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# Research on Vermicompost as Plant Growth Promoter and Disease Suppressive Substrate in Latin America

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## ABSTRACT

Composted organic materials have been used worldwide since ancient times. An increasing body of experimental evidence indicates that they stimulate plant growth and constitute a means to suppress crop diseases. Specially related to vermicomposts, many Latin American researchers have focused their work on chemical and microbiological analyses, crop production, plant health promotion and social benefits derived from their production and utilisation. This review summarizes published data on these subjects. In spite of the achievement of many interesting results, research needs to be intensified so as to improve the knowledge on these substrates, and favour a more generalized use of vermicomposts in the field.

**Keywords:** compost characterization, crop management, organic substrates, pathogen control, social benefits
**Abbreviations: VC**, vermicompost

## CONTENTS

## INTRODUCTION

The Green Revolution caused substantial changes in agriculture, as important improvement of yields based on the intensive application of industrialized products. However, its environmental consequences forced the search of alternative technologies that could guarantee rational use of natural resources, decrease in costs, economic and social development of rural areas and production of pesticide-free food (Calderón Fabián *et al*. 2007). These strategies fit within the definition of sustainable development, that is the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a way as to ensure the attainment and continued satisfaction of human needs for present and future generations. Sustainable agriculture conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable (Pétry 1995).

Composting is an effective sustainable strategy for diverting the organic fractions of different origins (Tognetti *et al*. 2005). It is a biological process that transforms organic wastes into useful soil amendments (Domínguez *et al*. 1997). So, this oxidative process can stabilize organic matter from different origins (for example biosolids, municipal solid waste, cattle manure).

Vermicomposting involves the utilization of earthworms to manage organic wastes and transform them into a stabilized product without including a thermophilic phase (Riggle and Holmes 1994). Although *Eisenia foetida* is the most universally known, other earthworms have also been studied, such as *E. andrei* (Castillo *et al*. 2005), *Eudrilus eugeniae* (Karmegam *et al*. 1999; Padmavathiamma *et al*. 2008), *Perionyx sansibaricus*, *Pontoscolex corethrurus* and *Megascolex chilensis* (Padmavathiamma *et al*. 2008). The obtained product – vermicompost (VC), earthworm humus or earthworm compost – has a good market acceptance due to its good visual aspect, high nutrient content and microbial activity (Subler *et al.* 1998; Ndegwa and Thompson 2000). Its use as a substrate or a component of a substrate is of extreme importance, since, it is universally accepted that the substrate is not merely a support for anchoring the plant. Its complexity and dynamics determine the ways the plants will grow and develop (Barassi *et al*. 2007).

The vermicomposting process is the result of the combined action of earthworms and microflora living in earthworms' intestines and in the growth medium. Earthworms accelerate manure composting by bioturbation and aeration, and also yield final products enhanced in available metallic ion nutrients for plants (Mangrich *et al*. 2000). In relation to plant health, two classes of biological control mechanisms known as general and specific suppression have been described for compost-amended substrates (Hoitink *et al*. 1991).

The compost and vermicompost quality is the most essential criterion in recycling organic waste, as well as its marketing and utilization in agriculture as organic amendments (Lasaridi *et al*. 2006).

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**Invited Review**

Many researchers worldwide have worked on compost and vermicompost production, and evaluated their composition and aptitude as soil amendments (Hoitink and Fahy 1986; Hill *et al*. 2000; Szczech and Smolińska 2001; Arancon *et al*. 2005). This review is focused on Latin American results on vermicompost and its future perspectives as growth promoter and pathogen suppressive.

## CHEMICAL, PHYSICAL AND BIOLOGICAL CHARACTERIZATION OF VERMICOMPOSTS

Many authors agree that VCs act as fertilizers and contribute to the improvement of soil physicochemical characteristics (Castillo *et al*. 1999). According to their composition, mature VCs are appropriate to be used in that way (Lamim *et al*. 1998). Numerous papers provide data of physical and chemical analysis of VCs, which are analysed in the next paragraphs and summarised in tables.

Sánchez Hernández *et al*. (2005) reported a clear effect on soil physical properties after the addition of VC. There was a decrease in bulk density and the amounts of macroaggregates, by increasing VC rates.

Worm feeding affects the final product physical characteristics. VC apparent and particulate densities vary according to the food source used to feed the worms. Differences can be also found between grain size, the coarser grain having greater aeration porosity as well as a lower water retention capacity (Valenzuela *et al*. 1998; Castillo *et al*. 2005; Hernández *et al*. 2008). VC's texture can be characterized as sandy loam (Lamim *et al*. 1998)

Reported pH values for VCs vary, ranging from 5.7 to 8.7 (**Table 1**). Alves *et al*. (2001) consider that differences in pH are probably related to raw materials used for vermicomposting. Information of these materials is not included in many papers. So, it is difficult to give general conclusions on this subject. Another fact that has to be taken into account is that authors not always inform the method used to determine pH, which may vary the results obtained.

