



DOCTORAL THESIS

Use of Gorse Compost as Growing Media in Organic Agriculture



NOELIA LÓPEZ LÓPEZ

Departamento de Producción Vegetal y Proyectos de Ingeniería

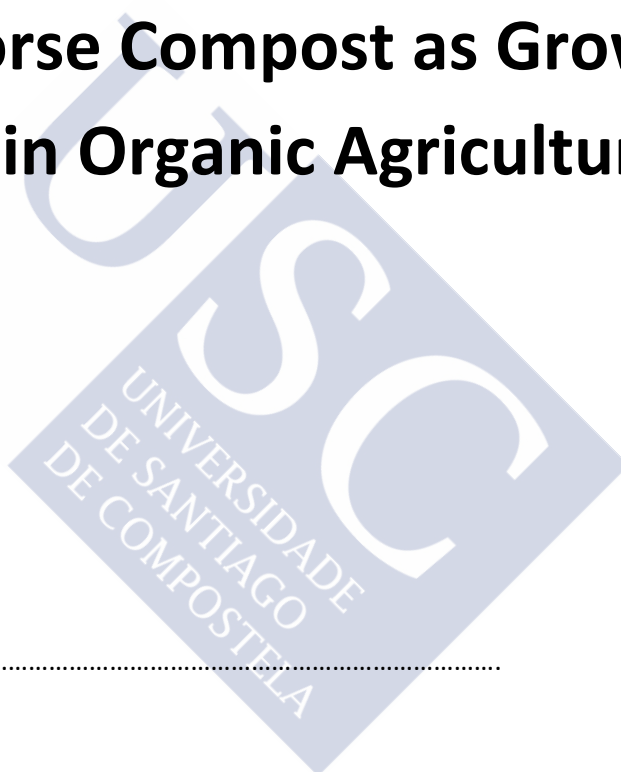
Escuela Politécnica Superior

Lugo 2017

DOCTORAL THESIS



**Use of Gorse Compost as Growing
Media in Organic Agriculture**



NOELIA LÓPEZ LÓPEZ

Departamento de Producción Vegetal y Proyectos de Ingeniería

Escuela Politécnica Superior

Lugo 2017



El profesor Dr. D. Adolfo López Fabal como Director de la Tesis Doctoral titulada: Use of Gorse Compost as Growing Media in Organic Agriculture.

Por la presente **DECLARA:**

Que la tesis propuesta por Doña Noelia López López es idónea para ser presentada, de acuerdo con el artículo 41 del *Reglamento de Estudios de Doctorado de la Universidad de Santiago de Compostela*, en la cual la doctoranda tuvo una participación de peso en el proceso de investigación y su contribución fue decisiva para llevar cabo este trabajo.

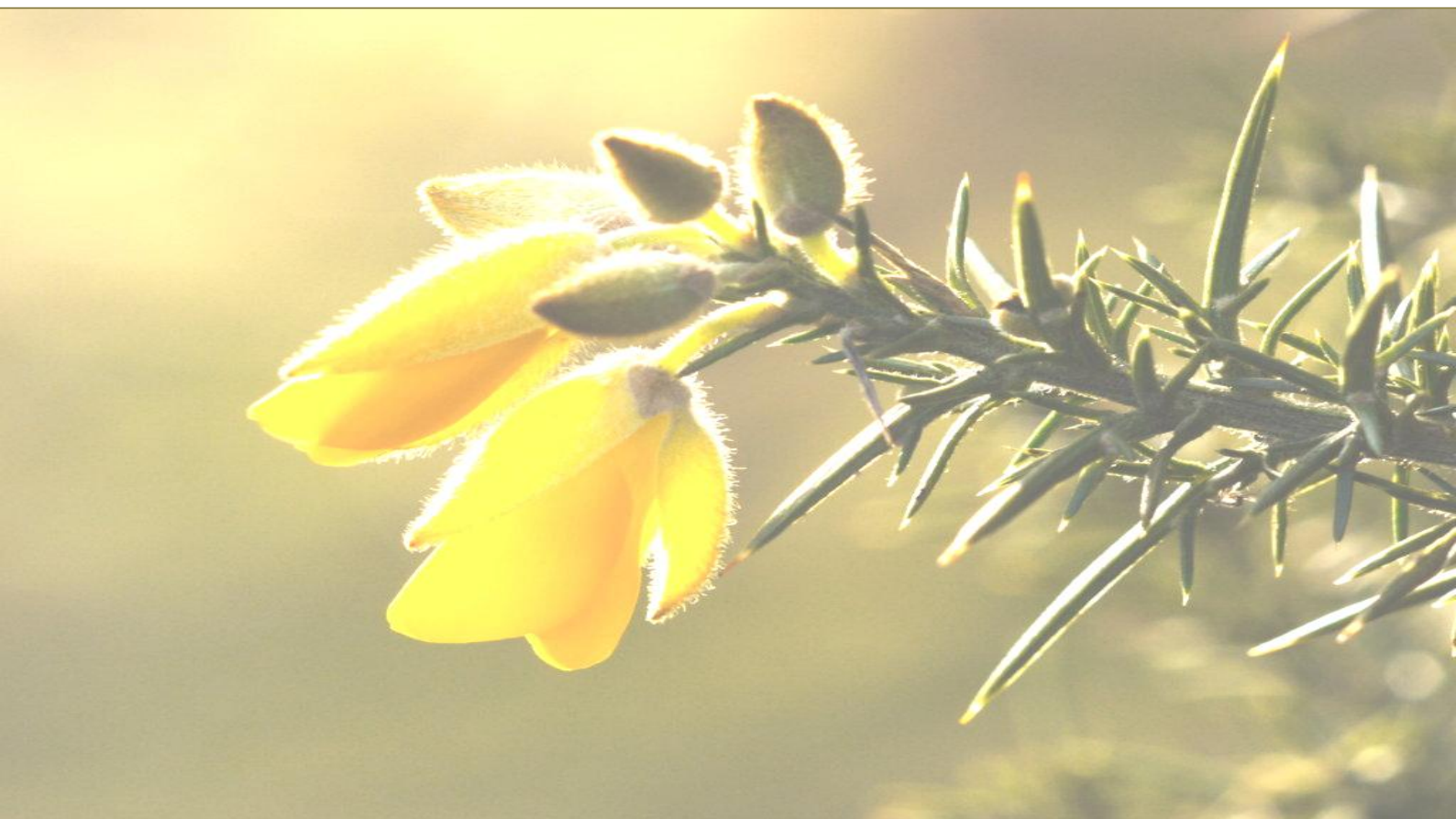
En Lugo, a 23 de febrero de 2017.

El director:

Dr. D. Adolfo López Fabal.



CHAPTER 0: Index and Abstracts



CHAPTER 0: INDEX AND ABSTRACTS

INDEX

CHAPTER 0: INDEX AND ABSTRACTS..... 1

INDEX 1

ABSTRACT 3

RESUMEN..... 4

RESUMO..... 5

CHAPTER I: GENERAL INTRODUCTION 7

1. REDUCING PEAT USE IN PLANT-GROWING SUBSTRATES 7

2. ECOLOGICAL SUBSTRATES 10

3. COMPOST AS A SUBSTRATE COMPONENT. QUALITY OF COMPOST..... 12

4. IMPROVING THE PROPERTIES OF COMPOST-BASED SUBSTRATES 15

5. OBJECTIVES..... 17

CHARTER II: COMPOST BASED ECOLOGICAL GROWING MEDIA ACCORDING EU ECO-LABEL REQUIREMENTS*..... 19

ABSTRACT 19

HIGHLIGHTS..... 19

1. INTRODUCTION..... 20

2. MATERIAL AND METHODS..... 21

 2.1. *Composting process*..... 21

 2.2. *Laboratory analyses* 22

 2.2.1. Analysis of raw materials 22

 2.2.2. Monitoring of the composting process..... 23

 2.2.3. Characterization of the final compost..... 23

 2.3. *Statistical analysis* 24

3. RESULTS AND DISCUSSION..... 25

 3.1. *Characterization of raw materials*..... 25

 3.2. *Monitoring of the composting process*..... 26

 3.2.1. Temperature 26

 3.2.2. Moisture 27

 3.2.3. pH..... 27

 3.2.4. Organic matter, N and C/N 29

 3.3. *Characterization of composts*..... 32

 3.3.1. Physical properties..... 32

 3.3.2. Chemical properties..... 34

 3.3.3. Biological properties 37

4. CONCLUSIONS 41

CHARTER III: GORSE COMPOST AS AN ECOLOGICAL GROWING SUBSTRATE FOR STRAWBERRY (*FRAGARIA X ANANASSA* DUCH “SELVA”) PRODUCTION: CROP NUTRITION AND FERTILITY STATUS 43

ABSTRACT 43

HIGHLIGHTS..... 44

1. INTRODUCTION..... 44

2. MATERIALS AND METHODS 46

2.1. Composts	46
2.1.1. Laboratory analyses	46
2.2. Strawberry crop	47
2.2.1. Crop monitoring	47
2.3. Statistical analysis	48
3. RESULTS AND DISCUSSION	49
3.1. Composts	49
3.2. Crop nutrition	54
3.3. Crop growth and production	61
4. CONCLUSIONS	64
CHAPTER IV: NATURAL SUPPRESSIVE COMPOST FROM FOREST CLEANING GREEN WASTE AND <i>TRICHODERMA ASPERELLUM</i> STRAIN T34 REDUCE THE INCIDENCE OF <i>FUSARIUM CIRCINATUM</i> DISEASE IN <i>PINUS RADIATA</i> SEEDLINGS.*	65
ABSTRACT	65
HIGHLIGHTS	65
1. INTRODUCTION	66
2. MATERIALS AND METHODS	68
2.1. Physical, chemical and physico-chemical properties of the composts	68
2.2. Microbial characterization of the composts	69
2.3. Microorganisms used	69
2.4. <i>Trichoderma</i> spp. concentration in the composts	69
2.5. Assessment of disease incidence	70
2.6. Biomass and physiological analysis of plants	71
2.7. Statistical analysis	71
3. RESULTS	71
3.1. Characterization of the composts	71
3.2. Assessment of disease incidence	74
3.3. Plant biomass and physiological analysis	77
3.4. Evolution of <i>Trichoderma</i> spp.	77
4. DISCUSSION	80
5. CONCLUSIONS	82
CHAPTER V: GENERAL DISCUSSION AND CONCLUSIONS	83
1. GENERAL DISCUSSION	83
2. CONCLUSIONS	91
APPENDIX I: RESUMEN EXTENDIDO	95
APPENDIX II: BIBLIOGRAPHY	107
ACKNOWLEDGEMENTS	133

