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Faculty of Veterinary Medicine and Biosciences
Department of Plant Sciences

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Revaluing residues: effects of composts and vermicomposts from corn, fig and citrus residues on the development of *Rosmarinus officinalis* L. and *Lavandula angustifolia* L.

Michael Ryan

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Abstract

Intensive agricultural production generates large quantities of organic waste and residue worldwide. Health and environmental hazards can result with the improper disposal and accumulation of these materials.

Composting and vermicomposting can be used to recycle crop residues, manures, and wastes as soil amendments and biofertilizers, thereby reducing the overall amount of waste and residue in the agroecosystem.

In this study, separate composts and vermicomposts were prepared from three crop residues (citrus, maize, fig) and precomposted rabbit manure. Cuttings of rosemary and lavender were grown in the prepared substrates for 4 months. Initial and final substrates were characterized chemically and growth characteristics of the plants were measured.

Vermicomposting resulted in significant reduction in carbon-to-nitrogen ratio (C/N) and an increase in total N (TN) compared to composting. Composts resulted in higher electric conductivity (EC) values than vermicomposts, implying that they may be more useful as soil amendments. Vermicomposted substrates had lower shoot/root ratio than composted substrates and could be due to the greater amount of humic compounds that promoted root development. Vermicomposts had significantly higher cation exchange capacity (CEC) values, which was found to be positively correlated to all plant growth traits, with the exception of branch number for rosemary plants. CEC was used as the main determining factor, which in conjunction with nutrient content helped explain the superior performance of vermicomposting over composting. It was concluded that vermicomposted citrus residues (VC) proved to be the superior substrate for both rosemary and lavender plants, as development traits were greater than both maize and fig residues for both species.

Keywords: Agroecosystems, biofertilizers, composting, CEC, C/N, crop residues, EC, organic wastes, TN, vermicomposting

List of Abbreviations

CEC: Cation exchange capacity
C/N: Carbon/nitrogen ratio
TOC: Total organic carbon
EC: Electric conductivity
TN: Total Nitrogen
OM: Organic matter
PVC: Polyvinyl chloride
RH: Relative humidity
WSC: Water Storage Capacity
VC: Vermicompost citrus residues
VM: Vermicompost maize residues
VF: Vermicompost fig residues
CC: Compost citrus residues
CM: Compost maize residues
CF: Compost fig residues
C: Citrus residues
M: Maize residues
F: Fig residues
St. sig: Statistical significance
Tech: Technique
Res: Residue
RxT: Interaction between residue and technique
Co: Composted technique
V: Vermicomposted technique
NPK: Chemically derived fertilizer with nitrogen, phosphorous and potassium
v: Volume

Glossary

Agroecosystem: ‘Human manipulation and alteration of ecosystems for the purpose of establishing agricultural production’(Gliessman, 2007).
Aerobic: relating to, involving, or requiring free oxygen.
Atomic emission spectrophotometry: a method of chemical analysis that uses the intensity of light emitted from a flame, plasma, arc, or spark at a particular wavelength to determine the quantity of an element in a sample.
Biogeochemical cycles: a pathway by which a chemical substance moves through both biotic and abiotic compartments of Earth.
Biomass: organic matter derived from living, or recently living organisms.
Detritus: organic matter produced by the decomposition of organisms.
Dioxins: a highly toxic compound produced as a byproduct in some manufacturing processes.
Eutrophication: Nutrient enrichment of water that leads to algal blooms, disruption of food webs, and in the worst cases, complete eradication of life through deoxygenation (Gliessman, 2007).
Humification: The decomposition or metabolization of organic material in the soil.
Litter fall: is dead plant material, such as leaves, bark, needles, and twigs, that have fallen to the ground.
Mineralization: The process by which organic residues in the soil are broken down to release mineral nutrients that can be utilized by plants.
Mesophilic: an organism that grows best in moderate temperature; between 20 and 45 °C.
Nutrient use efficiency: a measure of how well plants use the available mineral nutrients.
Organic material/Organic matter: is matter composed of organic compounds that has come from the remains of organisms such as plants and animals and their waste products in the environment.
Particulate matter: the term for a mixture of solid particles and liquid droplets found in the air.
Polycyclic aromatic hydrocarbons: are a group of more than 100 different chemicals that are released from burning coal, oil, gasoline, trash, tobacco, wood, or other organic substances.
Residues: materials left in an agricultural field or orchard after the crop has been harvested. Include stalks and stubble, leaves, and seed pods.
Rutger’s static pile: A system used to biodegrade organic material without physical manipulation by providing air circulation for controlled aeration.
Stabilization: alteration of soils to enhance their physical properties.
Terrestrial ecosystems: an ecosystem found only on landforms.
Thermophilic: A thermophile is an organism that thrives at relatively high temperatures, between 41 and 122 °C.
Waste: material that is not wanted; the unusable remains or byproducts of something.
Volatile organic compounds: large group of carbon-based chemicals that easily evaporate at room temperature.

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Introduction

Major functions in terrestrial ecosystems are biogeochemical cycling of carbon and other nutrients. This happens, respectively, through photosynthetic assimilation by plants of atmospheric CO_2 and solar energy and through plant–soil interactions where elements are taken up by plants and microbes from the soil and returned back in the form of litter fall, detritus and leaching from plants (Ågren and Andersson, 2011). Natural terrestrial ecosystems are self-sustaining. Temporal permanence is long, stability is high, nutrient cycles are closed and the system is independent of human control (Gliessman, 2007). Agroecosystems share many of the characteristics, processes and structures found in natural ecosystems. However, they differ in important ways.