Values of the C/N ratio vary among authors, ranging from 7 to 21 (**Table 2**), indicating great differences in the rates of biological humification or VC maturity. As any composted material, VCs usually show high percentages of organic matter. Although always high, this parameter is extremely variable, from 5 to 65% (**Table 2**). In any case, VCs

**Table 1** pH values determined for different vermicomposts.

| VC source | pH | Measurement method | Reference |
|---|---|---|---|
| Not stated | 5.7 | KCl (1:2.5) | Pereira and Arruda 2003 |
| Not stated | 5.8 | KCl (1:2.5) | Pereira and Arruda 2003 |
| B + sugarcane R (2.4:1 w) | 5.8 | $H_2O$ | da Silva *et al*. 2002 |
| B + sugarcane R (1:2.7 w) | 5.8 | $H_2O$ | da Silva *et al*. 2002 |
| Not stated | 5.9 | $CaCl_2$ | Danner *et al*. 2007 |
| Bovine M | 6.0 | $H_2O$ (1:2.5) | Jordão *et al*. 2002 |
| Not stated | 6.0 | Not stated | Premuzic *et al*. 2004a |
| B + sugarcane R (1:1.6 w) | 6.1 | $H_2O$ | da Silva *et al*. 2002 |
| B | 6.1 | $H_2O$ | da Silva *et al*. 2002 |
| Bovine M | 6.2 | $CaCl_2$ (1:2.5) | Soares *et al*. 2004 |
| Poultry and chinchilla litter | 6.3 | $H_2O$ (1:2.5) | Premuzic and Vilella 2002 |
| Bovine M | 6.4 | Not stated | Díaz *et al*. 2004 |
| Filter cake and bovine M (1:1) | 6.4 | Not stated | Sanchez Hernández *et al*. 2005 |
| B + sugarcane R (1.2:1 w) | 6.5 | $H_2O$ | da Silva *et al*. 2002 |
| Bovine M + coffee pulp (1:1) | 6.6 | Not stated | Acevedo and Pire 2004 |
| Bovine M + Kitchen W (1:1 w) | 6.7 | Potenciometric | Castillo *et al*. 2000 |
| Bovine M | 6.7 | Potenciometric | Castillo *et al*. 2000 |
| Bovine M + Kitchen W (3:1 w) | 6.7 | Potenciometric | Castillo *et al*. 2000 |
| Bovine M | 6,7 | $CaCl_2$ | Landgraf *et al*. 1999 |
| Bovine M | 6.8 | $H_2O$ (1:1) | Rivera *et al*. 2004b |
| Bovine M + Kitchen W (1:3 w) | 6.9 | Potenciometric | Castillo *et al*. 2000 |
| Not stated | 7.0 | Not stated | Premuzic *et al*. 1998a |
| UPR + CA | 7.0 | $CaCl_2$ | Suszek *et al*. 2007 |
| Bovine M | 7.1 | $H_2O$ (1:2.5) | Albuquerque da Silva *et al*. 2006 |
| Kitchen W | 7.1 | Potenciometric | Castillo *et al*. 2000 |
| Bovine M | 7.2 | KCl (1:2.5) | Lamim *et al*. 1998 |
| Farm W + UP (1.5:1 w) + CA | 7.2 | $CaCl_2$ | Suszek *et al*. 2007 |
| Farm W + UP (1.5:1 w) + water | 7.3 | $CaCl_2$ | Suszek *et al*. 2007 |
| Farm W + UP (1.5:1 w) + porcine water | 7.4 | $CaCl_2$ | Suszek *et al*. 2007 |
| Bovine M | 7.6 | Not stated | Hernández *et al*. 2006 |
| Backyard W | 7.7 | $H_2O$ (1:1) | Tognetti *et al*. 2005 |
| Kitchen W | 7.7 | $H_2O$ (1:1) | Zamora Morales *et al*. 2005 |
| Non shredded MOW + woodshavings (1:1 v) | 7.7 | $H_2O$ (1:10) | Tognetti *et al*. 2007a |
| Bovine M | 7.7 | $CaCl_2$ | Suszek *et al*. 2007 |
| Not stated | 7.8 | Potenciometric | Pereira and Arruda 2008 |
| Shredded MOW | 7.9 | $H_2O$ (1:10) | Tognetti *et al*. 2007a |
| Shredded MOW + woodshavings (1:1 v) | 7.9 | $H_2O$ (1:10) | Tognetti *et al*. 2007a |
| Shredded MOW | 7.9 | $H_2O$ (1:10) | Tognetti *et al*. 2008 |
| Agave R + coconut fiber | 8.1 | $H_2O$ (1:1) | Zamora Morales *et al*. 2005 |
| MOW + B (3:1) | 8.3 | $H_2O$ (1:10) | Tognetti *et al*. 2008 |
| MOW + B (3:1) | 8.3 | $H_2O$ (1:10) | Tognetti *et al*. 2007b |
| MOW + B (2:1) | 8.4 | $H_2O$ (1:10) | Tognetti *et al*. 2007b |
| MOW + B (2:1) | 8.4 | $H_2O$ (1:10) | Tognetti *et al*. 2008 |
| Non shredded MOW | 8.5 | $H_2O$ (1:10) | Tognetti *et al*. 2007a, 2008 |
| Sheep M | 8.6 | $H_2O$ (1:2.5) | Oliva *et al*. 2008 |
| Sheep M | 8.6 | $H_2O$ | Alves *et al*. 2001 |
| Sheep M | 8.6 | $H_2O$ (1:2.5) | Gutierrez-Miceli *et al*. 2007 |
| MOW | 8.7 | $H_2O$ (1:1) | Tognetti *et al*. 2005 |

B: biosolids, CA: commercial activator, M: manure, MO: municipal organic, R: residues, UP: urban pruning, W: waste

