pump and miscellaneous equipment	55	hour	0.03	1.65
Fixed cost total ($)				1046.10
Total cost ($)				4686.95
Breakeven price ($)				7.00
Contribution margin (net return) ($)				68,023.05

A total of 714 tonnes of shredded pecan biomass produced yearly on farm. Pecan tree biomass (P): 129 m^3 (83%); Manure (M): 27 m^3 (17%).

Table 4. Pecan, manure, and additions (PM/A) windrow enterprise budget.

	Quantity	Unit	Price ($)	Total ($)
Revenue	420	tonnes	110.00	46,200.00
	Variable costs ($/quantity)			
Pecan shredding's ($/hours of labor)	15	hour	15.00	225.00
Pecan limb horizontal grinder for shredding's production	15	hour	62.37	935.55
Dairy Manure	185	tonnes	6.62	1224.70
	A (Additional inputs)			
"Inoculant combination pack" ($/application)	5	applied	719.49	3597.45
"N-Converter" ($/application)	5	applied	128.16	640.80
Clay ($/application)	5	applied	725.67	3628.35
Compost (unfinished)($/application)	5	applied	895.44	4477.20

Table 4. *Cont.*

	Quantity	Unit	Price ($)	Total ($)
	Windrow management			
John Deere tractor 6120R (establishment)	10	hour	18.37	183.70
John Deere tractor front-end loader for establishment only.	10	hour	29.00	290.00
Bobcat skid steer (used for establishment only)	5	hour	6.58	32.90
Windrow establishment labor ($/hour of labor)	15	hour	15.00	225.00
Windrow processing (turning and watering) ($/hour of labor)	350	hour	15	5250.00
Total variable costs ($)				20,710.65
	Fixed costs ($/hour/year)			
John Deere tractor 6120R (windrow processing)	350	hour	18.37	6429.50
Aeromaster PT-130 compost turner (windrow processing)	350	hour	0.41	143.50
Aeromaster WT-3000 water wagon (windrow processing)	350	hour	0.21	73.50
Hydraulic pump and miscellaneous equipment (windrow processing)	350	hour	0.03	10.50
Fixed costs total ($)				6657.00
Total cost ($)				27,367.65
Breakeven price ($)				65.00
Contribution margin (net return)				18,832.35

A total of 714 tonnes of shredded pecan biomass produced yearly on farm. Pecan tree biomass (P): 126 m^3 (50%); Manure (M): 38 m^3 (15%); Landscaping material (Addition "A"): 38 m^3 (15%); Compost, unfinished (A)**:** 25 m^3 (10%); Clay (A): 25 m^3 (10%).

3.2. Compost Characterization

The location blocking factor was not significant for any of the treatments. As shown in Table 5, all the treatments resulted in compost of acceptable quality based on nutrient content, pH, EC and bulk densities. TKN was not significantly different amongst treatments, although the PM treatment had the highest levels. This difference as attributed to the higher manure content, by volume, in the PM treatment. Both PM/A and PMG/A treatments contained additional plant matter, and less manure by volume; manure has been shown to be higher in nitrogen [18]. Conversely, the lowest levels for plant available NO_3-N were seen in the PM treatment, indicating the addition treatments provided more readily available nitrogen. However, treatment NO_3-N was not significantly different due to large average variances. P, K, Ca, and Mg contents were significantly higher in the PM treatment, followed by Ca and Mg in the PM/A treatment (Table 5). Iron was not significantly different amongst treatments. Zinc and Cu concentrations were significantly higher in the PM treatment, while Mn concentration was significantly higher in the PMG/A treatment, followed by the PM treatment.

Table 5. Least square means for selected compost treatment variables.

Selected Variables	PM	PM/A	PMG/A	*p*-Value
TKN (mg kg^{-1})	12,782 †	5508	7666	0.6166
Nitrate_N (mg kg^{-1})	10.45	813.2	1279	0.1066
P (mg kg^{-1})	536.9 a	414.9 b	350.8 b	0.0089
K (mg kg^{-1})	4722 a	2018 b	2365 b	0.0269
Ca (mg kg^{-1})	49.50 a	34.60 b	21.73 c	0.0078
Mg (mg kg^{-1})	37.77 a	23.67 b	11.66 c	0.0001
Fe (mg kg^{-1})	13.85	16.57	10.13	0.0533
Mn (mg kg^{-1})	24.53 b	17.13 c	29.07 a	0.0027
Zn (mg kg^{-1})	25.29 a	16.67 b	20.00 b	0.0131
Cu (mg kg^{-1})	3.31 a	2.31 b	2.24 b	0.0091
EC (dS/m)	16.93 a	12.54 b	11.38 b	0.0012
SAR (meg/L)	6.54 b	9.02 a	6.68 b	0.0015
Na (meg/L)	43.13 a	48.77 a	27.33 b	0.0028
pH	7.63	7.73	7.67	0.4444