An agroecosystem is a natural ecosystem that has been converted for agricultural production and is dependent on human control (Altieri, 2002; Edwards et al., 1993; Gliessman, 2007; Kuyper and Giller, 2011; Tomich et al., 2011). A set of inputs and outputs are incorporated into the system in order to sustain productivity. Temporal permanence is short, stability is low, and nutrient cycles are open (Gliessman, 2007; Rosset and Altieri, 1997). The bulk of nutrients and energy are lost as an output when plant material and residues are taken out during the harvest. Inputs are required in order to replenish nutrient loss.

In traditional agroecosystems organic wastes and manures were recycled back into agricultural soils. Production of these wastes was small enough to be used in limited quantities without causing large impacts on ecosystem processes and services (Dominguez and Edwards, 2010). Organic wastes were treated as valuable resources. Productivity would decline without their reincorporation into the system.

As agriculture evolved and industrialized it became harder or problematic to reincorporate waste products back into the production cycle. Intensive farming strategies produced large amounts of organic waste too great for raw application. The untimely and intensive use of chemical fertilizers and irrigation in industrial agroecosystems can cause significant damage to aquatic ecosystems when excessive amounts of nutrients runoff and cause eutrophication (Fianko et al., 2009; Gliessman, 2007; Tirado et al., 2008). The addition of external inputs and loss of outputs in the agroecosystem alter biogeochemical cycles (Chapin III et al., 2011). Nutrient cycles of carbon, nitrogen, phosphorus, sulfur and water are disrupted.

The maintenance of organic matter and nutrient contents in the soil is important for the long-term productivity of agroecosystems. To counteract the progressive loss of organic matter and nutrients over time, techniques such as composting and vermicomposting can used to recycle agricultural residues and wastes while at the same time it produces organic amendments that when applied help sustain the productivity of the soil (Bonilla et al., 2012).

Particularly in industrialized countries, generation of poorly utilized crop residues is substantial. In Spain, for example, the annual generation of crop residues amounts to over 4 million tons (Carrión et al., 2008). The burning of agricultural wastes is the most preferred technique and is viewed as the easiest way to get rid of materials left over from agricultural production. According to Kambis and Levine (1996; 1990) the burning of biomass, including agricultural wastes attributes 20–40% of the total CO_2 released into the atmosphere. Disposing of crop residues by burning releases other air toxics as well such as volatile organic compounds, semi-volatile organic compounds, particulate matter, dioxins, and polycyclic aromatic hydrocarbons (Lemieux et al., 2004). Both the burning and accumulation of residues poses severe health risks for those involved and living near agricultural areas.

Composting and vermicomposting are two well-known processes useful for the reclamation and biological stabilization of organic wastes. Composting and vermicomposting not only improve soil and production capacity but furthermore help to reduce waste-related problems (Singh et al., 2011). Residues and contaminants left over from agriculture and food industries can be reused and the final products, composts and vermicomposts, can be reincorporated into agroecosystems in the form of soil amendments and value added biofertilizers (Aalok et al., 2008; El-Haddad et al., 2014; Garg et al., 2006; Mendoza-Hernández et al., 2014; Misra et al., 2003). Composting and vermicomposting can contribute to sustaining ecosystem viability. Waste size is reduced. Inputs available on the farm are recycled directly, thus reducing the need of off-farm inputs. These methods strengthen nutrient cycling and nutrient use efficiency (Ceglie and Abdelrahman, 2014). Composted crop residues used as soil amendments help to conserve soil and water, replenish soil organic matter through carbon sequestration, control soil erosion and runoff, and revitalize degraded soils and ecosystems (Wilhelm et al., 2004).

Composting is an aerobic process involving the accelerated degradation and partial humification of organic matter by microorganisms. It is characterized by two specific stages. In the thermophilic stage, high temperatures are reached allowing the sanitization of waste by the elimination of pathogenic microorganisms (Lazcano et al., 2008). The second stage is known as the maturation or mesophilic stage. During this stage, remaining organic compounds are broken down and there is a gradual decrease in temperature until it stabilizes.

Vermicomposting, unlike composting, is produced solely under mesophilic conditions. It involves the interaction between earthworms and microorganisms in the breakdown of organic matter. Specific species of earthworms are used to turn, aerate, condition and fragment the substrate, which results in increased microbial activity (Dominguez and Edwards, 2010). Vermicompost has two marked phases: the active phase and the maturation phase (Domínguez et al., 2010).

Tognetti et al. (2005) found that vermicomposts tend to have higher nutrient content and microbial activity than composts. Nutrient contents of vermicomposts can vary depending on the type of residues, manures, sludges, feedstocks, processing times and conditions. It has been determined that vermicomposting and composting can accelerate the decomposition of the organic matter and lower the C/N ratio (Albanell et al., 1988; Orozco et al., 1996). Indirectly, *Eisenia fetida*'s digestive system contains unique and indigenous microflora that positively contributes to soil biological communities and has been reported to change the microbiological properties of soil or potting media (Lazcano and Domínguez, 2011; Toyota and Kimura, 2000). In addition to increased microbial activity, it promotes the colonization of a unique microbial community that greatly differs from other types of organic fertilizers and amendments (Aira et al., 2007). Vermicompost has also been found to suppress plant pathogens, such as parasitic insects, nematodes, and fungal diseases (Lazcano and Domínguez, 2011).