**Table 2** Vermicompost main macronutrients analysis by different authors*.

| VC source | OM %** | C/N | C % | N | | | P | | K %** | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total % | $NH_4^+$ mg kg$^{-1}$ | $NO_3^-$ mg kg$^{-1}$ | Total %** | Extr. mg kg$^{-1}$ | | |
| Bovine M | 30 | - | - | 1.2 | - | - | 0.032 | - | 0.1 | Castillo *et al.* 2000 |
| Kitchen W | 23 | - | - | 0.6 | - | - | 0.027 | - | 0.7 | Castillo *et al.* 2000 |
| Bovine M + kitchen W (3:1 w) | 27 | - | - | 1.0 | - | - | 0.029 | - | 0.8 | Castillo *et al.* 2000 |
| Idem (1:1 w) | 29 | - | - | 1.1 | - | - | 0.030 | - | 0.3 | Castillo *et al.* 2000 |
| Idem (1:3 w) | 25 | - | - | 0.5 | - | - | 0.028 | - | 0.6 | Castillo *et al.* 2000 |
| Bovine M | 583$^1$ | 13 | - | 2.6 | - | - | 0.22$^1$ | - | 9.4$^3$ | Costa *et al.* 2006 |
| Not stated | 11 | - | - | - | - | - | 0.31$^1$ | - | 1.5$^1$ | Danner *et al.* 2007 |
| B | - | - | - | 2.0 | - | - | 1.6 | - | 1.23 | da Silva *et al.* 2002 |
| B + sugarcane R (1.2:1 w) | - | - | - | 1.7 | - | - | 1.7 | - | 2.10 | da Silva *et al.* 2002 |
| Idem (1:1.6 w) | - | - | - | 1.6 | - | - | 1.7 | - | 2.28 | da Silva *et al.* 2002 |
| Idem (1:2.7 w) | - | - | - | 1.5 | - | - | 1.7 | - | 2.55 | da Silva *et al.* 2002 |
| Idem (2.4:1 w) | - | - | - | 1.4 | - | - | 1.4 | - | 2.93 | da Silva *et al.* 2002 |
| Bovine M | 47 | - | - | 1.7 | - | - | 2.4 | - | 3.5 | Díaz *et al.* 2004 |
| Bovine M | 5 | - | - | - | - | - | 0.6 | - | 1.8 | Hernández *et al.* 2006 |
| Bovine M | 46 | 15 | 15 | 1.2 | - | - | - | - | - | Lamim *et al.* 1998 |
| Bovine M | - | 12 | 27 | 2.5 | - | - | - | - | - | Landgraf *et al.* 1999 |
| Horse M | 25 | - | - | 0.9 | - | - | 2232$^2$ | - | - | Moreno Reséndez *et al.* 2005 |
| Horse M + goat M (1:1 v) | 17 | - | - | 0.7 | - | - | 963$^2$ | - | - | Moreno Reséndez *et al.* 2005 |
| Goat M | 15 | - | - | 0.8 | - | - | 945$^2$ | - | - | Moreno Reséndez *et al.* 2005 |
| Goat M + garden R (1:1 v) | 9 | - | - | 0.8 | - | - | 673$^2$ | - | - | Moreno Reséndez *et al.* 2005 |
| Sheep M | - | - | 23 | 1.2 | 9 | 234 | - | - | - | Oliva *et al.* 2008 |
| Not stated | - | - | 17 | 2.0 | - | - | - | - | 0.06 | Pereira and Arruda 2003 |
| Not stated | - | - | 33 | 2.3 | - | - | - | - | 0.19 | Pereira and Arruda 2003 |
| Not stated | - | - | 10 | 0.7 | - | - | - | - | 0.27 | Pereira and Arruda 2003 |
| Not stated | 14 | 8 | - | 1.8 | - | - | 0.031 | - | 0.07 | Premuzic *et al.* 2004a |
| Not stated | 13 | - | - | 1.3 | - | - | 0.35 | - | 0.17 | Premuzic *et al.* 1998a |
| Bovine M | - | 9 | 21 | 2.3 | - | - | 1.18 | - | - | Soares *et al.* 2004 |
| Bovine M | - | 12 | 14 | 1.2 | - | - | 1.15 | - | - | Soares *et al.* 2004 |
| Bovine M | - | 14 | 13 | 0.9 | - | - | 1.00 | - | - | Soares *et al.* 2004 |
| Bovine M | - | 12 | 34 | 2.9 | - | - | 1.20 | - | - | Soares *et al.* 2004 |
| Filter cake + bovine M (1:1) | 53 | - | | 0.9 | - | - | - | - | - | Sanchez Hernández *et al*. 2005 |
| Farm W + UP (1.5:1 w) + CA | - | 11 | 14 | 1.2 | - | - | 0.17 | - | 1.30 | Suszek *et al.* 2007 |
| UP + CA | - | 11 | 12 | 1.2 | - | - | 0.12 | - | 0.45 | Suszek *et al.* 2007 |
| Farm W + UP (1.5:1 w) + porcine water | - | 7 | 12 | 1.7 | - | - | 0.20 | - | 1.05 | Suszek *et al.* 2007 |
| Farm W + UP (1.5:1 w) + water | - | 11 | 12 | 1.1 | - | - | 0.19 | - | 1.28 | Suszek *et al.* 2007 |
| Bovine M | - | 8 | 11 | 1.4 | - | - | 0.69 | - | 1.55 | Suszek *et al.* 2007 |
| Shredded MOW | 33 | 13 | - | 1.4 | 23 | 1179 | 0.40 | 228 | - | Tognetti *et al.* 2008 |
| Non shredded MOW | 26 | 12 | - | 1.2 | 31 | 615 | 0.30 | 263 | - | Tognetti *et al.* 2008 |
| MOW + B (2:1 v) | 43 | 12 | - | 1.9 | 19 | 200 | 0.60 | 694 | - | Tognetti *et al.* 2008 |
| MOW + B (3:1 v) | 39 | 11 | - | 2.0 | 20 | 142 | 0.70 | 637 | - | Tognetti *et al.* 2008 |
| MOW | 24 | 11 | - | 1.1 | 25 | 203 | 0.70 | 207 | 0.56 | Tognetti *et al.* 2005 |
| Backyard W | 21 | 12 | - | 0.8 | 7 | 527 | 0.62 | 247 | 0.82 | Tognetti *et al.* 2005 |
| Shredded MOW | 33 | 13 | - | 1.4 | 23 | 1179 | - | 228 | - | Tognetti *et al.* 2007a |
| Shredded MOW + woodshavings (1:1 v) | 48 | 21 | - | 1.3 | 38 | 186 | - | 314 | - | Tognetti *et al.* 2007a |
| Non shredded MOW | 26 | 12 | - | 1.2 | 31 | 615 | - | 263 | - | Tognetti *et al.* 2007a |
| Non shredded MOW + woodshavings (1:1 v) | 28 | 17 | - | 0.9 | 28 | 648 | - | 143 | - | Tognetti *et al.* 2007a |
| MOW + B (2:1 v) | 43 | 12 | - | 1.9 | 19 | 200 | - | 694 | - | Tognetti *et al.* 2007b |
| MOW + B (3:1 v) | 39 | 11 | - | 2.0 | 20 | 142 | - | 637 | - | Tognetti *et al.* 2007b |
| Bovine M | - | - | 16 | 2.4 | - | - | 1.3 | - | 0.50 | Yagi *et al.* 2003 |
| Kitchen W | 65 | - | - | - | - | - | 0.7$^2$ | - | 1900$^2$ | Zamora Morales *et al.* 2005 |
| Agave R + coconut fiber | 46 | - | - | - | - | - | 4.3$^2$ | - | 5631$^2$ | Zamora Morales *et al.* 2005 |