ABSTRACT

Whether alone or in mixtures, peat is the substrate most commonly used in horticulture to grow seedlings and soilless plants, but quality peat is a scarce resource in southern Europe. In addition peat is a very slowly renewable natural resource so environmental pressure against its extraction has risen. Green compost has an important role to play in peat replacement and the transition to sustainable growing media. But most users have never had confidence in its use or have it dented through past use of poor quality compost. Therefore, quality assurance is key to promote the inclusion of compost in substrates and progress in reducing the use of peat. In this work, it was obtained gorse (*Ulex europaeus* L.) compost to be used as peat-alternative in organic agriculture. Gorse now occupies large areas and is considered a highly invasive species, so its collection and transformation in growing media would reduce the environmental impact of agricultural activities and would lower the risk of forest fires. The shrubs, consisting mainly of 4-5 year's old gorse plants, were collected and composted attending two factors: the addition of 5% v/v of poultry manure and the previous irrigation of stacks. The resulted composts were physical, chemical and biologically characterized to be used as substrate and according the requirements for award of the European Union eco-label. Gorse composts were assed as a growing media for organic strawberry container production focusing on its capacity to supply nutrients along the crop cycle and the requirements for additional fertilization. The natural suppressiveness against *Fusarium circinatum* in *P. radiata* seedlings of different gorse composts was evaluated too; as well as the effect of *Trichoderma asperellum* strain T34 as biological control. All composts obtained were mature, stable and pathogen-free. All of them were suitable for use as growing media, exhibiting a high aeration and drainage capacity, little water retention and adequate level of available nutrients. They all fulfilled the requirements of the Community eco-label except for the content in weed seeds in some of them. The addition of poultry manure resulted in substantial changes in the properties of the substrates, which showed higher content in soluble elements and an increased salinity, but this difference was not so much evident during strawberry crop in terms of fruit production or growth. Gorse compost produced on a large scale exhibited natural suppressive properties against *Fusarium circinatum* disease and inoculation with *Trichoderma asperellum* strain T34 reduced pre- and post-emergence of disease incidence.

RESUMEN

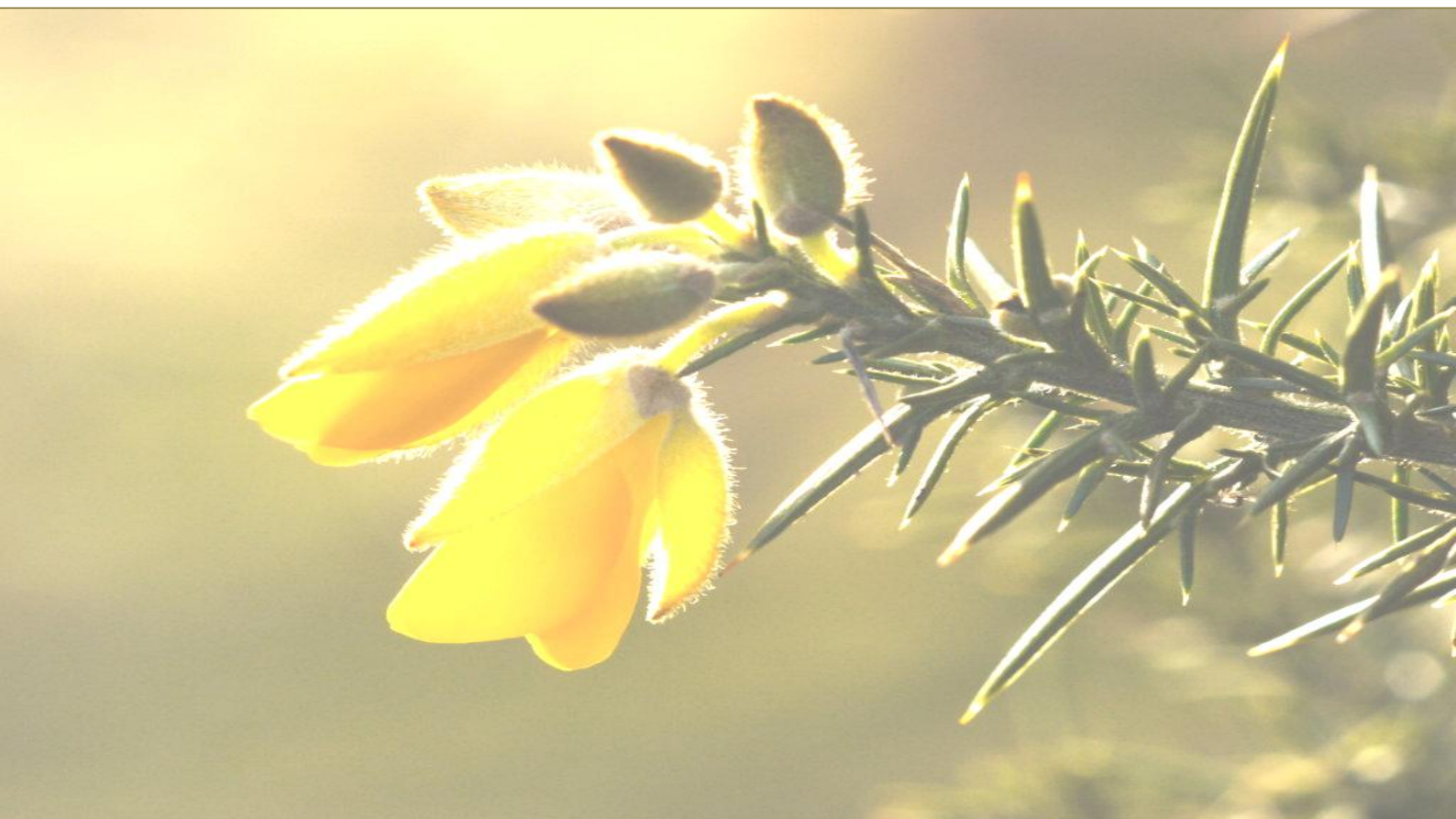
Ya sea sola o en mezcla la turba es el material más usado como sustrato en viverismo para producción de planta, pero la turba de calidad es un recurso escaso en el sur de Europa. Además la turba es un recurso muy lentamente renovable, por lo que la presión ambiental en contra de su extracción está creciendo. Los composts verdes están llamados a jugar un importante papel en la sustitución de la turba y en la transición hacia el uso de sustratos más sostenibles. Pero muchos usuarios nunca han tenido mucha confianza en su uso o la tienen mermada por experiencias pasadas de uso de materiales de mala calidad. Por tanto asegurar la calidad de los materiales es un factor clave para promover la inclusión del compost en los sustratos y progresar en la sustitución de la turba. En este trabajo se ha obtenido compost de tojo (*Ulex europaeus* L.) para ser usado como sustrato alternativo a la turba en agricultura ecológica. Actualmente el tojo ocupa grandes extensiones a nivel mundial y es considerado una especie invasora, por lo que su recolección y transformación en sustrato reduciría el impacto medioambiental de las actividades agrarias y reduciría el riesgo de incendios forestales. Se recogió tojo de 4-5 años de edad y se compostó atendiendo a dos factores: la adición de gallinaza al 5% v/v y el mojado de las pilas al inicio. Los composts resultantes fueron completamente caracterizados física, química y biológicamente para ser usados como sustratos y de acuerdo a los requisitos para la obtención de la etiqueta ecológica europea. Los compost también fueron evaluados como sustratos para el cultivo ecológico de fresa en contenedor, enfocando en su capacidad para suministrar nutrientes al cultivo y determinar los requerimientos de fertilización adicional. También se evaluó la supresividad natural de diferentes composts de tojo frente a *Fusarium circinatum* en semilleros de *P.radiata*, así como el efecto de *Trichoderma asperellum* strain T34 como agente de control biológico. Todos los compost obtenidos estaban maduros, estables e higienizados. Todos fueron adecuados para uso como sustrato, mostrando alta capacidad de aireación y drenaje, baja capacidad de retención de agua disponible y adecuado nivel de nutrientes. Todos cumplieron con los requerimientos para la concesión de la etiqueta ecológica a excepción, en algunos de ellos, del límite de semillas de malas hierbas. La adición de gallinaza resultó en cambios importantes en las propiedades de los sustrato, mostrando mayor contenido en nutrientes solubles y mayor salinidad; pero esta diferencia no resultó muy evidente durante el cultivo de fresa en cuanto a producción de fruto o crecimiento. El compost de tojo producido a gran escala mostró supresividad natural contra *Fusarium circinatum* y la inoculación de *Trichoderma asperellum* strain T34 redujo la incidencia de la enfermedad en pre- y post-emergencia.

RESUMO

Xa sexa soa ou en mestura a turba é o material máis usado como substrato en viveirismo para produción de planta, pero a turba de calidade é un recurso escaso no sur de Europa. Ademais a turba é un recurso moi lentamente renovable, polo que a presión ambiental en contra da súa extracción está a crecer. Os composts verdes están chamados a xogar un importante papel na substitución da turba e na transición cara ao uso de substratos máis sustentables. Pero moitos usuarios nunca tiveron moita confianza no seu uso ou a teñen minguada por experiencias pasadas de uso de materiais de mala calidade. Por tanto asegurar a calidade dos materiais é un factor cruce para promover a inclusión do compost nos substratos e progresar na substitución da turba. Neste traballo obtívose compost de toxo (*Ulex europaeus* L.) para ser usado como substrato alternativo á turba en agricultura ecolóxica. Actualmente o toxo ocupa grandes extensións a nivel mundial e é considerado unha especie invasora, polo que a súa recolección e transformación en substrato reduciría o impacto ambiental das actividades agrarias e o risco de incendios forestais. Recolleuse toxo de 4-5 anos de idade e se compostou atendendo a dous factores: a adición de galiñaza ao 5% v/v e o mollado das pilas ao comezo. Os composts resultantes foron completamente caracterizados física, química e bioloxicamente para ser usados coma substratos e de acordo aos requisitos para a obtención da etiqueta ecolóxica europea. Os compost tamén foron avaliados como substratos para o cultivo ecolóxico de amorodo en contedor, focalizando na súa capacidade para fornecer nutrientes ao cultivo e determinar os requirimentos de fertilización adicional. Tamén se avaliou a supresividade natural de diferentes composts de toxo fronte a *Fusarium circinatum* en sementeiros de *P.radiata*, así como o efecto de *Trichoderma asperellum* strain T34 como axente de control bioloxico. Todos o compost obtidos estaban maduros, estables e hixienizados. Todos foron adecuados para uso como substrato, mostrando alta capacidade de aireación e drenaxe, baixa capacidade de retención de auga dispoñible e adecuado nivel de nutrientes. Todos cumpriron cos requirimentos para a concesión da etiqueta ecolóxica a excepción, nalgúns deles, do límite de sementes de malas herbas. A adición de galiñaza resultou en cambios importantes nas propiedades dos substratos, mostrando maior contido en nutrientes solubles e maior salinidade; pero esta diferenza non resultou moi evidente durante o cultivo de amorodo en canto a produción de froito ou crecemento. O compost de toxo producido a gran escala mostrou supresividade natural contra *Fusarium circinatum* e a inoculación con *Trichoderma asperellum* strain T34 reduciu a incidencia da enfermidade en pre- e post-emerxencia.