Previous studies have confirmed the usefulness of both composting and vermicomposting. Specific criteria and parameters have been proposed for testing compost maturity and stability. According to Harada and Inoko (1980) the measurement of CEC (Cation Exchange Capacity) can help indicate the quality of the compost as during the humification process functional groups are produced increasing oxidation of the organic matter and leading to a rise in CEC. It was determined that CEC values above 60 cmol/kg is expected for compost that has fully matured (Antil et al., 2014; Harada and Inoko, 1980; Roig et al., 1988). Similar studies found that an essential sign of compost maturity is a C/N ratio below 20, with ratios of 15 or less being preferred and those low as 12 as optimal (Jimenez and García, 1992; Maheshwari et al., 2014). C/N ratio and CEC, in combination with other chemical parameters such as EC and pH, can help determine the degree of maturity and stability, respectively, in terms of fertilizing value.

One of the most significant factors affecting the quality of composts and vermicomposts is the original raw material that is processed (Fornes et al., 2013). In the rehabilitation of tropical soils using compost and vermicompost, no greater effect could be found using vermicompost versus compost, however, there were significant improvements in the chemical properties of the soil (Jouquet et al., 2010). Another study has shown that vermicompost outperformed both compost and peat for rooting cuttings in respect to growth and development (Mendoza-Hernández et al., 2014). However, some plants like rosemary, onion and lettuce, showed sensitivity to high amounts of compost suggesting their optimal use as a fertilizer in smaller proportions (Morales-Corts et al., 2014). Best results were found when combining both processes (composts and vermicomposts) in a proportion of 20/80 (v:v) (Kumar Srivastava et al., 2011), and only potential salinity problems appeared in compost (Fornes et al., 2012).

Because of the weaknesses of industrial agriculture caused by neglect of basic ecological principles, e.g., diversity and cycling of organic energy and nutrients (Gliessman 2007), more research is needed to evaluate ways to reuse and recycle organic waste as sustainable alternatives to chemical fertilizers. This study explored how various crop residues (citrus, maize and fig) and methods of composting (static composting versus vermicomposting) compared in overall plant development. The specific research questions asked were:

1. How do (I) various crop residues (II) treated by composting and vermicomposting with pre-composted rabbit manure compare with regard to (1) chemical parameters known to influence plant growth and (2) the development of lavender (*Rosmarinus officinalis* L.) and rosemary (*Lavandula angustifolia* L.) cuttings in a pot experiment?
2. Can possible effects of the substrates on plant development be explained by differences in chemical characteristics of the substrates?

Based on the results it will be discussed how various crop residues and wastes may be combined to reduce waste problems and develop better sustainable alternatives to chemical fertilizers and reclosing nutrient cycles.

Materials and Methods

Three composts and three vermicomposts were derived using pre-composted rabbit manure and plant residues of citrus, fig and maize. Cuttings of rosemary (*Rosmarinus officinalis* L.) and lavender (*Lavandula angustifolia* L.) were rooted and grown in the substrates and the analysis of plant development was measured.

The experiment was divided in steps. First, processing of residues followed by composting and vermicomposting procedures, analysis of initial and final substrates and measurement and analysis of plant development.

Plant residues and their processing

Plant residues from citrus (C), maize (M) and fig (F) production were procured from local farmers in the area. Each residue was ground separately resulting in particle size ranging from 0.4-1cm using a VIKING® GE 345 shredder. Residues were mixed and homogenized by pitchfork separately in 50:50 (v:v) proportion with pre-composted rabbit manure in metal bins. Prior to mixing, the rabbit manure was processed in heaped piles outdoors on unpaved ground for 21 days. It was exposed to temperatures of 29 to 32 °C and was periodically aerated and watered when necessary to keep moisture content above 50% (dry weight basis).

The preparation of the compost and vermicompost was carried out on the premises of the Polytechnic University of Valencia (UPV), Spain.

For vermicomposting, a total of 15 kg (wet weight) of each mixture was placed in circular PVC containers measuring 20cm in height and 30cm in diameter. *Eisenia fetida* worms were added to each of the containers in a proportion of 40 individuals/Liter. Thin layers of nylon mesh were placed on top with perforated lids for aeration. Containers were kept in a dark room at 25°C and moisture content was maintained at 70% (dry weight basis) by sprinkling containers with tap water throughout the process. At the end of sixteen weeks the substrates appeared stable and the worms were separated by hand.

For composting, the remains of each mixture were processed using the Rutger's static pile system (Polytechnic University of Valencia, Spain) with forced aeration and pile turning. It was conducted under controlled conditions of 20°C, and kept at

60-70% moisture content (dry weight basis) with periodic watering during sixteen weeks.

Experimental design and set-up

Two processing techniques were tested with three different types of crop residues thus obtaining six different substrates. Those six substrates were divided for two different analyses: chemical characterization of the substrates and differences in plant development for each substrate.

For the chemical parameters, 10g were subsampled from each of the initial mixtures of precomposted rabbit manure and plant residues of C, M, F as well as in the final substrates with three repetitions, (6 substrates x 3 repetitions) 18 samples in total. Total organic carbon (TOC) was determined by oxidation with potassium dichromate (Walkley and Black, 1934). Electric conductivity (EC) and acidity (pH) were measured by glass electrode respectively using the 1:2.5 and 1:5 (sample:water) ratios. Total nitrogen (TN) and carbon contents were measured using CE instruments EA 1110 CHNS-O element analyzer. Water storage capacity (WSC) was calculated from methods described by Gandullo (1985) in which the soil sample is placed in a cylinder and is saturated with water and allowed to drain due to gravity. The calculation is based on the weight of the water held in the sample under natural atmospheric pressure conditions versus the sample dry weight. Soil cation exchange capacity (CEC) was determined in 5g samples using the ammonium acetate method at pH 7.0 (Hendershot et al., 1993; Lavkulich, 1981). Micronutrient composition: Available Phosporus (P_2O_5) was determined by the Olsen P test (Olsen et al., 1954); Calcium (CaO), Magnesium (MgO), Sodium (Na_2O) and Potassium (K_2O) were determined by atomic emission spectrophotometry. Table 1 shows the initial chemical parameters of the residues before processing with the stabilization techniques.