*when possible, values have been modified so as to unify units of measurement, **except indicated

$^1$g dm$^{-3}$, $^2$mg dm$^{-3}$, $^3$mmol$_c$ dm$^{-3}$

B: biosolids, CA: commercial activator, M: manure, MO: municipal organic, R: residues, UP: urban pruning, W: waste

constitute an important source of organic matter when added to any soil or substrate. The organic fraction includes chemically defined components as alkanes, fatty acids, polysaccharides and humic acids (HAs) (Lamim *et al.* 1998).

The presence of HAs in earthworm-composted materials has been widely demonstrated. In recent times, the amount and the chemical and physicochemical properties of HAs in compost and VC are considered as important indicator of their biological maturity and chemical stability and warranty for safe impact and successful performance in soil (Campitelli and Ceppi 2008a). HAs extracted from sheep, cow, goat and rabbit vermicomposted manures show high nitrogen (N) contents and aromatic and/or unsaturated aliphatic conjugated structures, as well as low carboxylic functionality content. Differences among them show that it is possible to prepare distinct worm-composts to solve specific problems of degraded soils. Mangrich *et al.* (2000) reported high N content, low carboxylic acidity, as well as high degree of conjugated aliphatic and/or substituted or condensed aromatic structures for the HAs extracted from VC. Carbon (C), hydrogen (H) and oxygen (O) contents in VC HAs are similar to those registered for soil HAs while those of nitrogen and sulphur (S) are higher (Senesi 1989). Landgraf *et al.* (1999) characterized cattle manure VC, concluding that three-month vermicomposting period is enough to obtain a good fertilizer, due to its contents of HAs and N. Chemical characteristics determined in VCs obtained from different combinations of biosolids and sugarcane bagasse indicate that it can be used as organic fertilizer, mainly with regard to organic matter content, pH, C/N ratio,