CHAPTER I: General Introduction



CHAPTER I: GENERAL INTRODUCTION

1. Reducing peat use in plant-growing substrates

Although plant-growing substrates produced in Europe are made from a wide range of materials, most substrates for seedbedding and container growing contain more than 80% peat (Bohlin, 2002; Schilewski, 2009), particularly sphagnum peat (IPS, 2007; EU Commission, 2012). Peat-based substrates usually possess good water retention, aeration, drainage and cation-exchange properties; as a result, they provide effective sources of nutrients throughout plant growth (Rainbow and Wilson, 1998; Barrett *et al.*, 2016). However, such properties —and substrate quality— can vary widely depending on how the peat is obtained (Bragg, 1990; Michel, 2010). According to Fonteno (1999), the quality and usefulness of peat is dictated by the starting plant species, its degree of decomposition, local weather, the cropping method used and the moisture conditions during harvest. Thus, young, scarcely decomposed peat tends to retain water more easily than does older, more markedly decomposed peat (Maher and Prasad, 2004). The high variability and heterogeneity of this material make it flexible enough for use by a wide range of plant growing sectors (Barrett *et al.*, 2016).

Despite the large variety of raw materials available for use as substrates, only about 0.1–1.0% of the overall European production ($37 \cdot 10^6 \text{ m}^3$ each year) is completely peat-free (Schilewski, 2005). In fact, few materials fulfil cropping requirements, are so easily available in large amounts or are so amenable to use in greenhouses as peat. Unsurprisingly, peat continues to lead the plant-growing substrate market, partly as a result of its excellent physical, chemical and biological properties (Bragg, 1990; Robertson, 1993; Krucker *et al.*, 2010; Shmilewski, 2008).

Based on a report by the US Geological Service (USGS, 2013), 44% of the world production of peat ($32 \cdot 10^6 \text{ t}$) is used as fuel and 36% for agricultural purposes. Both figures are higher in Europe; thus, 47% of the $68 \cdot 10^6 \text{ m}^3$ produced on the continent each year is used for plant growing or soil amending, and 50% for energy (EU Commission, 2012).

Spain used 240 037 tons of peat in 2013, of which 177569 were imported mostly from Germany but also from Estonia, Latvia, The Netherlands and Lithuania. Spanish peat use has seemingly decreased slightly over the past decade following the marked increase from the

1980s to 2003 (IGME, 2015). The price of Spanish peat has also decreased slightly (to 164.02 €/t; USGS, 2015) in recent years. Despite the slight decrease in price at the source —usually central and northern European countries—, the increase in transportation costs has led to a sustained price rise (Ribeiro *et al.*, 2007, Ostos *et al.*, 2008).

The increase in peat import costs can be ascribed to a great extent to the growing environmental pressure in response to the impact of peat extraction on natural ecosystems (Larcher and Scariot, 2009). In Europe, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats, and of wild fauna and flora, protects peat bog ecosystems by rejecting new exploitation licences and restricting extraction from existing bogs. As a result, peat supply in Europe has shifted from Germany to the Baltic countries, detracted from quality in the raw materials and increased transportation distances.

One other environmental argument for restricting exploitation of peatlands is that they are potential sources of atmospheric carbon emissions and hence climate change contributors (Mäkiranta *et al.*, 2010; Bullock *et al.*, 2012). In fact, although peat ecosystems span only about 3% of the earth's surface (Maltby and Proctor, 1996), they account for one-third of all soil in the world (Schaller and Kantelhardt, 2009). Also, their renewal is very slow, with an estimated growth rate of 0.1–10 mm yr⁻¹ depending on the particular climatic conditions (Masaguer *et al.*, 2015).

This scenario has promoted the development of more sustainable substrates, which is paramount for biological systems (Carlile and Coules, 2011). The United Nation's Bruntlan Commission (Anon, 1987) defined "sustainable development" as that fulfilling present needs without compromising the ability of future generations to meet their own. The definition was expanded at the 2005 World Summit (Anon, 2005) by acknowledging that sustainability entails reconciling environmental, social and economic demands. Environmental concern with plant-growing substrates (especially peat-based substrates) has elicited strong reactions by some lobbies —particularly in the United Kingdom— leading to the development of effective peat reduction strategies and the conduct of research into alternative materials (Carlile, 1997). These concerns have been shared with government organizations and considerably influenced domestic policies. One case in point is United Kingdom setting the goal that horticulture should be 90% free of peat by 2010. Such an

ambitious goal was not reached, however, and superseded by a less restrictive one: completely removing peat from retailer markets by 2020 and professional markets by 2030 (Anon, 2010).

The increasing price of quality peat and environmental awareness have led the soilless cropping sector to search for alternative, more sustainable materials for use as growing substrates (Heisnaken, 2013). In Europe, peat is being replaced rather slowly because switching to an alternative material is often very complicated and expensive unless the properties of the new material are very similar to those of peat. For example, materials with a considerably different particle size may damage automatic packaging equipment originally designed for peat or directly render it useless (Barrett *et al.*, 2016)

Especially common among the alternative materials used in the past few decades are some by-products of coconut industrial processing including fibre, chips, peat and powder (Arenas *et al.*, 2002). These materials are very similar to peat in physical properties and easier to rewet (Michel, 2010). The nearness to sea of some coconut plantations has raised the sodium and potassium contents what derives to too high levels that require industrial leaching of the product prior to marketing (Poulter, 2014). This requirement, and the large transportation distances from countries such as the Philippines, Indonesia, India and Shri Lanka (Barrett *et al.*, 2016) to Europe, have considerably raised costs and challenged environmental sustainability.

Pine bark has also been used as a substitute for peat for a long time (Burés, 1997). In fact, it has gradually expanded as a container-growing substrate in southern Europe, southern and eastern United States (Lu *et al.*, 2006; Bilderback *et al.*, 2013), Australia (Handreck, 2011) and New Zealand (Smith, 2008). Pine bark is a by-product of the wood industry. Because, like coconut by-products, it is not produced as a growing substrate, its physical and chemical properties differ markedly depending on its origin and production method (Barrett *et al.*, 2016). In any case, excessively high drainability and a low water retention capacity (Burés, 1997) make bark pine unsuitable for some uses.

Wood fibre is one other replacement for peat. Although it has grown substantially in use in recent years, it has to be mixed with other materials owing to its low water retention capacity and high compressibility (Domeño *et al.*, 2010). An obvious potentially effective

substitute for peat as a growing substrate is compost (Landis and Morgan, 2009), which has grown steadily in use over the past 40 years (Poole, 1970; Sanderson, 1980; Raviv, 2013).

2. Ecological substrates

Spain's Royal Decree 865/2010 constitutes the basic norm for growing substrates and sets the rules for coordination with the country's regional authorities. The decree defines and classifies the growing substrates that can be safely used (i.e., without health and environmental risks) for agricultural, gardening and landscaping purposes. Thus, only the materials fulfilling the following requirements can be used as substrates: (a) enabling efficient plant growth; (b) allowing ready sampling for analysis and testing of quality and properties; (c) having no deleterious effects on health or the environment under normal usage; (d) containing no pests or plant pathogens; and (e) being completely free of weed seeds and propagules.

Sustainable use of natural resources (especially local resources) and minimization of environmental impacts are two of the major goals of organic farming. At present, substrates for organic agriculture are sanctioned by regulatory councils in each Spanish region under the umbrella of EEC Regulation 834/2007 on the production, labelling and control of organic products. The regulation prescribes that only those fertilizers and soil conditioners approved for organic production pursuant to Article 16 can be used in organic agriculture. As per this article, any products and substances to be used as fertilizers or soil conditioners should be of vegetable, animal, microbial or mineral origin unless they cannot be obtained in large enough amounts from their sources, their quality is inadequate or no alternative materials exist. EEC Regulation 889/2008 also allows peat to be used, but only for horticultural purposes (vegetables, flowers, trees, nurseries).

There are various regulations for the award of organic labels. For example, Ecolabelling is a voluntary certification and labelling scheme recognizing environmental performance that currently operates worldwide. Labels and certificates allow consumers to choose products in terms of their environmental merits and hence to reduce environmental impacts through their consumption habits. ISO standards have established three different types of labels or declarations with a view to facilitating reliable communication between society and

enterprises as regards environmentally friendly consumption, namely: ecolabels (Type I, ISO 14024 (1999)), environmental self-declarations (Type II, ISO 14021 (1999)) and environmental product declarations (Type III, ISO 14025 (2000)).

Also, some policies are intended to lighten the environmental burden of waste production by promoting recycling and valorization of residues —which has boosted the use of composts as plant-growing substrates. In 2001, the European Union laid the foundations for award of the EU ecolabel to growing substrates and soil amendments (EU Commission, 2001), and agreed to periodically review the awarding criteria. As a result, it issued a specific norm in 2007 (EU Commission, 2006) and a new one in 2015 (EU Commission, 2015a) that is currently in force for growing media, soil amendments and mulch. Those ecolabels awarded in accordance with former criteria (EU Commission, 2006) were retained for a short time but had to be re-assessed according to the new ones (EU Commission, 2015a). As a result, no growing substrate possesses an ecolabel at present (EU Commission, 2017).