Table 5. *Cont.*

Selected Variables	PM	PM/A	PMG/A	*p*-Value
Organic matter (%)	24.30	13.38	20.31	0.2389
Organic carbon (%)	14.14	7.78	11.81	0.2395
Bulk density (g/cm^3)	0.44 c	0.63 a	0.51 b	0.0005
Diversity indices	1.30	1.33	1.37	0.8291
Total microbial biomass (ng/g)	12,860 a	4908 c	8208 b	0.0017
Volumetric water content (%)	32.92	37.06	24.06	0.2937

† Each value represents a mean of three replications. Significantly different values are followed by differing letters in each row, using the F-protected LSD level with *p*-value ≤ 0.05. a, b, c: denotes similarly statistically significant differences within rows/variables (a's are simi-larly statistically significant; b's are similarly statistically significant; c's are similarly statisti-cally significant).

There was no significant difference amongst treatments for pH, organic C and OM (Table 5). Electrical conductivity was significantly higher for the PM treatment, followed by the PM/A and PMG/A treatments. SAR and Na were significantly different amongst the treatments. The highest SAR was seen in the PM/A treatment, followed by both similarly equal PMG/A and PM treatments. The highest Na contents were seen in the PM/A and PM treatments, followed by the PMG/A treatment. The highest total microbial biomass (ng/g) was seen in the PM treatment. All three treatments had low bulk densities, less than the 1.6 g/cm^3 level that tends to restrict plant root penetration [29]. The PM treatment was 439.9 kg/m^3, potentially a bit lower on moisture content as a compost with approximately 50% moisture content is on average 593.3 kg/m^3 [27]. The significantly lower bulk density with the PM treatment as compared to the addition treatments was likely due to no clay or additional heavy material substrate inputs.

All windrow moisture levels remained at approximately 50% for the curation duration. All windrow temperature and carbon dioxide levels dissipated, similarly, over time. PM carbon dioxide levels decreased by 4% (Figure 1) and PM windrow temperature dissipated by 20 °C (Figure 2). The PM/A windrow carbon dioxide levels decreased by 1% (Figure 1) and PM/A windrow temperature dissipated by 4 °C (Figure 2). The carbon dioxide levels in the PMG/A windrow decreased by 4% (Figure 1) and windrow degrees dissipated by 28 °C and (Figure 2). A decrease in windrow carbon dioxide emissions and temperature is an indicator of compost maturity and completion [30].

In summary:

1. All three treatments varied in initial estimated C:N substrate ratios and finished treatment mineralized macro, secondary and micronutrients. TKN and nitrate-N were not significantly different due to high variability among treatments. Higher P and K values were seen in the PM treatment. As an indicator of compost quality, all treatments were within acceptable amendment EC and pH ranges. All treatments varied in bulk density and microbial biomass; however, the PM treatment was highest in microbial biomass, likely because of the naturally inoculated manure treatment input and the PM treatment did include any additional non-inoculated inputs. Bulk density plays a critical role in relation to financial factors with materials transportation and with buyers in greenhouse application settings, etc., where the compost may be the primary plant growing medium.
2. Only the PM/A treatment, not the PMG/A treatment, displayed faster decomposition kinetics, but this was not due to increased microbial biomass. The PMG/A treatment showed similar decomposition kinetics as the standard, minimally turned and watered PM treatment. The PMG/A and PM treatments showed similar carbon dioxide emission rates.
3. The PM treatment was significantly highest in both EC and total microbial biomass, likely due to the high manure input. There was no significant difference amongst treatments for nitrate-N. Higher P and K values were seen in the higher volume ratio manure input PM treatment likely because of the higher initial P and K availabilities in manure. The treatments with "additional" inputs were not, in most cases, higher

than the PM treatment in secondary and micronutrients. As the addition compost treatments did not display additional biological, chemical and physical attributes, the windrow additions do not justify the additional costs.