**Table 3** Vermicomposts content of Ca, Mg and micronutrients, as determined by different authors*.

| **VC source** | **Ca** | **Mg** | **Na** | **Fe** | **Zn** | **Cu** | **Mn** | **Reference** |
|---|---|---|---|---|---|---|---|---|
| | **%**** | **%**** | **mg kg$^{-1}$**** | **mg kg$^{-1}$**** | **mg kg$^{-1}$**** | **mg kg$^{-1}$**** | **mg kg$^{-1}$**** | |
| Not stated | $143^3$ | - | - | - | - | - | $120^3$ | Danner *et al.* 2007 |
| B | 0.15 | 0.7 | - | - | - | - | - | da Silva *et al.* 2002 |
| B + sugarcane R (1.2:1 w) | 0.17 | 1.2 | - | - | - | - | - | da Silva *et al.* 2002 |
| Idem (1:1.6 w) | 0.15 | 1.1 | - | - | - | - | - | da Silva *et al.* 2002 |
| Idem (1:2.7 w) | 0.13 | 1.0 | - | - | - | - | - | da Silva *et al.* 2002 |
| Idem (2.4:1 w) | 0.11 | 1.1 | - | - | - | - | - | da Silva *et al.* 2002 |
| Sheep M | - | - | - | 5300 | - | 42 | 2700 | Guimarães *et al.* 2001 |
| Cow M | - | - | - | 15700 | - | 25 | 2300 | Guimarães *et al.* 2001 |
| Goat M | - | - | - | 3700 | - | 28 | 3700 | Guimarães *et al.* 2001 |
| Rabbit M | - | - | - | 8900 | - | 69 | 700 | Guimarães *et al.* 2001 |
| Bovine M | 0.30 | 0.5 | - | 0.8 | 1.8 | 1.0 | 6.5 | Hernández *et al.* 2006 |
| Bovine M | - | - | - | - | - | $0.5^3$ | - | Lamim *et al.* 1998 |
| B | - | - | - | 32000 | 455 | 197 | 272 | Mantovani *et al.* 2004 |
| Horse M | $14.7^4$ | $0.8^4$ | $8.4^4$ | $26^2$ | $12^2$ | $1.8^2$ | $21.2^2$ | Moreno Reséndez *et al.* 2005 |
| Horse M + goat M (1:1 v) | $14.0^4$ | $0.8^4$ | $5.7^4$ | $45^2$ | $12.2^2$ | $1.6^2$ | $20.4^2$ | Moreno Reséndez *et al.* 2005 |
| Goat M | $11.2^4$ | $1.2^4$ | $25.8^4$ | $15^2$ | $7.8^2$ | $1.4^2$ | $24.4^2$ | Moreno Reséndez *et al.* 2005 |
| Goat M + garden R (1:1 v) | $16.5^4$ | $0.7^4$ | $6.5^4$ | $58^2$ | $13.8^2$ | $2.3^2$ | $23.2^2$ | Moreno Reséndez *et al.* 2005 |
| Not stated | 0.65 | 0.11 | 0.04 | - | - | - | - | Pereira and Arruda 2003 |
| Not stated | 0.42 | 2.21 | 0.15 | - | - | - | - | Pereira and Arruda 2003 |
| Not stated | 1.04 | 0.02 | 0.21 | - | - | - | - | Pereira and Arruda 2003 |
| Not stated | 0.30 | 0.036 | - | - | - | - | - | Premuzic *et al.* 2004a |
| Not stated | 0.05 | 0.06 | 110 | 430 | - | - | - | Premuzic *et al.* 1998a |
| Farm W + UP (1.5:1 w) + CA | - | - | - | - | 27.4 | 80.5 | - | Suszek *et al.* 2007 |
| UP + CA | - | - | - | - | 34.6 | 65 | - | Suszek *et al.* 2007 |
| UP + farm W (1.5:1 w) + porcine water | - | - | - | - | 27.9 | 61.3 | - | Suszek *et al.* 2007 |
| Farm W + UP (1.5:1 w) + water | - | - | - | - | 13.6 | 62.7 | - | Suszek *et al.* 2007 |
| Bovine M | - | - | - | - | 127.0 | 138 | - | Suszek *et al.* 2007 |
| Bovine M | 2.5 | 0.6 | - | 28000 | 197 | 107 | 649 | Yagi *et al.* 2003 |
| Kitchen W | $880^2$ | $267^2$ | - | - | - | - | - | Zamora Morales *et al.* 2005 |
| Agave R + coconut fiber | $2750^2$ | $168^2$ | - | - | - | - | - | Zamora Morales *et al.* 2005 |

*when possible, values have been modified so as to unify units of measurement, **except indicated

$^1$g dm$^{-3}$, $^2$mg dm$^{-3}$, $^3$mmol$_c$ dm$^{-3}$, $^4$meq dm$^{-3}$

B: biosolids, CA: commercial activator, M: manure, MO: municipal organic, R: residues, UP: urban pruning, W: waste

N and P levels (da Silva *et al.* 2002). Guimarães *et al.* (2001) analyzed VC HAs by electron paramagnetic resonance and hydrogen nuclear magnetic resonance spectroscopies, finding that carboxylic acids, amine, amide, ester, ether and phenol functions bonded to saturated aliphatic, unsaturated aliphatic conjugated double and single bonds, and aromatic chains constitute their backbone structure.

There are some interesting data on VC nutrient content and their differences due to vermicomposted material or composting procedure. Castillo *et al.* (1999) compared VC obtained from different raw and mixed organic wastes, and found differences among them regarding N-P-K levels. In general, the highest N content suggests that the earthworms used in the maturation procedure lead to an efficient degradation of organic matter (Soares *et al.* 2004). In general, the highest N and P contents were found in VC made from bovine manure (**Table 2**). High P values are usual in these materials. Hernández *et al.* (2006) concluded that contents of organic matter, macro- and microelements in VC were not influenced by the frequency of irrigation of containers where the compost was formed. Many publications provide micro and macronutrients contents in VC, which are shown in **Table 3**. These results are extremely variable, and do not seem to be associated with the raw materials used for vermicomposting. In most cases, values cannot be compared, because of the units in which they were expressed. For example, nutrient contents provided as mg dm$^{-3}$, when there are no data on VC density for mg 100 g$^{-1}$ (%) calculations.

The maintenance of soil fertility is intimately related with the ability of the organic matter to form complexes with trace metals. The interaction of humic substances with metal ions is of great importance for the environment, as its study has always been of considerable interest. The transport of soil micronutrients to the plants, as well as the immobilization of toxic elements in soils and waters, is greatly influenced by metal ion complexation capacity of the existing humic substances (Ramallo Mercê *et al.* 1996). VCs contain macro and micronutrients, mainly Ca, Mg, K, S, Cu and Zn (Soares *et al.* 2004). Metal micronutrients and pollutants Zn and Cu, are adsorbed by VC, in pH dependant phenomena (Lamim *et al.* 1998). Urban waste VC may content high levels of heavy metals, such as Ni, Pb, Cu and Zn (Mantovani *et al.* 2004). Iron, present in VCs as chelated complexes, is more available for plants than Fe in the form of soluble salts. In the same way, Cu complexes in VC humic substances would be a copper reserve during the continuing humification process on the soil (Guimarães *et al.* 2001). The metal retention is affected by both pH (Lamim *et al.* 1998; Soares *et al.* 2004) and adsorption time (Soares *et al.* 2004). Adsorption follows the order $Cu^{2+} \geq Zn^{2+} \geq Co^{2+}$. Metals are present in the studied VCs in concentrations not compatible with environmental contamination, in case they are used as soil amendments (da Silva *et al.* 2002; Soares *et al.* 2004). Also, VC shows an interesting capacity for Cd adsorption, due to high cation exchange capacity, high surface area (porous material), chelating groups and a maximum adsorptive capacity for Cd at pH 5 (Pereira and Arruda 2003). When mixed with soil, VC increased the levels of Ca and cation exchange capacity (Yagi *et al.* 2003). **Table 3** shows reported values for many VC ions.