In order to apply for the European ecolabel, the product concerned must meet the requirements for raw materials, hazardous substances, contaminants, nutrient loadings, product performance and product safety. Thus, only those materials containing no peat, and all organic matter in which comes from processed recycled waste, can be awarded the label —which has promoted the use of composts as growing substrates. Also, any candidate materials should have no adverse effect on seed germination or plant growth, contain no specific primary pathogens above established levels, be free of viable weed seeds and propagules, and no contain hazardous elements at levels above their safety thresholds.

The previous criteria have been present in the successive regulations of the European ecolabel for growing substrates and continue to be in force. However, the current regulation (EU Commission, 2015a) has set new requirements for substrates and specified the methods to be used to measure the relevant quality-related parameters. Such parameters include the maximum content in polycyclic aromatic hydrocarbons, and the acceptable limits for individual and mixed substances that are toxic or environmentally hazardous, skin or respiratory sensitizers, carcinogens, mutagens and teratogens as per CE Regulation 1271/2008. The regulation also sets criteria to ensure stability in candidate materials in terms of the respirometric index and the lowest Rottegrad grade, and limits for physical

contaminants, in addition to compelling the determination of dry and organic matter. Also, it sets a limit of $1.0 \text{ dS}\cdot\text{m}^{-1}$ for electrical conductivity in 1:5 (v/v) extracts, down from $1.5 \text{ dS}\cdot\text{m}^{-1}$ in the previous norm.

3. Compost as a substrate component. Quality of compost.

For several decades, compost of diverse origin and properties has been used as an alternative or replacing substrate for sphagnum peat to grow ornamental and forestry plants, cut flowers and horticulture (Abad, 2002; Urrestarazu *et al.*, 2006; Carlile, 2008; Masaguer *et al.*, 2015). In fact, composting is the most widespread method of stabilizing and hygienizing organic by-products in order to valorize organic residues or materials as fertilizers, soil amendments or growing substrate components (Bertoldi *et al.*, 1983; Ansorena *et al.*, 2014).

Compost for container growing is used in pure form or mixed with other materials. Some substrates contain 75–100% compost, whereas others contain only 25% (Carrión *et al.*, 2006; Carmona and Abad, 2008). A number of studies have shown that composting some organic materials and residues provides effective partial (Iglesias-Díaz *et al.*, 2004a; López-López and López-Fabal, 2013; Barrett *et al.*, 2016) or total replacements for peat (Pérez-Murcia *et al.*, 2006; Benito *et al.*, 2005; Abdelrahman *et al.*, 2012).

The range of raw materials explored for use as compost-based substrates include olive oil by-products (Papafotiu *et al.*, 2004, 2005; Sofiadou and Tzortzakis, 2012), sewage sludge (López-López and López-Fabal, 2013; Hernández-Apaolaza *et al.*, 2015), cork by-products (Carmona *et al.*, 2004), depleted compost from mushroom production (Topcuoğlu, 2011; Zhang *et al.*, 2012) and grape marc (Baran *et al.*, 2001). In any case, most compost-based commercial substrates are obtained from green residues or materials (Barrett *et al.*, 2016), particularly those from municipal gardening and horticultural activities (grass cuttings, leaves, trimmed branches) (Carlile, 2008). The properties of the resulting growing substrates vary widely with the origin of the raw materials and commercial composts made from green materials span a broad range of characteristics (Abad *et al.*, 2001, NiChualain *et al.*, 2011).

The wide variety of raw materials used has led to the development of a number of methods for composting and assessing compost maturity and stability (Reinikainen and

Herranen, 2001; Raviv, 2013), which has precluded establishing uniform quality criteria for the end-products (Moore, 2005). Quality and its assessment become especially important when compost is to be directly used a substrate for seedbed or container growing (Moreno *et al.*, 2008) because lacking appropriate physical, chemical or biological properties can render it useless (Carmona and Abad, 2008). Knowing its intended use is essential with a view to accurately assessing its quality (Abad *et al.*, 2008; Masaguer *et al.*, 2015). As can be seen from Table 1.1, the properties of compost dictate to a great extent its use.

The greatest challenges met by producers of compost-based substrates are their high bulk density and the also high transportation costs incurred (Benito *et al.*, 2005; Rainbow, 2009); the high biological instability (Burger *et al.*, 1997), phytotoxicity (Lumis and Johnson, 1982; Hartz *et al.*, 1996), salinity (Raviv, 2013) or pH (Prasad and Maher, 2001; Benito *et al.*, 2005) of some; and an air–water imbalance resulting from unfavourable particle size and distribution in others (Abad *et al.*, 2008). There are also, however, some commercial hindrances such as contamination of the raw materials by —mainly— herbicides (WRAP, 2010), and the presence of sharp bits or human pathogens (Tognetti *et al.*, 2007; Wever and Scholman, 2011).

Table 1.1. Parameters used to assess the quality of compost depending on its intended use.

Parameter	Use			
	Seedbed substrate	Substrate	Organic fertilizer or amendment	Mulch
Response to plant growth	++	++	++	–
Nutrient contents	–	+	+	–
pH/Soluble salts	++	++	+	–
Colour/Odour	++	++	+	+
Presence of inert materials	+	++	–	+
Maturity/Stability	++	++	+	–
Particle size	++	+	+	+

– Scarcely influential + Moderately influential ++ Strongly influential

Source: Sullivan and Miller, 2001

Compost stability is defined in terms of organic matter lability. Thus, compost containing a high proportion of matter that can be easily biodegraded by microorganisms is deemed unstable (Lasaradi and Stetiford, 1998). The maturity of compost, which influences its phytotoxicity and the ability of plants to grow in it (Iannotti *et al.*, 1993), is used to confirm whether it is fit for a given purpose (Brewer and Sullivan, 2001). The phytotoxic effects of immature compost are due to various factors including its contents is ammonium ion and volatile organic acids (Brewer and Sullivan, 2003), in addition to those in heavy metals and salts. At high concentrations, these substances can adversely affect plant growth by inhibiting seed germination or root development. Thus, using immature compost in special nursery substrates can have an adverse impact on plants owing to the presence of intermediate metabolites (Zucconi *et al.*, 1985). In fact, compost to be used as a substrate should be highly stable and mature. For this reason, composting materials for use as substrates usually takes a long time relative to compost for other purposes (Cáceres *et al.*, 2006; Cunha-Queda *et al.*, 2007).

Many organic composts contain high levels of soluble minerals that introduce a high salinity (Abad *et al.*, 2001). Saline composts are unfit for nursery and seedbed production because plants are highly sensitive to the salinity of the growing medium at their early stages of development (Carrión *et al.*, 2005). Also, many composts have an over-optimal pH that diminishes the availability of nutrients —particularly micro elements (Abad *et al.*, 2001). The alkaline nature of these composts is due to the presence of substantial amounts of carbonates, high concentrations of exchangeable cations (especially Ca^{2+} and Mg^{2+}) or a low proton concentration in the exchange complex (García de la Fuente *et al.*, 2007; Carrión *et al.*, 2008).

Organic materials usually possess a high ion-exchange capacity that prevents leaching of cations. This property is especially useful with background and coverage fertilization or intermittent fertirrigation, but not with continuous fertirrigation (Masaguer *et al.*, 2015) —or even undesirable for hydroponic cultivation.

Particle and pore size distribution govern the balance of the water and air contents in a compost-based substrate at any moisture level and are thus very important (Abad *et al.*, 2004, Noguera *et al.*, 2003). Materials with average particle and pore size smaller than 0.25

mm and 30 μm , respectively, are deemed fine, whereas those with an average size exceeding 0.9 mm and 100 μm , respectively, are deemed coarse (Masaguer *et al.*, 2015). Fine materials retain large amounts of scarcely available water and are poorly aired, whereas coarse materials have the opposite properties. As a result, fine materials occasionally cause root hypoxia, especially in shallow containers (Abad *et al.*, 2008). On the other hand, coarse materials can cause water stress in crops by effect of the hydraulic conductivity of the substrate decreasing as it dries (Abad *et al.*, 2008). The most suitable particle size distribution for a growing substrate depends mainly on container size and on the particular species to be grown, but also, to a lesser extent, on crop duration. As a rule, the most suitable growing substrates have a medium to coarse texture (*viz.*, an average particle size of 0.25–2.50 cm) (Raviv *et al.*, 1986; Abad *et al.*, 1993; Puustjärvi, 1994), whereas compost usually consists of coarse or very coarse particles (Abad *et al.*, 2001).

Odour and colour are also often used to assess compost quality. Thus, although odour is subjective, it can confirm that compost is at an early maturation stage or has been exposed to anaerobic conditions (Moreno *et al.*, 2008). Off-odours in immature compost are due to the decomposition of organic acids (acetic, propionic, butyric) early in the bio-oxidative stage (Costa *et al.* 1991). Under anaerobic conditions, off-odours are due to the formation of ammonia and hydrogen sulphide. The decomposition of fresh materials causes them to acquire a dark brown to blackish colour depending on the characteristics of the starting material; thus, green residues lead to a dark (black) colour, whereas manure gives rise to brown hues (Moreno *et al.* 2008).

4. Improving the properties of compost-based substrates

Compost that is mature and stable enough, hygienic, and neither phytotoxic nor environmentally hazardous, may still be unfit for use as a plant-growing substrate owing to its having (a) a small or very small particle size, (b) an alkaline pH, (c) high contents in soluble minerals —and hence a high salinity— and (d) a tendency to easily fix nitrogen (Abad *et al.* 2008).

Selective screening is an effective method for composts containing different grain size fractions from very fine to very coarse, which can influence crops in also different manners

(López-Fabal *et al.*, 2008; Masaguer *et al.*, 2015). Alternatively, those materials can be mixed with others for the same purpose (Blythe and Merhaut, 2007; Atland, 2010). Thus, fine compost can be mixed with others possessing complementary physical properties (so-called “structuring agents” such as rice husk or tree bark) (Carmona and Abad, 2008). On the other hand, coarse substrates can be mixed with materials possessing a high water retention capacity or with physical conditioners such as superabsorbents (López-Fabal *et al.*, 2011).