In order to test the substrate's effect on plant development, a total of 200g (wet weight) were taken from each of the processed substrates and were used to fill 36 (3 type of residues x 2 processing techniques x 2 species of aromatic plants x 3 repetitions) PVC containers of 500 cm^3. The substrates were distributed as follows;

Composted Citrus (CC), Composted Fig (CF), Compost Maize (CM), Vermicompost Citrus (VC), Vermicompost Fig (VF) and Vermicompost Maize (VM).

Rosemary and lavender cuttings of 3 cm long were obtained from the UPV greenhouse. They were placed in the containers with the experimental substrates with a 2 cm layer of water underneath in a growing chamber at 60% RH, 25°C/12 hours and 20°C/12 hours. Rooting took place after 3 weeks of keeping the substrates moist, and the plants were moved to a greenhouse at 20°C 60% RH, where they were distributed in a randomized block design. The plants were watered twice per week with 250 cm^3 of water for 4 months to simulate conditions of annual rainfall amounting to 400mm. After this period, plants were harvested washed and dried in a stove at 60°C for 24 hours. Plants were weighed and measured individually, separating roots and shoots. Number of branches, shoot diameter, shoot length, and shoot weight were determined. Root length and weight were also measured.

Table 1. Initial chemical characteristics of residues and precomposted rabbit manure.

Residue Mixture	E.C. (dS/m) 1:10	pH 1:5	OM (%)	Total Carbon (%)	C/N	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)
Citrus	2.3	5.7	92.0	53.5	41.2	0.5	0.5	6.5	1.3	0.1
Maize	3.7	5.7	72.5	42.2	41.3	0.9	2.4	1	1.6	0.05
Fig	4.7	6.7	85.3	49.6	52.5	1.6	0.5	2.9	0.2	0.03

Data Analysis

Plant measurement data was analyzed using Minitab express statistical software. Two-way ANOVA was run to find significant differences between: the two stabilization techniques (compost and vermicompost), the three residues (citrus, maize and fig) and the interactions among them in regards to substrates characteristics and plant development. Tukey HSD test ($P \leq 0.05$) was carried out to establish significant differences between means.

Two-way ANOVA was carried out on delta values (V_i-V_f/V_i) to compare initial characteristics of the residues with those after processing (table 3).

Pearson correlation was calculated to study the relationship between chemical characteristics of the substrates and plant development parameters. Only those correlation coefficients greater than 0.5 were considered in this study.

Results

Chemical Characteristics Analysis

Final chemical characteristics values, represented in Table 2, showed that composting resulted in a significantly higher C/N ratio than vermicomposting as well as higher EC values. Vermicomposting had higher pH, TOC loss and CEC. A negative correlation of 0.53 (Appendix 1) was determined from final values of C/N and CEC. After processing, the nutrient contents of the substrates resulted as follows (Table 2); Vermicomposts had significantly higher K content. Maize residues had the highest K content followed by fig and citrus. Composts had significantly higher Ca content than vermicomposts. Maize residues had the highest Ca content followed by fig and citrus residues. Citrus residues had the highest Mg content followed by fig and maize residues.

Changes in chemical characteristics following processing of residue and rabbit manure mixtures.

Fig substrates had the largest reduction in C/N ratio following processing (Table 3) intermediate for citrus and lowest for maize substrates, suggesting the decomposability of the initial residues in decreasing order. The C/N values of the residues suggest that a higher potential N fertilizer value might be expected for the C residues, followed by F and M, as it is expressed in final TN values (Table 2). During processing, citrus residues had stable TN values while for fig and maize, the amount of TN greatly increased from initial values. No significant change in TOC loss was observed for the three different residues, which decreased an average of 36% (Table 3).

Fig residues had the highest initial P content, however citrus residues had the largest change in P values. Maize had intermediate change in P content and fig had the lowest. Fig residues showed the greatest change in K content followed by citrus residues. Maize residues showed a decrease in K values yet it had the greatest increase of Ca content while citrus and fig residues Ca values decreased. Fig substrates showed the greatest change and increase in Mg and Na values when compared to citrus and maize residues. Citrus residues had the largest increase in pH, maize was intermediate, and fig had the lowest change. Citrus residues showed the largest positive change in EC values, while maize and fig residues had negative changes in EC.

Plant Development

For both species, rosemary and lavender, the best performance was found in VC followed by CC, VM, VF, CM, CF. Citrus residues caused the largest total biomass production followed by maize, and fig had the lowest (Table 4 and Table 5). Total plant dry weight was significantly higher for vermicomposts than composts. Vermicomposts developed higher values for both shoot and root traits (shoot diameter, shoot length, branch number, root length) in comparison to composts. However, these differences were less obvious in rosemary plants (Table 4). There were no interactions found between the type of technique and residue used in plant growth except for shoot length in lavender plants (Table 5). Composts caused higher shoot/root ratio than vermicomposts in lavender plants.

Correlations between chemical characteristics and plant growth traits

The strongest correlation between characteristics of the substrates and plant development was CEC. For rosemary plants it was strongly correlated with all plant growth parameters with the exception of branch number and shoot/root ratio. For lavender plants CEC was strongly correlated with all characteristics with the exception of shoot/root ratio. In addition to CEC, other correlations were found. K had negative correlations for shoot length for both plants and was negatively correlated to root length in rosemary plants. Ca was negatively correlated to root length for both plants. Ca also was negatively correlated to branch number for rosemary plants and shoot length for lavender plants. pH was positively correlated with shoot/root ratio for both rosemary and lavender plants. Mg had a significant positive correlation on root length for both rosemary and lavender and was significantly positive for shoot length in rosemary plants. Na was negatively correlated to total dry weight and P was negatively correlated to branch number in lavender plants.