In an attempt to bioremediate a soil contaminated with petroleum, VC had an effect on the initial dissipation of some polycyclic aromatic hydrocarbons (Álvarez-Bernal *et al.* 2006). This, together with VC heavy metals adsorption capacity related in the previous paragraph, show an interesting potential use of VC in bioremediation.

Electric conductivity is usually high in VCs, and often constitutes a limitation for their use in crop production. Its values can be reduced by watering during VC formation, due to salt percolation (Hernández *et al.* 2006). Variability in VC electric conductivity is shown in **Table 4**. Few authors have focused their research on VC biological charac-

**Table 4** Values for vermicompost electric conductivity reported by different authors.

| VC source | Electric conductivity (mS $cm^{-1}$) | Reference |
|---|---|---|
| MOW | 0.5 | Tognetti *et al.* 2005 |
| Backyard W | 1.2 | Tognetti *et al.* 2005 |
| MOW + B (3:1 v) | 1.4 | Tognetti *et al.* 2007b |
| MOW + B (3:1) | 1.4 | Tognetti *et al.* 2008 |
| MOW + B (2:1 v) | 1.5 | Tognetti *et al.* 2007b |
| MOW + B (2:1) | 1.5 | Tognetti *et al.* 2008 |
| Non shredded MOW + woodshavings (1:1 v) | 1.8 | Tognetti *et al.* 2007a |
| Filtercake and bovine M (1:1) | 1.9 | Sanchez Hernández *et al.* 2005 |
| Shredded MOW + woodshavings (1:1 v) | 1.9 | Tognetti *et al.* 2007a |
| Bovine M + coffee pulp (1:1) | 2.3 | Acevedo and Pire 2004 |
| Non shredded MOW | 2.3 | Tognetti *et al.* 2007a |
| Non shredded MOW | 2.3 | Tognetti *et al.* 2008 |
| Shredded MOW | 2.6 | Tognetti *et al.* 2007a |
| Shredded MOW | 2.6 | Tognetti *et al.* 2008 |
| Bovine M | 3.1 | Hernández *et al.* 2006 |
| Sheep M | 8.0 | Oliva *et al.* 2008 |
| Kitchen W | 8.7 | Zamora Morales *et al.* 2005 |
| Agave R | 14.7 | Gutiérrez-Miceli *et al.* 2007 |
| Agave R + coconut fiber | 14.7 | Zamora Morales *et al.* 2005 |
| Not stated | 18.0 | Premuzic *et al.* 1998a, 2004a |

B: biosolids, M: manure, MO: municipal organic, R: residues, W: waste

terization. We can highlight studies of Oliva *et al.* (2008) that reported no seed germination inhibiting compounds, as well as absence of coliform bacteria, fecal coliforms, *Salmonella* spp., *Shigella* spp. and helminth eggs. However, Tognetti *et al.* (2005) found fecal coliforms (80 most probable number per g) in two VCs. The authors consider that, because VC lack a thermophilic phase, human pathogen reduction in the final product is not guaranteed. Some biological and biochemical properties (urease, protease, phosphatase, dehydrogenase, microbial biomass) were also determined. VC microflora was explored in order to identify biological components responsible of patience plants (*Impatiens wallerana*) growth promotion (Asciutto *et al.* 2006) and fungal strains were confirmed as antagonic to *Rhizoctonia solani*.

Considering the high variability in final product quality, that depends of raw material, composting process and time of process, Campitelli and Ceppi (2008b) applied multivariate statistical analysis methods as a new approach to characterize many VCs and composts through nineteen chemical, physical and biological parameters. Linear Discriminant Analysis (LDA) is a supervised classification tool used to discriminate groups of samples as a function of one or several combinations of experimental variables. Each combination is called a “Discriminant Function” (DF), which resembles the idea of the Principal Component Analysis (PCA) (Brito *et al.* 2006). LDA allows the classification of new materials in the previous groups on the basis of a classification rule created with independent variables (Alonso-Salces *et al.* 2006). PCA led to data compression, capture of the main features, finding out useful information from data sets and detection of trends in the variables and in the samples (Tognetti *et al.* 2007a). As a result, composts could be classified into quality categories due to differential analytical data, as total organic C, pH, total N and water soluble C and seed germination index, which depend on the characteristics of each process. PCA can be successfully used to manage large quantities of experimental data (Rivera *et al.* 2009). LDA has not been extensively used to evaluate compost and vermicompost differences (Campitelli and Ceppi 2008b). Tognetti *et al.* (2007a) also applied PCA to characterize composts prepared from the same raw material and different management practices, through chemical parameters. These could be recommended methods to provide VCs global analysis and characterization.

## EFFECT OF VERMICOMPOSTS ON PLANT GROWTH

VCs have been studied alone or as components of growing media, mixed with mineral soil or commercial substrates. Even more, an attempt was made to formulate substrate mixtures using linear programming (Zamora Morales *et al.* 2005), as to minimize feedstock cost. The influence of VC on many different crops has been well documented.