It was shown in this research that minimal compost processing provides similar or enhanced nutrient availabilities, as compared to the additional compost processing inputs. More research is needed to identify potential additional economic benefits associated with compost treatments. In addition to supplying several organically derived nutrients, soils applied compost treatments may also increase soil water availability. Extension resources and on-farm collaborators with educators are needed to advise on regional compost modeling, so that agricultural organic waste management is aided in the process, rather than hindering its implementation.

4. Conclusions

This research aimed to demonstrate organic waste-to-resource modeling via value-added organic waste collaborations in the pecan and dairy industries, and assessment of various treatment inputs and procedures. The proximity of carbon and nitrogen-based waste materials is important, as transportation of heavy materials may be financially prohibitive. This research has demonstrated the importance of compost processing techniques and that high economic processing costs may not result in increased compost quality and as-sociated soil, plant, and environmental benefits. With the onset of climate change, water conservation tactics and localized resource utilization will become critical. There is scalability potential with this research to other regions, both locally and globally, especially in places with high carbon and nitrogen organic waste streams.

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Appendix A

Table A1. Windrow turner and water applier economic parameters.

Windrow Turner and Water Applier	Salvage Value	Yearly Depreciation
- The windrow turner is affixed with a 500 gallon water drum and sprayer. - Water is supplied at no cost via grandfathered on-farm water rights and solar generated water pumping. - The 180-PTO diesel tractor powering the turner has a listed price of $200,000. With an estimated economic life of 15 years, a 180-PTO diesel tractor can be used approximately 400 h per year [21].	Salvage value (current list price × remaining value factor): $200,000 × 23% = $46,000 Total depreciation = purchase price−salvage value= $180,000−$46,000 = $134,000	Windrow turner/water applier yearly depreciation: $125,000 × 29% is $36,250; $88,750/15 (yearly depreciation) = $5916.67

Table A2. Finished compost treatments economic parameters.

PM Finished Compost	PM/A Finished Compost	PMG/A Finished Compost
129 m^3 + 27 m^3 = 156 m^3 (initial substrate material) (1000 lbs./yd^3 (density of finished compost) × 1 tonne/2204.62 lbs. × 1.3 yd^3/1 m^3 × 156 m^3) × 0.5 (compost decomposition rate) = 46 tonnes	126 m^3 + 38 m^3 + 38 m^3 + 25 m^3 + 25 m^3 = 252 m^3 (initial substrate material) (1000 lbs./yd^3 (density of finished compost) × 1 tonne/2204.62 lbs. × 1.3 yd^3/1 m^3 × 252 m^3) × 0.5 (compost decomposition rate) = 74 tonnes	61 m^3 + 15 m^3 + 90 m^3 + 15 m^3 + 15 m^3 = 196 m^3 (initial substrate material) (1000 lbs./yd^3 (density of finished compost) × 1 tonne/2204.62 lbs. × 1.3 yd^3/1 m^3 × 196 m^3) × 0.5 (compost decomposition rate) = 58 tonnes

Table A3. On-farm pecan biomass and biomass shredding economic parameters.

On-Farm Pecan Biomass	Pecan Carbon Biomass Economic Factors	Pecan Shredding Labor Factors
67.5 (acres/year trimmed) × 50 (trees/acre) × 258 (lbs. of tree mass trimmed) = 870,750 lbs. = 394.97 tonnes	Pecan rental limb horizonal grinder per year: $15,000 $15,000/394.97 tonnes = $37.98/tonne	For a 175 PTO tractor with $196,751 estimated price: Cost ($/hour) of use: Total = Overhead + Fuel + Labor Per Hour = $90.54 [22]

Table A4. Dairy manure economic parameters.

Dairy Manure	Relevant Parameters	Economic Factors
Dairy manure is approximately 17% of the total PM (control treatment) windrow volume. The density of dairy manure is 1674 lbs./cubic yard [31]. Initial dairy manure substrate for the PM compost treatment was 27 cubic yards. To determine dairy manure initial PM treatment substrate, in tonnes: 1674 lbs./cubic yard (density of dairy manure [31]) × 1 cubic yard/ 0.765 cubic meter × 1 metric ton/2204.62 lbs. × 27 cubic meters (initial dairy manure substrate material) = 27 tonnes.	PM treatment: 129 cubic meters of initial pecan biomass substrate	Density is 61 lbs./cubic foot for pecan biomass [32]. 61 (density) lbs./cubic foot × 1 tonne/2204.62 lbs. × 35.31 cubic feet/1 cubic meter × 129 cubic meters = 126 tonne $6/ton for manure delivery: $6/ton × 0.907 metric ton/ton = $6.62/tonne

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