Table 2. Final characteristics of citrus (C), maize (M) and fig (F) residue-based substrates after processing with composting (Co) and vermicomposting (V) techniques.

Tech	Res	WSC (%)	pH	EC (dS/m)	CEC(c mol/kg)	C/N	OM (%)	TN (%)	TOC (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)
	C	85.8a	8.1a	4.0a	72.4b	12.5c	61.1a	2.9a	35.5a	1.7	0.9d	2.2c	2.4c	0.3b
Co	M	71.3bc	7.6b	2.9b	64.1d	22.2a	55.9b	1.6d	32.5b	1.6	1.5b	3.2b	2.1d	0.5a
	F	70.0c	7.8ab	2.3cd	64.9cd	22.1a	59.0a	1.8c	34.3a	2.0	1.2c	4.2a	2.9b	0.4ab
	C	71.9bc	7.8ab	2.1d	85.0a	14.0c	55.6b	2.3b	32.3b	1.5	0.9d	2.1c	3.7a	0.4ab
V	M	78.0b	7.7b	2.7bc	72.2b	18.2b	47.3d	1.4d	27.5d	1.4	1.9a	3.2b	1.4e	0.3b
	F	74.1bc	7.8ab	1.5e	71.0bc	9.8d	49.5c	2.8a	28.8c	2.0	1.1c	1.2d	2.0d	0.5ab
Main effects														
	Co	75.71	7.88	3.07	67.15	18.64	58.66	2.09	33.99	1.71	1.20	3.17	2.48	0.44
	V	74.71	7.76	2.11	76.08	14.03	50.80	2.17	29.55	1.60	1.30	2.16	2.38	0.41
	C	78.80	7.97	3.06	78.72	13.26	58.35	2.59	33.77	1.58	0.90	2.14	3.09	0.35
	M	74.69	7.65	2.82	68.16	19.77	51.60	1.49	29.95	1.48	1.70	3.19	1.76	0.43
	F	72.06	7.83	1.90	67.96	15.98	54.25	2.31	31.58	1.90	1.15	2.67	2.45	0.49
St. sig														
Tech		ns	ns	***	***	***	***	ns	***	ns	**	***	ns	ns
Res		**	*	***	***	***	***	***	***	ns	***	***	***	ns
RxT		***	ns	***	ns	***	***	***	***	ns	***	***	***	**

Tech: technique; Res: residue; Co: composting technique; V: vermicomposting technique; R × T: interaction residue × technique; WSC: water storage capacity; pH: acidity; EC: electric conductivity; C/N: carbon/nitrogen ratio; OM: organic matter; TN: total nitrogen; P: phosphorus; K: potassium; Ca: Calcium; Mg: magnesium; Na: Sodium; CEC: cation exchange capacity.
St Sig: statistical significance. ns, *, **, *** indicate not significant, and statistically significant differences at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively. Values in the same column with different letter differ at $P \leq 0.05$ (Tukey's test).

Table 3. Relative change (V_i-V_f/V_i) in chemical characteristics during processing of citrus (C), maize (M) and fig (F) residues.

Tech	Res	Δ pH	Δ EC	Δ C/N	ΔTN	Δ TOC	Δ P	Δ K	Δ Ca	Δ Mg	Δ Na
	C	0.43c	0.75d	-0.69b	0.10a	-0.34c	2.39b	0.82b	-0.66a	0.88c	1.86a
Co	M	0.34b	-0.22c	-0.48d	1.78c	-0.23e	0.74a	-0.38a	2.18c	0.31b	10.13bc
	F	0.17a	-0.50b	-0.57c	1.56c	-0.31d	0.17a	1.4c	0.43b	13.56f	1.05c
	C	0.37bc	-0.083c	-0.65b	0.20a	-0.39b	1.93b	0.8b	-0.68a	1.88d	3.16a
V	M	0.35b	-0.25c	-0.55c	0.84b	-0.35c	0.54a	-0.21a	2.2c	0.1a	5.0ab
	F	0.16a	-0.68a	-0.81a	2.20d	-0.23a	0.20a	1.2c	-0.59a	8.93e	15.67c
Main effects											
	C	0.40c	0.33	-0.67a	0.15	-0.37	2.16	0.81	-0.67	1.38	2.52
	M	0.34b	-0.24	-0.52b	1.31	-0.29	0.64	-0.29	2.19	0.10	7.56
	F	0.17a	-0.59	-0.69a	1.88	-0.36	0.19	1.30	-0.07	11.25	15.33
	Co	0.31	0.01	-0.58	1.15	-0.29	1.10	0.61	0.65	4.92	9.00
	V	0.29	-0.34	-0.67	1.08	-0.38	0.89	0.59	0.31	3.57	7.94
St. sig											
Tech		ns	ns	ns	ns	***	ns	ns	ns	ns	ns
Res		***	***	**	***	ns	***	***	***	***	***
TxR		***	***	***	***	***	***	***	***	***	***

Tech: technique; Res: residue; Co: composting technique; V: vermicomposting technique; Δ: delta value or increment value; pH: acidity; EC: electric conductivity; C/N: carbon/nitrogen ratio; TN: total nitrogen; TOC: Total organic carbon; P: phosphorus; K: potassium; Ca: Calcium; Mg: magnesium; Na: Sodium.
St Sig: statistical significance. ns, *, **, *** indicate not significant, and statistically significant differences at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively. Values in the same column with different letter differ at $P \leq 0.05$ (Tukey's test).