Vegetable crops are the most studied in relation to VCs application. Growth, total productivity and commercial quality observed in radish (*Raphanus sativus*) were slightly increased by VC, whose properties were probably not sufficiently expressed due to soil high content of organic matter (Costa *et al.* 2006). The addition of 8 ton VC/ha raised broccoli (*Brassica oleracea*) yields (López Fuentes *et al.* 2007). White cabbage (*B. oleracea* var. *capitata*) head size and vitamin C (Premuzic *et al.* 1998b) and K (Premuzic *et al.* 1998a) contents were increased by growing in VC. Yields of greenhouse grown lettuce (*Lactuca sativa*) were improved by cultivation in VC and light supplementation (Premuzic *et al.* 2002a; Premuzic and Vilella 2002; Premuzic *et al.* 2004a) in field and greenhouse experiments; and high yield, low nitrate content and high vitamin C content were obtained, compared with inorganic fertilization treatments (Premuzic *et al.* 2002b). A tendency to promote vitamin content was also observed (Premuzic *et al.* 2004b). Mantovani *et al.* (2003) also worked with lettuce and their results show that urban waste VC at high rates limited lettuce yield in two types of soils (Oxissol and Alfissol). Even at these rates, however, the crop did not become inappropriate as food from the point of view of heavy metal (Cd, Ni, Cu, Fe, Mn, Zn) contamination. Ca and vitamin C contents in tomatoes (*Lycopersicon esculentum*) were higher for plants grown in VC or VC-soil 1: 1 (v/v) compared with hydroponics (Premuzic *et al.* 1998a, 2001). Dry weight in roots and N content in the aerial part were greater in 100% VC compared with hydroponic cropping (Premuzic and Iorio 1998). Moreno Reséndez *et al.* (2005) also studied the response of tomatoes to VC amended substrates, concluding that yield and soluble solids were higher for treatments with VC + sand 1:3 and that mixtures 1:1 (w/w) satisfied tomato nutrient demand. Tomato growth and yield as well as fruit soluble and insoluble solid were increased by VC as a substrate component (Gutiérrez-Miceli *et al.* 2007). In studies with other Solanaceous crop, Romero Lima *et al.* (2000) reported that VC produced the highest concentration of N in potato (*Solanum tuberosum*) tubers and consequently, better biological quality because of the increase in protein.

The influence of VC on fruiting species has been nearly as studied as that on vegetable crops, including research on plant vegetative growth, yield and commercial quality as influenced by VCs. They were assayed as a substratum component for seedlings of the native *Plinia* sp., with good results (Danner *et al*. 2007). Alves da Silva *et al*. (2008) also experimented with seedlings, studying the effect of VC on the activity of arbuscular mycorrhyzal fungi, and their combined effect on soursop (*Annona muricata*), concluding that the use of organic amendment together with mycorrhiza may constitute an alternative to grow this crop, also contributing to improve soil quality. VC was adequate as component of substrates for the establishment and activity of growth promoting diazobacteria and the growth of micropropagated pineapple (*Ananas comosus*) plantlets (Weber *et al*. 2003). Oliva *et al*. (2008) confirmed that VC determined survival, growth and photosynthesis efficiency of tamarind (*Tamarindus indica*) plantlets grown in high salinity substrates. VC also promoted the growth of avocado (*Persea americana*) seedlings (Reyes Alemán *et al*. 2001a, 2001b) and the development of rootstocks (Reyes Alemán *et al.* 2001c). The results obtained by Acevedo and Pire (2004) show benefits of VC as a substrate amendment for vegetative growth of melon-tree (*Carica papaya*) plants under nursery and field conditions, replacing N fertilizers. Raspberry (*Rubus idaeus*) was another studied fruiting species. In this case, Jara-Peña *et al*. (2003) established the optimum VC proportions for pot growth. In spite of reported successful experiments, when mixed with other organic matter sources, VC did not promote the rooting of acerola (*Malpighia emarginata*) cuttings (Rivero Maldonado *et al*. 2005).

Extensive crops have scarcely been explored in relation to growth promotion mediated by VC. Marana *et al*. (2008) grew potted coffee (*Coffea arabica*) plantlets in VC mixed with rice hull (4: 1, v/v), that required the application of a slow-releasing fertilizer; and evaluated vegetative parameters. VC also probed to be a good substrate for the root growth and acclimatization of sugarcane (*Saccharum officinale*) plants obtained by micropropagation, that is a limiting phase during *in vitro-in vivo* inter-phase (Díaz *et al*. 2004). Regarding cereals, VC solutions added in hydroponic growth of forage wheat (*Triticum aestivum*) increased dry weight, crude and soluble proteins compared with the addition of inorganic nutrient solutions (Müller *et al*. 2006). Also, VC increased growth (Tognetti *et al*. 2005) or growth and yield (Castillo *et al*. 2005) of ryegrass (*Lolium perenne*), other gramineous species.

The effect of VC on floral crops was studied by few authors, on only a few species. Rodríguez Navarro *et al*. (2000) measured vegetative growth, chlorophyll content and yield (number and diameter of inflorescences) of African daisy (*Gerbera jamesonii*), concluding that 20% is the optimum volume of VC as substrate component for this crop, that provides an optimum level of micronutrients. Milanés Figueredo *et al*. (2005) reported an optimum of 10 and 20 ton VC/ha to increase crop yield of pot marigold (*Calendula officinalis*) and chamomile (*Matricaria recutita*). Rates of 75% VC improved vegetative growth of patience plant (Asciutto *et al*. 2006). In tropical ornamental species, like red ginger (*Alpinia purpurata*) and beehive ginger (*Zingiber spectabile*), substrates with VC promoted growth and reduced arbuscular mycorrhizal colonization. During the acclimatization period, application of VC was useful to induce formation of healthy seedlings of both species (Albuquerque da Silva *et al*. 2006).