As with peat, an unsuitable pH in compost should be corrected before it can be used as a growing substrate (Raviv, 2011). Compost with too high a pH can be mixed with neutral materials, acid peat or an acid amendment such as micronized sulphur, aluminium sulphate or iron sulphate —which are oxidized or hydrolysed to sulphuric acid (Black and Zimmerman, 2002; Abad *et al.*, 2008; Atland, 2010). These compounds neutralize carbonates and replace most exchange bases. On the other hand, compost with too low a pH can be treated with liming amendments (Lemaire *et al.*, 2003) such as active lime forms (calcium oxide or hydroxide), natural limestone (calcium carbonate, dolomite) or some calcium-rich industrial by-product. It should be noted that an organic material with a high cation-exchange capacity such as compost possesses a high buffering capacity and hence a flatter neutralization curve than an inert material. This property makes it rather difficult to alter compost pH during plant growth (Masaguer *et al.*, 2015).

Excessive salinity in compost can be alleviated by mixing with a non-saline material (Masaguer *et al.*, 2015) or by leaching (Urrestarazu *et al.*, 2001; Carrión *et al.*, 2005); the latter method additionally reduces phytotoxic hazards (Aviani *et al.*, 2010). Compost can be leached in various ways to remove excess soluble salts (Abad *et al.*, 2008), namely: (a) prior to preparation of the growing substrate; (b) in the container, by repeated irrigation with water or a nutrient solution prior to plant growing; and (c) by irrigating the plants throughout the growing period (especially in shallow containers). However, these corrective actions raise economic and environmental costs owing to the need to recycle the resulting leachates (Jarecki *et al.*, 2005).

One other typical constraint of vegetable starting materials (particularly lignocellulosic materials such as tree bark, wood fibre, cork residues or saw dust) is that they tend to fix nitrogen, especially if they are inadequately composted (Ortega *et al.*, 1999). In fact, roots

have to compete with microorganisms in compost for available nitrogen. The microbes easily decompose biodegradable organic under mineral nitrogen-limiting conditions, thereby causing a nitrogen deficiency that leads to impaired plant growth and production (Abad *et al.* 2008). Nitrogen fixation in immature compost poses a serious problem, especially when the raw materials are poor in nitrogen. The problem, however, can be avoided by using raw materials with an appropriate C/N ratio for increased compost stability; alternatively, the adverse effects on plants can be prevented by applying nitrogen fertilizer to the compost (Stoffella and Kahn, 2005).

5. Objectives

The increasing social concern with the environmental impact of non-renewable materials such as peat has promoted a search for alternative, sustainable growing substrates of local rather than distant origin. The forests in Galicia (NW Spain) can provide large amounts of as yet unexploited resources whose valorization may provide enormous environmental benefits. This general objective of this doctoral work is specified in three different objectives that are developed in the following three chapters:

1.- Obtain gorse compost suitable for use as growing media by

- composting the raw material and monitoring the process in order to examine the influence of the variables potentially affecting its outcome on the characteristics of the end-product;
- characterizing the resulting composts for use as substrates in organic agriculture, and
- assessing them as candidates for award of the Community ecolabel for growing substrates.

2.- Assess the composts as substrate in organic crop production by

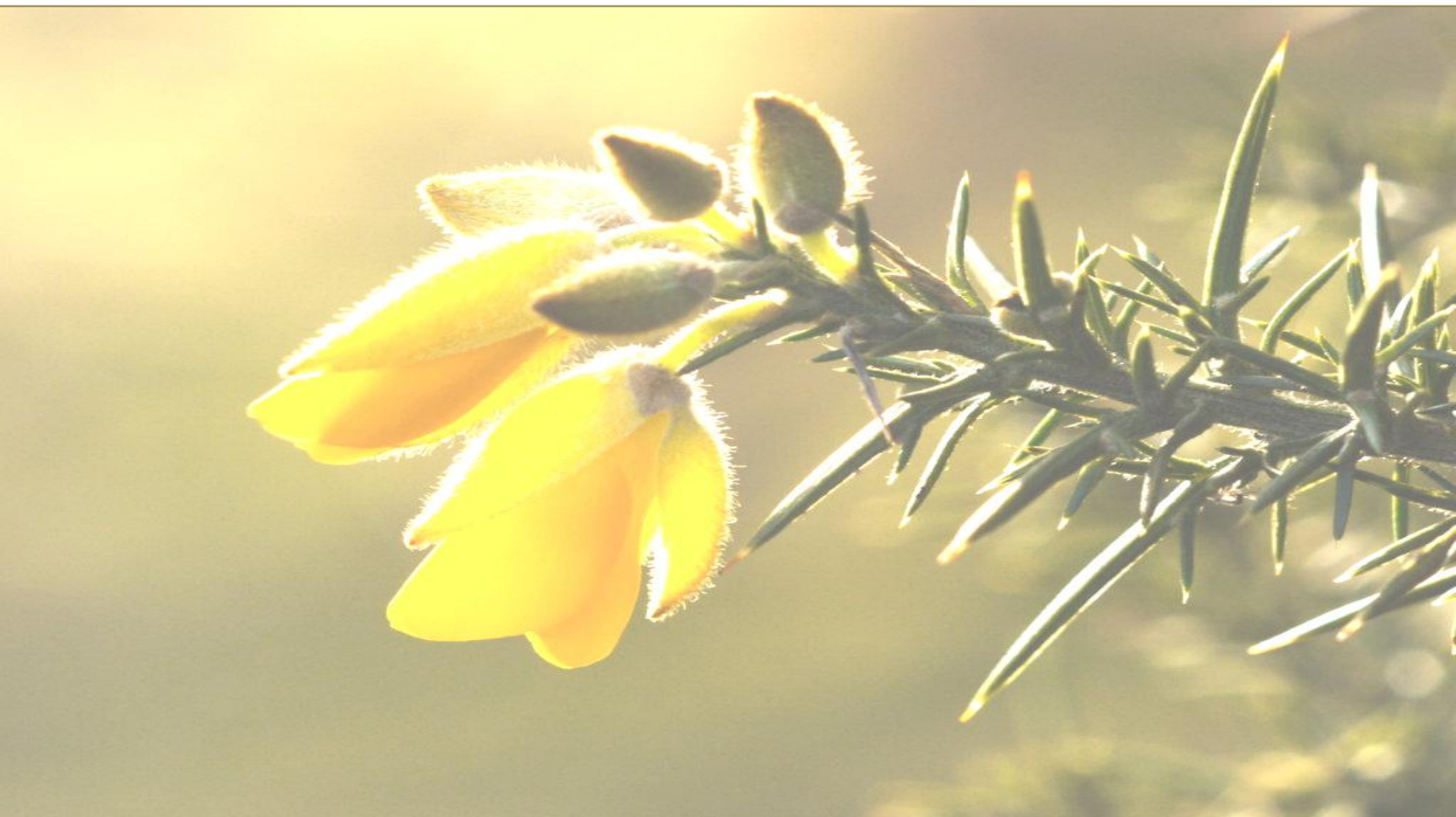
- examining the performance of the composts during a container-based organic growing;
- evaluating the capacity to supply nutrients along the crop cycle, and
- assessing the agronomic response of a container-grown crop to the composts.

3.- Evaluation of the suppressiveness capacity of gorse compost by

- assessing the ability of various compost-based substrates to suppress a quarantine pathogen in seedbeds; and
- examining the suppressive response of various compost-based substrates to inoculation of seedbeds with a control agent.



CHAPTER II: Compost Based Ecological Growing Media According EU Eco-label Requirements



*Addapted from

López-López, N., López-Fabal, A., 2016. Compost based ecological growing media according EU eco-label requirements. *Sci Hortic-Amsterdam* 212: 1-10.

CHARTER II: COMPOST BASED ECOLOGICAL GROWING MEDIA ACCORDING EU ECO-LABEL REQUIREMENTS*.

Abstract

Green compost is seen as one of the best solutions for peat replacement in growing media and for increasing their sustainability. However, the poor quality of many composts has restricted their use as substrate components. The EU Ecolabel may be awarded to products and services that have a reduced environmental impact throughout their life cycle. It is voluntary and ensures certain aspects of the origin and quality. The primary aim of this work was to obtain a gorse compost-based substrate fulfilling the requirements for award of the eco-label.

Forest biomass consisting mainly of gorse was composted in dynamic piles with or without irrigation (I) at the beginning and with or without addition of 5% v/v poultry manure (PM). There were thus four different composting treatments that were designated PM0I, PM5I, PM5 and PM0. Temperature, moisture, pH and the C/N ratio of the composting biomass were monitored over a period of nearly 10 months. The resulting composts were characterized in physical, chemical and biological terms, and evaluated for compliance with the requirements of the European Union eco-label for growing media. All composts were found to be mature, stable and pathogen-free. All of them were suitable for use as growing media, exhibiting a high aeration and drainage capacity, little water retention and adequate level of available nutrients. In general they also met the requirements of the EU eco-label, although not all were weed seed-free, which was possibly the sole unfulfilled EU eco-label requirement.

Key words: Substrate, poultry manure, forest biomass, gorse, *Ulex europaeus* L

Highlights

Growing media based on gorse compost fulfilling EU-ecolabel requirements was obtained.

All the composts obtained were mature and stable enough and were properly sanitized.

The piles containing manure reached higher temperatures than those not containing it. The composts had a high aeration and drainage capacity but little available water. Windrows should be enough isolated to avoid re-infestation by weed seeds.

1. Introduction

Whether alone or in mixtures, peat is the substrate most commonly used in horticulture to grow seedlings and soilless plants. But quality peat is a scarce resource in southern Europe, where there is a significant soilless crop production sector. Peat must therefore be imported from northern and central Europe and recently has become more expensive (*Ribeiro et al.*, 2007), but resort to low cost products involves problems of quality and heterogeneity. In addition, peat is a very slowly renewable natural resource and its exploitation entails C emissions which could greatly influence climate change (*Boldrin et al.*, 2010), so environmental pressure against its extraction has risen.

In response to these concerns and the need for efficient recycling of wastes, the EU Commission (2006) has established the ecological criteria for the award of the Community's eco-label to growing media. The EU Ecolabel is a voluntary scheme promoting environmental excellence which can be trusted. It may be awarded to products and services that have a reduced environmental impact throughout their life cycle, from the extraction of raw material through to production, use and disposal. To apply for the European Eco-label the products have to meet requirements for raw materials, hazardous substances, contaminants, nutrient loadings, product performance and product safety.