Table 4. Effects of compost (Co) and vermicompost (V) of citrus (C), maize (M) and fig (F) residues on growth of rosemary.

Tech	Res	Dry weight (g/plant)			Shoot/root ratio	Shoot length (cm)	Shoot diameter (mm)	Branch (number/plant)	Root length (cm)
		Shoot	Root	Total					
Co	C	10.40a	7.07	17.80a	1.47	15.83ab	3.00ab	4.00ab	11.87ab
	M	4.30ab	2.07	6.73ab	2.07	14.17ab	2.17b	3.33ab	8.20bc
	F	0.90b	0.87	1.77b	1.03	14.33ab	2.00b	2.00b	6.33c
V	C	12.90a	8.70	21.60a	1.48	18.77a	5.17a	4.33a	16.53a
	M	11.95a	8.90	20.85a	1.34	11.67b	3.33ab	3.33ab	9.17bc
	F	3.80ab	4.05	8.35ab	0.45	15.33ab	2.66ab	3.33ab	9.17bc
Main effects									
	Co	5.20	3.33	8.76	1.87	14.77	2.38	3.11	8.8
	V	9.55	7.21	16.93	1.27	15.25	3.72	3.66	11.62
	C	11.65	7.88	19.7	2.05	17.3	4.10	4.16	14.2
	M	8.12	5.48	13.79	1.71	12.91	2.75	3.33	8.68
	F	2.35	2.45	5.05	0.95	14.83	2.33	2.66	7.75
St. sig									
Tech		*	ns	**	ns	ns	*	ns	**
Res		**	ns	**	ns	**	*	*	***
RxT		ns	ns	ns	ns	ns	ns	ns	ns

Tech: technique; Res: residue; Co: composted technique; V: vermicomposted technique; R × T: interaction residue × technique.
St Sig: statistical significance. ns, *, **, *** indicate not significant, statistically significant differences at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively. Values in the same column with different letter differ at $P \leq 0.05$ (Tukey test).

Table 5. Effects of compost (Co) and vermicompost (V) of citrus (C), maize (M) and fig (F) residues on growth of lavender.

Tech	Res	Dry weight (g/plant)			Shoot/root ratio	Shoot length (cm)	Shoot diameter (mm)	Branch (number/plant)	Root length (cm)
		Shoot	Root	Total					
Co	C	11.73ab	7.07a	18.80 ab	1.66	18.70 ab	3.17 ab	6.33abc	12.36b
	M	6.30bc	2.73a	10.97 bc	2.31	13.50 bcd	2.17 b	4.00bc	8.86bc
	F	2.57c	1.53a	3.25 c	1.68	7.67 d	1.50 b	1.67c	7.13c
V	C	13.27a	10.80a	25.23 a	1.22	22.43 a	5.17 a	10.67a	15.66a
	M	10.63ab	7.93a	17.67 ab	1.34	11.67 cd	3.33 ab	7.67ab	9.23bc
	F	3.87c	3.37a	6.50 c	1.15	15.33 bc	1.83 b	2.67bc	9.26bc
Main effects									
	Co	6.86	3.77	11.00	2.41	13.28	2.27	4.00	9.45
	V	9.25	7.36	16.46	1.32	16.47	3.44	7.00	11.38
	C	12.5	8.93a	22.01	2.20	20.56	4.16	8.5	14.01
	M	8.46	5.33b	14.31	1.86	12.58	2.75	5.83	9.05
	F	3.21	2.45ab	4.87	1.53	11.5	1.66	2.16	8.20
St. sig									
Tech		ns	*	**	ns	**	**	**	**
Res		***	*	***	ns	***	***	***	***
RxT		ns	ns	ns	ns	**	ns	ns	ns

Tech: technique; Res: residue; Co: composting technique; V: vermicomposteing technique; R × T: interaction residue × technique.
St Sig: statistical significance. ns, *, **, *** indicate not significant and statistically significant differences at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$, respectively.
Values in the same column with different letter differ at $P \leq 0.05$ (Tukey's test).

Table 6. Correlation matrix between rosemary (black characters) and lavender (blue characters) plant development traits and chemical characteristics of substrates.

Rosemary Lavender	Shoot length	Shoot diameter	Branch number	Root length	Total dry weight	Root weight	Shoot weight	Shoot/Root ratio
CEC	0.58* 0.75***	0.72*** 0.77***	0.73***	0.84*** 0.87***	0.73** 0.74***	0.61* 0.64**	0.74** 0.66**	
K	-0.75*** -0.54*			-0.51*				
Ca	-0.67**		-0.51*	-0.50* -0.51*				
Mg	0.68**			0.55* 0.54*				
pH								0.66* 0.70**
Na					-0.54*			
P			-0.53*					
TN	0.58*							
C/N	-0.66**							

CEC: cation exchange capacity; K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; P: phosphorus; TN: total nitrogen; C/N: carbon/nitrogen ratio. Pearson correlation coefficients. *, **, *** indicate statistically significant at P ≤ 0.05, P ≤ 0.01, P ≤ 0.001, respectively. Coefficients in black are for rosemary plants and those underneath in blue are for lavender plants.

TN was positively correlated to shoot length and C/N was negatively correlated to shoot length for lavender plants. Micronutrient concentrations of P, TN, Mg, Ca, and K did not have any significant positive effect on total dry weight.