## USE OF VERMICOMPOST AS A DISEASE SUPPRESSIVE TOOL

It is generally accepted that composts have the potential to provide biological control of plant diseases. However, data on plant disease suppression mediated by VC is scarce. Costa *et al*. (2006) investigated the role of VC on crop physiologic disturbances. Incidence of cracked and spongy root – common in radish and attributed to nutritional disorders – was diminished by addition of VC to the soil. VC contributed to the control of *Sclerotium cepivorum* and *Sclerotinia sclerotiorum* in soil (Pereira *et al*. 1996a, 1996b). Rodríguez Navarro *et al*. (2000) found that incorporation at 20% rate, with or without chemical fertilizer, reduced the incidence of gerbera root and crown rot caused by *Rhizoctonia solani*, the area under disease progress curve and the disease growth rate. In contrast, higher disease incidence was observed in treatments with 40% VC. This soil-borne pathogen was also controlled in seedling plots of white pumpkin (*Benincasa hispida*) (Rivera *et al*. 2004a), tomato (*L. esculentum*) (Rivera *et al*. 2004b) and, with less efficiency, patience plant (Asciutto *et al*. 2006). VC microorganisms responsible of disease suppression were explored (Asciutto *et al*. 2006). Optimum VC rates varied among assays.

## VERMICOMPOST AND ITS SOCIAL BENEFITS

Some successful attempts have been made to involve the whole society in the role of VC in environmental care. In that way, VC production and utilization emerged as a viable alternative for rural and urban communities in different countries.

Cuban economical crisis, for instance, made it necessary to strengthen urban agriculture so as to ensure family feeding. In this context, VC intensive production – together with the development and use of bio-pesticides – provided a means for food production and food security (González Novo and Merzthal 2002). In México, social service students trained in VC production by University professors, organized workshops for city housewives. As a result, vermicomposting was adopted in many houses; and included home waste classification, organic matter recycling and humus production for garden use. So, these experiences enabled the socialization of environmental knowledge (Alejo López *et al.* 2007). Other experiences took place in urban houses, where cattle manure produced in the outskirts was used for worm feeding (Ruiz Martínez *et al.* 2007). Also, interesting social work carried out in rural areas included instruction on vermicomposting benefits and potentials, and basic information on worm feeding. This led to the establishment of manure-based vermiculture in the farms and the potential utilization of produced VC in crop production (Calderón Fabián *et al*. 2007).

As it can be appreciated in **Tables 1** to **4**, many authors have focused their work in evaluating local sources of vermicompostable substrates. Some of their results should be highlighted, such as the recycling of urban wastes and sewage sludge – that constitute a substantial point in city environments – and animal manure, which may be also critical in farm management. Work on the utilization of residues of special local crops as raw materials for VC production has also been issued, for example sugarcane bagasse (da Silva *et al.* 2002), cotton industry residuals (Toccalino *et al.* 2004), fruit and vegetable market residues (Sánchez de Pinto *et al.* 2005), puffed rice scrap (Schuldt *et al.* 2005), agave residues and coconut fiber (Zamora Morales *et al.* 2005), egg shell (Castro *et al.* 2007), drumstick tree (*Moringa oleifera*) leaves (Cova *et al.* 2007), African palm fruit residues (Hernández *et al.* 2008).

## CONCLUSION

A great number of papers related to VC properties have been published by Latin American researchers, from -in alphabetic order- Argentina, Brazil, Cuba, Chile, México and Venezuela. Most of them deal with VC characterization and its use as substrate for crop growing. It was proved that they improve substrates quality, and can provide better commercial aptitudes to crop production. Plant protection achieved by the use of VCs has not been extensively considered. Research was conducted in greenhouses and field, including seedling plots, micropropagated plantlets, and adult plants. Worldwide distributed crops as well as native or local ones were included in research materials. The majority of the work – when stated – was performed with bovine manure VCs. However, VCs obtained from other sources have also been studied (horse, sheep, cow and goat manures, rabbit and poultry litter, urban wastes, backyard wastes, kitchen wastes, agave residues, African palm fruit residues from oil production, woodshavings, coffee pulp, biosolids). A high variability was determined for many measured VC chemical parameters, which may depend on the nature of composted raw materials, and the composting process itself. Unfortunately, this information is not included in most of the reviewed papers.

In the present worldwide-increasing demand of safe food, VC technology turns out to be a valuable tool to satisfy consumers' demand, and simultaneously increase yields. VC relationship with sustainability is not only related with its application in crops, but with an important solution for the destination of urban, field and industry organic residues.

On the basis of the achieved results, a great job is still to be done, that is the regulation of VC stability and maturity indexes, as stated by Tognetti *et al.* (2005). Furthermore, in concordance with Campitelli and Ceppi (2008b) criteria of admissibility (including contents of heavy metals and pathogenic microorganisms) and classification (due to physical, chemical and biological characteristics) should be determined for VCs, as to be safely used as organic amendments.

These concerns are not limited to Latin America, and not only regarded to VCs. A wide range of potting substrates has replaced mineral soils in crop production. A hard scientific and technical work is undergoing throughout the world towards the standardization of analytical techniques for growing media, and the determination and quality standards for VC and other substrates.

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