A growing media shall only be considered for the award of the eco-label if it does not contain peat and its organic matter content is derived from the processing and/or re-use of waste. In the organic constituents content of heavy metals (Zn, Cu, Ni, Cd, Pb, Hg and Cr) is limited, and also other hazardous substances (Mo, Se, As and F) for products containing materials from industrial processes. Products have to show low level of primary pathogens (absence of salmonella and helminth ova and *E. coli* <1000 MPN g⁻¹) and of viable weed seed/propagules (<2 units L⁻¹). Besides, growing media must not adversely affect plant emergence or subsequent growth and its electrical conductivity must not exceed 1.5 dS m⁻¹.

Although it will not be the sole solution, green compost has an important role to play in peat replacement or the transition to sustainable growing media. However some users of growing media have never had confidence in the use of green compost and others have had their confidence in its use dented through past use of poor quality compost (Knight, 2012). Lack of uniformity, less-than-optimal physical properties, high salinity, low pH, occasional phytotoxicity and threats as human or plant pathogens are the most frequent constraints of green compost to be used as growing media component (Raviv, 2013). Therefore quality assurance is key to promote the inclusion of compost in substrates and progress in reducing the use of peat.

The literature abounds with studies on the potential of various types of compost as growing media and nutrient sources (Fiasconaro *et al.*, 2015; Papafotiou *et al.*, 2004) the best among which might fulfil the EU eco-label requirements. However, none of the 63 substrates currently holding the eco-label consists solely of compost; also, pine bark-based substrates aside, those containing any compost account for less than 10 % of all (EU Commission, 2015).

Organic residues successfully used as growing media include compost from green waste such as pruning (Aleandri *et al.*, 2015; Benito *et al.*, 2005; Morales-Corts, 2014,) or forestry cleaning residues (Ribeiro *et al.*, 2007). Galicia, a region in NW Spain, has a number of forest areas abounding with scrub bush largely consisting of gorse (*Ulex europaeus* L.). Although gorse originated in central and western Europe, and the British Isles, it is also present in North America, New Zealand and Australia, where it was introduced as an ornamental plant and now occupies large areas and is considered a highly invasive species. It is therefore a material available in good quantities around the world. The aim of this work was to obtain a gorse compost-based substrate fulfilling the requirements for award of the European Union eco-label.

2. Material and methods

2.1. Composting process

Forest scrub was used to obtain four different composts. The shrubs, consisting mainly of 4-5 year's old gorse (*Ulex europaeus* L.) plants, were collected and chopped with a flail

forage harvester. An experimental design consisting of two factors at two levels each was used. The two factors were irrigation (I) at the beginning of the process and the addition of 5% (v/v) poultry manure (PM) from an organic egg producing farm. The addition of manure was intended to facilitate the process by lowering the C/N ratio to about 30 at the start, and also to increase nutrient levels in the end-product. A proportion of 5 % (v/v) was thought to suffice in order to fulfil both aims while reducing the risk of too high salinity in the composted material. Irrigation was intended to increase moisture and reduce salt contents as far as possible in the starting gorse. Layers of the material 25 cm thick received 175 L m⁻² of tap water and then were left to drain two days. There were thus four different treatments, namely: PM0I (irrigation without addition of PM), PM5I (irrigation plus addition of PM), PM5 (addition of PM but no irrigation) and PM0 (no irrigation neither PM).

Composting was started in July and followed by maturation. The overall process thus lasted 9 months. Piles were frustoconically shaped and approximately 6 m³ in volume and 2 m high. They were mechanically turned over about once a month at the beginning and every 2 months later. Moisture was maintained by hose irrigation beginning two weeks after the start of the experiment; and the piles were covered during the periods of increased precipitation. Pile temperature was measured at three different depths (0.2, 0.4 and 0.6 m) by inserting a thermometer through a side of the pile-roughly at the middle of total height-to the centre.

2.2. Laboratory analyses

2.2.1. Analysis of raw materials

The materials examined included the gorse before and after irrigation, and the poultry manure. pH was measured in their saturation extracts and moisture contents by oven drying at 105 °C to a constant weight. The total contents in C, N and S were determined with a LECO TruSpec CHNS autoanalyzer and those in Ca, Mg, Na, K and P by ICP-OES after digestion of finely ground samples of each material with HNO₃ (USEPA, 1995).

2.2.2. Monitoring of the composting process

Samples were periodically obtained from the piles to determine pH, electrical conductivity (EC), moisture content, and total C and N. EC and pH were measured in the saturation extracts, moisture content was determined by oven drying, and total C and N by using the LECO TruSpec CHNS autoanalyzer.

2.2.3. Characterization of the final compost

The obtained composts were fully characterized prior to use as growing media. A representative portion of each compost pile was sieved to 6 mm and transferred to the laboratory for comprehensive physical, chemical, physico–chemical and biological analyses with a view to assessing the potential of the composts for organic agriculture.

2.2.3.1. Physical properties

The specific physical properties determined were the moisture retention curve (De Boodt *et al.*, 1974), total porosity, bulk density, particle density and shrinkage value (EN-13041,1999), compacted bulk density (EN-13040, 2007) and particle size.

2.2.3.2. Chemical and physico–chemical properties

EC, pH and soluble elements were assessed in both saturation extracts and 1:5 (v/v) extracts (EN-13652, 2001). Also, C and N were determined as described in Section 2.1, and the total content in Ca, Mg, K, P, Cr, Cu, Cd, Pb, Zn, Hg and Ni were determined by ICP-OES after digestion with HNO₃ (USEPA, 1995). The organic matter and ash contents (EN-13039: 1999), and the stability of organic matter (Saña *et al.*, 1989), were also determined.

2.2.3.3. Biological properties

Compost maturity was assessed via the germination bioassay of Emino and Warman (2004) with slight modifications. To this end, 20 lettuce seeds (*Lactuca sativa* var. Reina de Mayo) were sown in Petri dishes between pieces of filter paper moistened with 6 mL of aqueous 1:10 (w/w) extract, using distilled water as control and four repetitions per

treatment. The dishes were placed in the dark at 20 °C for 3 days, after which the number of germinated seeds in each was counted and root lengths were measured. The germination index (GI) was calculated as the product of the mean number of germinated seeds by the mean root length, both of them relative to the control (Zucconi *et al.*, 1981).

A germination–growth bioassay was also conducted by using barley (*Hordeum vulgare* var. Scarlet) in accordance with the guidelines of FCQAO (1994). All composts and their 75/25, 50/50 and 25/75 % (v/v) mixtures with white sphagnum peat were tested, the peat being used as control (0 % compost). Four 450 mL pots per treatment were prepared and 50 seeds sown in each. After 12 days in a growth chamber, the number of germinated seeds was counted and the fresh and dry weight of the aerial part of the plants measured.

Trays containing 1 L of substrate each were allowed to stand under controlled light and temperature conditions for 1 month prior to counting germinated seeds. The amount of microorganisms for which the EU Commission (2006) has set limits in plant growing media (viz. salmonella, helminth eggs and *E. coli*) was also measured.

2.3. Statistical analysis

The two principal components (independent variables) examined were (a) wetting of the ground gorse material before piling and (b) the addition of poultry manure mixed with gorse in a 5% (v/v) proportion. The variation of the target parameters during the composting process was examined by using a Repeated Measures General Linear model with date as the between-subject variable. The characteristics of the composts obtained were processed by using Multivariate Analysis of Variance (MANOVA) for statistical analysis and Tukey's test for post-hoc analysis. Those differences between data pairs with a probability in the statistic *F* less than 0.05 were assumed to be significant. Data normality was previously confirmed in terms of the Kolmogorov–Smirnov test and variance homogeneity as determined with Levene's comparison test. All statistical calculations were done with the software PASW Statistics 18.

3. Results and discussion

3.1. Characterization of raw materials

The composition of the raw materials is shown in Table 2.1. The gorse was more acidic (pH = 5,5-6) than that used in previous compost test (Brito et al., 2010) and also than most of the green waste used for composting (Belyaeva and Haynes, 2010; Belyaeva *et al.*, 2012), which tends to be neutral, or even than other more lignified materials such as pruning residues (Estévez-Shwarz *et al.*, 2012). Also, the gorse exhibited a high C/N ratio typical of a lignified green waste and exceeding the typically accepted levels for composting (Jhorar *et al.*, 1991). Its chemical composition was comparable to that of gorse used as a bulking agent for composting (Brito *et al.*, 2010), but poorer in N and, overall, poorer in nutrients than that of younger, less lignified gorse used as feed (Lambert *et al.*, 1989). Irrigating it prior to composting raised its pH slightly but caused no substantial changes in total element contents, even though it increased the C/N ratio somewhat as a result of the loss of soluble substances lowering the N content and slightly raising the C content.

Table 2.1. Composition of the raw materials.

	IG	DG	PM
Moisture (g g⁻¹)	0.62	0.47	0.39
pH	5.99	5.51	6.88
C (g kg⁻¹ dm)	484.0	478.0	215.5
N (g kg⁻¹ dm)	11.4	13.3	23.1
C/N	42.48	35.94	9.33
S (g kg⁻¹ dm)	1.08	1.25	1.45
P (g kg⁻¹ dm)	0.38	0.44	14.25
K (g kg⁻¹ dm)	5.13	6.80	9.34
Ca (g kg⁻¹ dm)	1.80	2.09	40.68
Mg (g kg⁻¹ dm)	0.92	0.88	5.06
Na (g kg⁻¹ dm)	1.08	1.23	2.97

IG = irrigated gorse, DG = dry gorse, PM = poultry manure. Mean values. pH in saturation extract and all elements on a dry matter basis.

The poultry manure was near-neutral and had higher element contents —C excepted— than the gorse; such contents, however, were lower than those of materials used by other authors, possibly because of its increased proportion of pine shaving bedding. Based on the densities of the starting materials and on their moisture contents at the time the mixtures were prepared, adding 5 % v/v poultry manure led to a mixture of approximate composition 70:30 dry weight. Therefore, the initial C/N ratio in the mixtures containing PM was 28–32.5 depending on whether irrigated or dry gorse was used. These ratios are similar to the target value (30) and fall within the optimum range established at the beginning of the composting process: 25–35 (Jhorar *et al.*, 1991).

3.2. Monitoring of the composting process

3.2.1. Temperature

Figure 2.1 shows the variation of the temperature at different depths in the composting piles (20, 40 and 60 cm). The highest temperature was recorded after 25 days in all treatments. The composts reaching the highest temperatures (> 60 °C at depths > 40 cm) were those that were previously irrigated (PM0I and PMI). The factor irrigation was significant at the depths 20 cm ($p = 0.018$) and 40 cm ($p = 0.040$). The piles initially wetted reached higher maximum temperature than the corresponding ones without initial irrigation. Although the natural moisture content of dry gorse may suffice for composting under some circumstances (Bueno *et al.*, 2008), there is wide consensus that it should exceed 50% (Tiquia *et al.*, 1996; Walker *et al.*, 1999). In this work, moisture was a determining factor by effect of the strong evaporation at the beginning of the composting process —which led to a more marked effect at lower depths.