Discussion

During composting and vermicomposting the mineralization of organic matter is reflected by the increase of other chemical compounds such as P, Na, K, Mg, and Ca (Kaushik and Garg, 2004). In this study the initial values of P, Na, and Mg in the residue manure mixtures increased as expected in the final products. However, Ca and K values varied in final substrates. In maize substrates K values decreased from initial content. According to Marschner (1995) potassium is highly mobile in plant cells and within plant tissues. Therefore part of the K found in maize residues was most likely lost during composting and vermicomposting. Citrus and fig substrates showed a decrease in Ca from initial content as well. The decrease in calcium content could be due to leaching of cations by excess water that drained through the mixtures, as similar results were reported by Kaushik and Garg (2003) for vermicomposting of cow dung and agricultural residues.

The raw materials and their ion concentrations greatly affect the EC of final substrates (Atiyeh et al., 2002). Generally, increases in EC are expected during composting and have been reported (Garcia-Gomez et al., 2002; Sánchez-Monedero et al., 2001; Villar et al., 1993). The decrease in EC was unexpected for maize and fig substrates. Tognetti et al. (2007), Lazcano et al. (2008) and Mitchell (1997) reported similar decreases in EC following vermicomposting. The decrease in EC could be due to the precipitation of dissolved salts and the production of ammonium (NH_4^+) (Lazcano et al., 2008; Mitchell, 1997). Soumaré et al. (2002) proposed that substrate EC should not exceed 3 dS/m. The EC values in this study for composted citrus were slightly above this limit suggesting potential salinity problems that could affect plant development if it were used in great quantity. It might be more useful to use citrus composts as soil amendments in smaller quantities the potential of toxicity due to high EC values were also reported by Morales-Corts et al. (2014) in their evaluation of green pruining waste compost and vermicompost used in the growth of rosemary, Leyland cypress, lettuce, onion, petunias, and pansies.

In agreement with the knowledge that C/N decreases as a result of the carbon mineralization process, the findings in this study correspond to those documented by previous studies (Bernai et al., 1998; García-Gómez et al., 2003; Kaushik and Garg, 2004; Riffaldi et al., 1983). The C/N of vermicomposted residues decreased significantly to a greater extent than composted residues with the exception of composted citrus residues. It is due to an effect of the nitrogen concentration triggered by the release of carbon in the form of CO_2. Microflora found in the residues as well as those found in worm intestines cause decomposition leading to CO_2 emission, N retention (immobilization) in microbial biomass and mineralization of N in excess of the demand of the biomass (Kaushik and Garg, 2004). The decrease in C/N in vermicomposted substrates, together with lower TOC, OM and higher TN, support conclusions found in previous studies that the earthworms strongly modify soil characteristics and help accelerate the decomposition of organic material (Edwards, 1988; Yadav and Garg, 2009).

According to Marschner (1995), natural vegetation's shoot/root ratio increases as soil fertility increases. However results obtained in the current study did not show this correlation. Vermicomposts were linked to stronger plant development but shoot/root ratios were lower than composts (Table 4 and 5). These unexpected results in vermicomposts may be explained by its influence on root growth and stimulation. It has been shown that vermicomposts can promote greater hormone-like activity, which in turn promotes greater biomass allocation towards roots and root initiation (Bachman and Metzger, 2008; Tomati et al., 1988; Zaller, 2007). The hormonal activity has been associated with non-nutritional growth promoting humic compounds and vermicomposts have been shown to have 40-60% higher levels than composts (Dominguez et al., 1997).

Significantly higher values of CEC were found in vermicomposted substrates, which was consistent with previous studies from Vasanthi and Kumaraswamy (1999) and Parthasarathi et al. (2008). In their studies they attributed these results to the presence of humic substances in vermicomposts. A negative but weak correlation, (-0.52), was found between CEC and C/N ratio (Appendix 2). These results were in agreement with those found by Harada and Inoko (1980), who found a strong relationship between CEC and C/N. CEC was strongly correlated to all plant growth traits (Table 6), and it was concluded that CEC and plant development are strongly linked. Therefore CEC was one of the key factors, which helped to determine superior performance in the substrates.

The increase in CEC during processing might be explained by the accumulation of new negatively charged organic materials (Antil et al., 2014; Harada and Inoko, 1980; Roig et al., 1988). Lax et al. (1986) determined that it was due to the humification process as well, which produced functional groups that increased the CEC.

Citrus residues showed the best performance, with VC and CC exhibiting the best plant growth for both lavender and rosemary (Tables 3 and 4). This could be due to fact that citrus substrates had the highest values for those characteristics which positively correlated to plant growth characteristics (CEC, pH, Mg and TN) and also had the lowest values for those other characteristics which were negatively correlated to plant growth (K, Ca, Na, P and C/N) suggesting the possible explanation of citrus' superior performance in plant growth when compared to maize and fig substrates. Similar results were found by Bernal-Vicente et al. (2008), where both higher nutrient content and hormone-like compounds of citrus residues influenced plant growth. Unfortunately, studies on citrus residues and citrus residue processing are rather limited. Further research is needed in this area and would benefit Mediterranean countries such as Spain as it produced over 6.3 million tons of citrus in 2013 (FAO 2013).

To compare plant yield with one of the most used substrates, the study could be revised to include peat as well as other manures and solely NPK fertilized controls. This could help to determine if alternatives to peat and NPK fertilizers may be used with good results. Study of the biological interactions in the substrates could also help determine additional factors at work within the substrates. Further research could process a wider range of residues from different sources as well as test the quality of the end products as fertilizers under field conditions.