The piles containing poultry manure (PMI5 and PM5) reached higher temperatures in the thermophilic phase than those not containing it (PM0I and PM0) ($p = 0.037$ for period 7-26 days). The difference reached 8 °C between treatments with initial irrigation (PM0I and PM5I). Also, the thermophilic phase ($T^a > 45^\circ\text{C}$ at 60 cm depth) was shorter in the manure-containing piles (60 vs 90 days) as a result of the latter having a higher proportion of readily microbe-available labile organic matter, and hence facilitating metabolic activity (Hassen *et al.*, 2001) and a more rapid depletion of the labile organic substrate. Temperatures above

55° C for more than 3 days reduce and may even eliminate pathogen, thus ensuring the safety of the material (USEPA, 2003).

Pile temperature equilibrated with ambient temperature after about 200 days. This is consistent with previous results of Belayaeva and Haynes (2010) for the composting of green waste, and co-composting of green waste and chicken manure.

3.2.2. Moisture

The initial moisture contents in the four piles ranged from 40 to 60% and levelled off at 50-60 % at the end of the composting process (Fig. 2.2a). The irrigated piles exhibited an increased moisture only at the beginning, after which the moisture content was primarily dependent on the amount of water received. Overall, the piles containing no manure (PM0 and PM0I) retained more water, whether from irrigation or precipitation, and remained significantly wetter ($p = 0.019$). In fact, their moisture levels were occasionally too high (> 60 %) and could limit aeration and microbial activity (Bueno *et al.*, 2008, Tiquia *et al.*, 1996) during the winter (after day 140) owing to the supply of rainwater and low evaporation even though the piles were covered during the rainiest periods. On the other hand, moisture in the piles containing poultry manure increased during the winter but never reached too high levels.

3.2.3. pH

The pH of the raw materials, which initially exceeded 5, rapidly increased to near-neutral values but later decreased again to acid levels (Fig. 2.2b). The initial pH need not have inhibited microbial activity on organic matter (Plana, 2009), since composting shredded leafy branches of pH < 5 has been found to give a product with a near-neutral pH (Bakry *et al.* 2011). The presence of poultry manure resulted in significant differences ($p = 0.002$); in fact, the piles containing it exhibited a higher pH than those excluding it throughout. Initially, differences were slight (roughly 1), and due to the increased N content and more marked release of ammonia through decomposition. After 140 days, however, the piles containing no poultry manure exhibited strong acidification ($p = 0.001$) and their pH was about 2 points lower than in the piles containing manure. The difference can be ascribed to excessive

moisture in the piles containing no manure leading to anoxic conditions. Compost can occasionally undergo strong acidification by effect of the anaerobic conditions and the accumulation of short-chain fatty acids; these acids tend to lower the pH of the medium to an extent proportional to the importance of anaerobic processes occurring in the composting mass (Plana, 2009).

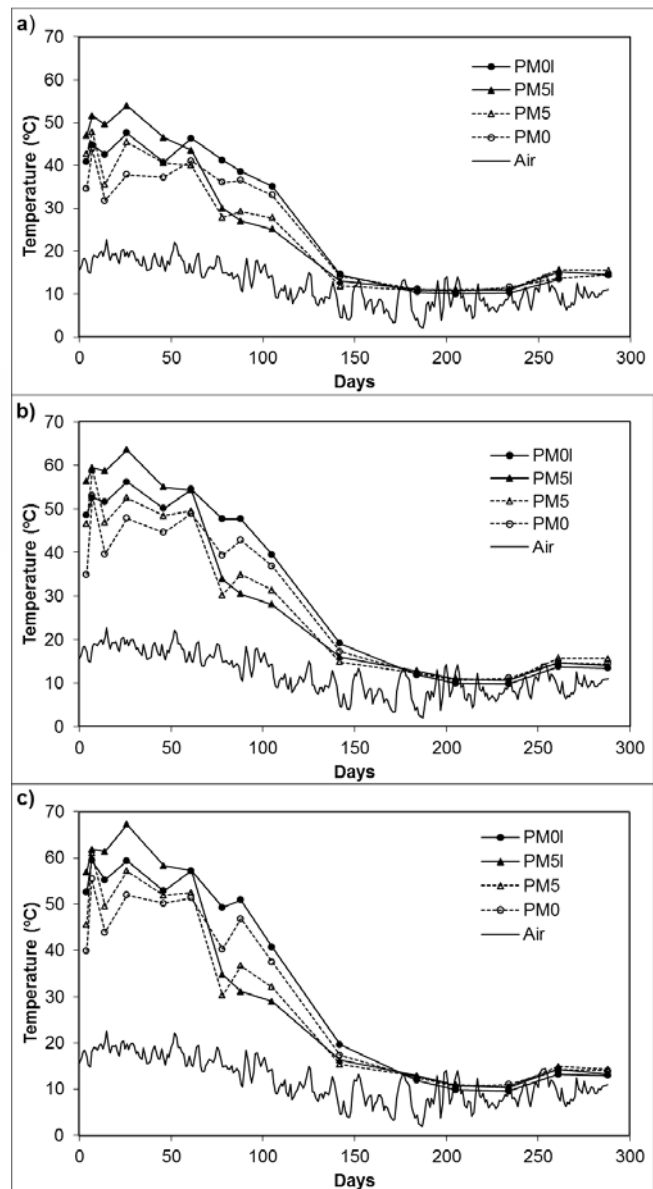


Fig.2.1. Variation of temperature (°C) in the air and inside the compost piles during the composting process. Depth: (a) 20 cm, (b) 40 cm and (c) 60 cm. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

3.2.4. Organic matter, N and C/N

The release of CO₂ reduced the organic matter content of the materials considerably during composting (from 690 to about 390 g kg⁻¹ d.m. in the piles containing poultry manure and from 830 to 540 g kg⁻¹ d.m. in those excluding it) (see Tables 2.1 and 2.3). The materials also lost some N; however, the increased concentrations resulting from the loss of organic matter led to increased N contents in the composts (about 20 g kg⁻¹ d.m.) (Table 2.3) relative to the starting materials (1.1–1.6 g kg⁻¹ d.m. depending on the particular treatment) (Table 2.1).

The losses of organic matter and N from the piles during composting were calculated from the contents at the beginning (OM₀, N₀) and at each sampling date (OM_i, N_i), using the methodology of Paredes et al. (2000) and the equations:

$$\text{OM-loss} = \text{OM-lost} / \text{OM-initial} = 1 - [(1-OM_0) OM_i] / [(1-OM_i) OM_0]$$

$$\text{N-loss} = \text{N-lost} / \text{N-initial} = 1 - [(1-OM_0) N_i] / [(1-OM_i) N_0]$$

As can be seen from Fig. 2.2d, organic matter losses were accurately fitted to a two-fraction first-order kinetic model (Molina *et al.*, 1980) based on the equation:

$$\text{OM-loss} = OM_1 (1-\exp(-k_1t)) + OM_2 (1-\exp(-k_2t))$$

where OM_1 and OM_2 denote maximum degradation of organic matter in each of the two fractions, k_1 and k_2 are the respective mineralization rate constants (days⁻¹), and t is the composting time (days)

Overall, composting resulted in the loss of about 77% of the initial amount of OM present irrespective of treatment (Fig. 2.2 d). This proportion is high relative to previously reported values (Paredes *et al.*, 2000; Brito *et al.*, 2010). Despite converging on the same final value, in a first stage unirrigated piles (PM5 and PM10) lost less OM than irrigated piles (PM5I and PM0I), which exhibited a near-zero OM lost between days 14 and 46. This result suggests that the initial moisture content of the unirrigated piles was inadequate and restricted composting during that period, where the materials had only available their initial moisture.

The models obtained help to explain the behaviour of the composting process relating it with the parameters previously studied. The second term of the equation (OM_2 , k_2)

correspond to the most labile fraction of the OM ($k_2 > k_1$) which is intensely mineralized in the first stage of the process increasing the thermophilic phase; it accounted for the 30-38 % of the initial OM. Whereas the first term (OM_1, k_1) correspond to a more mineralization-resistant fraction of the OM which is mineralized more gradually along the process and it was the 40-47 % of the initial OM.

The statistical comparison of the fittings according to the procedure described by Pérez-Cruzado *et al.* (2015) and using the α -trimmed mean test and the Wilcoxon signed-rank test showed that the model obtained for treatment PM5I (with PM and initially irrigated) was significantly different ($p < 0.04$) to that of PM0I (without PM and irrigated) and these two were significantly different ($p < 0.04$) to those of unirrigated treatments (PM5 and PM0), which were equivalents ($p > 0.50$). Also these unirrigated piles exhibiting a lower regression coefficient than the irrigated ones and, in fact, no two distinct OM fractions were identified because k was identical for both ($k_1 = k_2$). This clearly reflects that the lack of water in the first stage limited the degradation of the most labile OM in the unirrigated piles and it was the major determinant of the process, preventing any effect of the addition of PM. By contrast, in piles initially irrigated, without such limitation, the manure contributed to the labile fraction so the degradation of OM in the first phase increased.

Nitrogen was lost throughout and losses amounted to 45% of the initial content, with no differences between treatments (results not shown). The amount of N lost through decomposition was much smaller than that of C lost as CO_2 ; as a result, the C/N ratio decreased during the process (Fig. 2.2c). The initial C/N ratio differed markedly between piles: it peaked in the absence of manure (PM0 and PM0I) and the irrigated piles had higher values than corresponding ones without initial irrigation. However, the ratio decreased as soon as composting was started, albeit more abruptly in the irrigated piles by effect of increased metabolic activity in them. As a result, the ratio in the irrigated piles fell below that in the unirrigated piles within 2 weeks. The index levelled off after about 100 days, with final values of 11-16, indicating a high degree of stabilization was achieved (Sanchez-Monedero *et al.*, 2001). Then the initial differences between the piles with and without PM remained ($p = 0.016$), but those due to irrigation did not ($p = 0.823$).