Potential limitations of this study could include that it was site specific with controlled conditions. Crop residues and manures from the Mediterranean area worked well, since they were in abundance and local. However it may be different in other areas where crops such as citrus, fig and maize do not grow, where rabbits are not raised, or crops such as lavender and rosemary are unimportant or limited by climatic conditions. Each place will have to gather information specifically based on which residues and manures are available, and the plant species in production. In regards to the species of worm, *Eisenia fetida*, worked well for Mediterranean conditions although other species are better suited for other climates, for example tropical areas with higher annual rainfall and less soil organic matter, or soils in colder areas that are frozen during winter.

Conclusion

After composting and vermicomposting, maize and fig residue substrates showed decreases in EC. This could have occurred due to events of precipitation of salts and the production of ammonium.

In maize substrates K content decreased, while fig and citrus substrates showed a decrease in Ca content. High mobility of these ions as well as leaching was likely the cause for their decline.

Vermicomposting resulted in a significantly stronger reduction in C/N and increase in TN of the substrates than composting. C/N and TN values helped to determine the potential N-fertilizer value was highest for processed citrus residues, followed by fig and maize, respectively.

Composting resulted in higher EC values than vermicomposts. Potential phytotoxicity problems could result for composted substrates with high EC. Therefore composted crop residues and rabbit manure might be better used as soil amendments in smaller quantities.

Vermicomposted substrates caused lower shoot/root ratio of lavender and rosemary plants than did composted substrates. Vermicomposts had significantly higher CEC and was found to be positively correlated to all plant growth traits, with the exception of branch number for rosemary. CEC was used as the main determining factor, which in conjunction with chemical parameters helped explain the superior performance of vermicomposting over composting.

Citrus residues showed the greatest effect on plant development for both techniques due to its ample amount of nutrients, which positively and negatively correlated to specific plant growth traits which caused superior growth and performance. The results of this study concluded that vermicomposted citrus residues (VC) proved the best revalued residue and technique for both rosemary and lavender plants.

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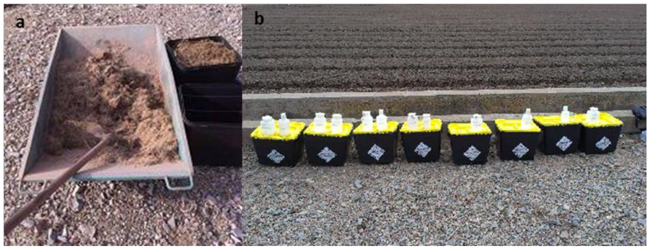
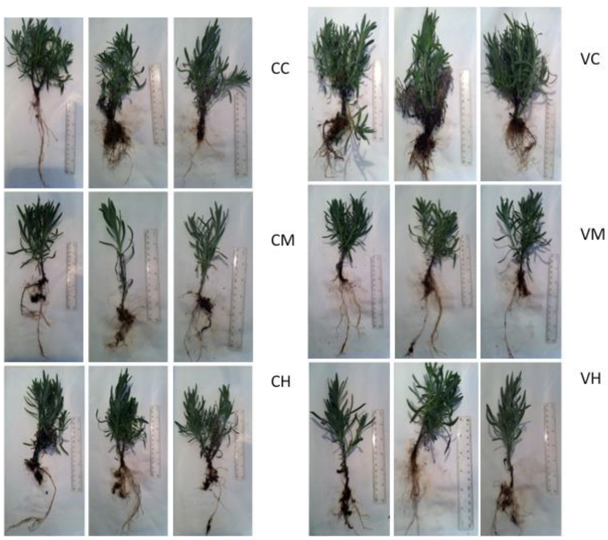
Appendix 1



Mixing of Substrates

Plant characterization



Washing

Chemical analysis

Appendix 2

Correlations

	EC	ph	TN	TOC	C/N	P	Ca	K	Mg	Na	CEC
ph	0.322343										
	0.192										
TN	0.035236	0.598038									
	0.8896	0.0088									
TOC	0.482634	0.457216	0.243365								
	0.0425	0.0564	0.3305								
C/N	0.136458	-0.397183	-0.840125	0.210402							
	0.5893	0.1027	<0,0001	0.402							
P	-0.203234	0.247148	0.335326	0.164046	-0.135482						
	0.4186	0.3228	0.1737	0.5154	0.5919						
Ca	0.235091	-0.21775	-0.745779	0.272235	0.943282	-0.088784					
	0.3477	0.3854	0.0004	0.2744	<0,0001	0.7261					
K	0.039184	-0.570058	-0.793553	-0.624062	0.535377	-0.32212	0.478718				
	0.8773	0.0135	<0,0001	0.0056	0.022	0.1924	0.0444				
Mg	-0.149933	0.200055	0.266826	0.605935	-0.041	0.021738	-0.019518	-0.727564			
	0.5526	0.4261	0.2845	0.0077	0.8717	0.9318	0.9387	0.0006			
Na	-0.438959	-0.296814	-0.160818	0.03665	0.254519	0.243431	0.084504	-0.03784	0.139453		
	0.0684	0.2317	0.5238	0.8852	0.3081	0.3304	0.7388	0.8815	0.581		
CEC	-0.151584	0.117153	0.359682	-0.101016	-0.528333	-0.331365	-0.493424	-0.395251	0.519141	-0.365427	
	0.5482	0.6434	0.1426	0.69	0.0242	0.1792	0.0374	0.1045	0.0273	0.1359	
WSC%	0.667454	0.518596	0.449041	0.063892	-0.417154	-0.015737	-0.288236	-0.093698	-0.28077	-0.617691	0.134498
	0.0025	0.0275	0.0616	0.8011	0.085	0.9506	0.2461	0.7115	0.2591	0.0063	0.5947

Norwegian University
of Life Sciences

Postboks 5003
NO-1432 Ås, Norway
+47 67 23 00 00
www.nmbu.no