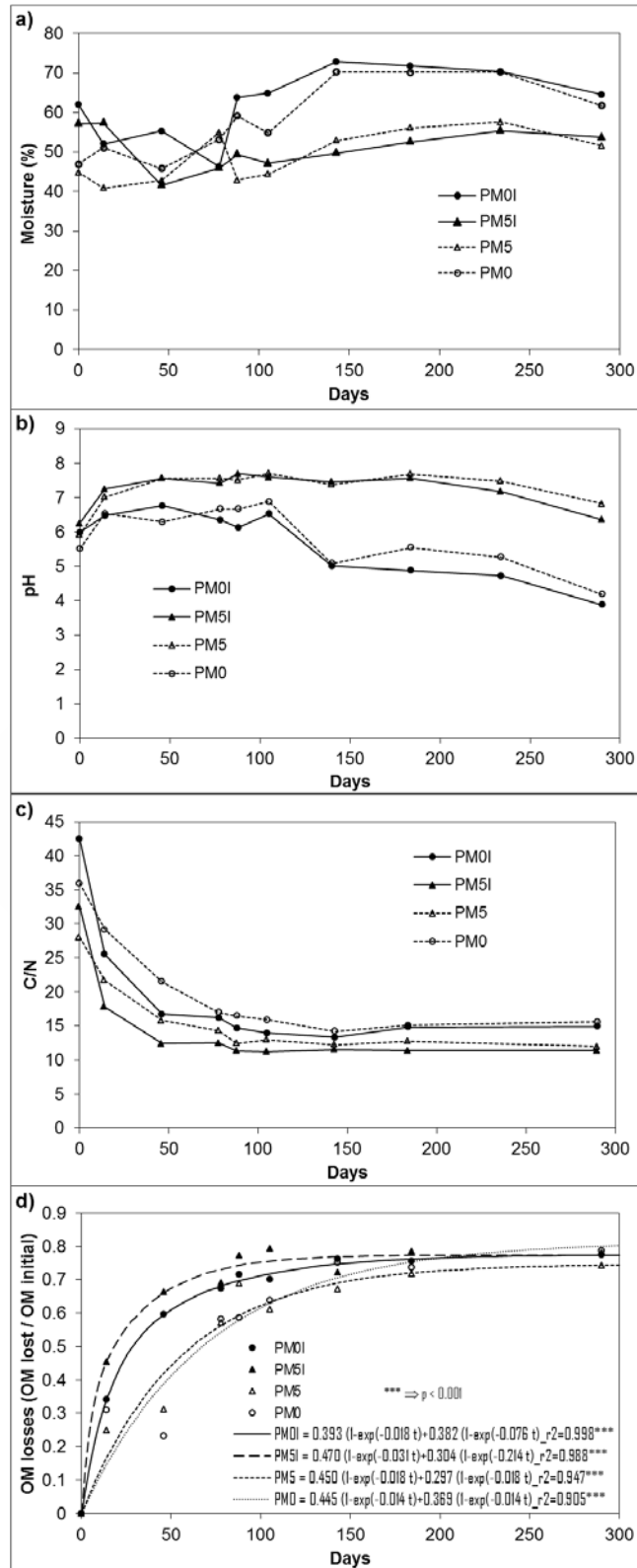


Fig. 2.2. Variation of (a) moisture (%), (b) pH, (c) C/N ratio and (d) losses of OM during the composting process. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

3.3. Characterization of composts

3.3.1. Physical properties

Figure 2.3 shows the grain size distribution of each compost after sieving through 6 mm mesh. As a rule, the predominant fractions were those 2–5, 1–2 and 0.5–1 mm in size, which jointly accounted for 60–70% of the total material weight. Grain size distribution is the key to pore size distribution in the solid, porous matrix of this substrate, which in turn influences air–water relationships and other physical properties (Noguera *et al.*, 2003). The most suitable grain size for an adequate air-water balance in growing media is equivalent to the 0.25–2.5 mm fraction (Abad *et al.*, 1993). The high proportion of coarse grains (> 1 mm) in the four composts (Fig. 2.3) was responsible for their high porosity (> 86.7 %) and for the presence of an also high proportion of non-capillary pores (macropores) (Abad *et al.*, 2001), which caused materials possessed a high aeration capacity (AC > 40 %) but retained small water volumes even at very low pressures (<1 kPa) (Table 2.2). Mean values of *R* (viz. the pressure at which the water and air contents of the substrate were identical) were lower than 1 kPa in the four piles, which is also indicative of substrates highly aired but containing little easily available water (De Boodt *et al.*, 1974).

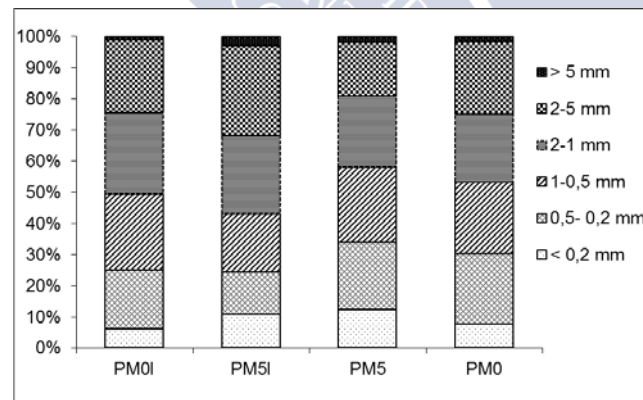


Fig. 2.3. Particle size distribution of the composts. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

Table 2.2. Physical properties of the composts.

	PM0I	PM5I	PM5	PM0	Optimum ¹
BD (g cm⁻³)	0.18 ± 0.00 c	0.27 ± 0.00 a	0.25 ± 0.00 b	0.18 ± 0.01 c	<0.4
PD(g cm⁻³)	1.9 ± 0.0 b	2.1 ± 0.0 a	2.1 ± 0.0 a	1.9 ± 0.0 b	1.45–2.65
S (% v/v)	17.7 ± 1.6 a	18.1 ± 4.7 a	20.4 ± 1.6 a	16.4 ± 0.8 a	<30
TP (% v/v)	90.1 ± 0.2 a	86.9 ± 0.3 c	88.1 ± 0.2 b	90.5 ± 0.3 a	>85
AC (% v/v)	48.8 ± 1.5 a	49.7 ± 1.5 a	44.8 ± 0.4 a	48.7 ± 1.7 a	10–30
EAW (% v/v)	10.0 ± 0.6 c	9.8 ± 0.7 c	13.1 ± 0.4 a	11.5 ± 0.3 b	20–30
WBC (% v/v)	2.4 ± 0.1 ab	2.2 ± 0.1 b	2.51 ± 0.1 a	2.62 ± 0.1 a	4–10
UW (% v/v)	28.9 ± 0.8 a	25.2 ± 0.4 b	27.7 ± 0.1 a	27.7 ± 1.3 a	
R (kPa)	0.9 ± 0.0 b	0.9 ± 0.0 b	0.9 ± 0.0 b	0.9 ± 0.0 ab	1–3

PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

BD = Bulk Density; PD = Particle Density; TP = Total Porosity; S = Shrinkage Value; AC = Aeration Capacity; EAW = Easily Available Water; WBC = Water Buffer Capacity; UW = Unavailable Water; R = suction that equalizes the water and air contents

¹ Optimum values for an ideal substrate (Abad et al., 1993; Abad et al., 2001; Noguera et al., 2003).

Mean values ± SD and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at $p < 0.05$.

Based on the foregoing, the composts had a high total porosity and aeration capacity, as well as a too low proportion of available water in relation to the ideal substrate. These results are consistent with those reported by Díaz *et al.* (2008) for gorse compost and those of Benito *et al.* (2005) for pruning waste compost. With AC > 20%, the substrates are suitable for epiphytic plants such as bromeliads or azaleas. Their low water availability would require their frequent, mild irrigation to ensure adequate amounts of plant available water and also to reduce drainage and its associated loss of nutrients. Since the amount of water retained by a given volume of substrate depends on the container height (Wallach, 2008), these substrates can be effectively used in containers less than 10 cm tall, where adequate aeration can be ensured. Besides, these composts can confer porosity and drainability to potting mixes, and they are suitable to be combined with materials with a good water retention capacity.

The particle density (d_p) of the substrates ranged from 1.9 g cm⁻³ for those containing no poultry manure to 2.1 for those containing it; the difference can be ascribed to the increased mineral content of the manure. According to Abad *et al.* (1993), the bulk density (d_b) of a growing media should be less than 0.4 g cm⁻³; but potted plants of large size or

under relatively strong wind require densities of up to 0.5–0.75 g cm⁻³ (Ballester-Olmos, 1993). As can be seen from Table 2.2, all of the substrates had $d_b < 0.25$ g cm⁻³, suitable for small plants grown in small pots. Also, the shrinkage values for the substrates fell below the upper limit recommended by Abad *et al.* (2001) and Noguera *et al.* (2003): < 30%. Volume shrinkage is important because it increases medium compaction and root damage, thereby reducing the efficiency of irrigation and plant quality.

3.3.2. Chemical properties

The organic matter contents of the four compost were comparable to other green composts made from low lignified materials (Morales-Corts *et al.*, 2014) but they were much lower than typical of those made from lignified plant materials (Aleandri *et al.*, 2015; Benito *et al.*, 2005) and also fell below those of other gorse composts (Díaz *et al.*, 2008) (Table 2.3). This result can be ascribed to the young age of the gorse plants used and to the mineralization of the material during the long composting period used in this work

According to Abad *et al.* (1993), the C/N ratio of compost ranges from 20 to 40; according to Burés (1997), however, it spans the range 5–30 and a value below 20 is suggestive of compost maturity and stability. Based on these figures, our gorse composts possess an optimum C/N ratio (see Table 2.3). The fact that the piles containing PM had a lower C/N ratio than those excluding it was a result of the manure being richer in nitrogen than gorse (PM contains 2.3% nitrogen versus an average 1.4% for dry and wet gorse), of the total carbon content of gorse nearly doubling that of PM and of the PM-containing piles undergoing stronger decomposition of organic matter and consequent release of carbon as CO₂.

Although interpreting the C/N ratio is made difficult by differences in element bioavailability and biodegradability, the values for our composts fall within the acceptable range for mature compost. The stability degree (SD) of organic matter affords a more accurate interpretation than the C/N ratio because it is determined with provision for biodegradability in organic matter fractions. Our composts had SD > 50% and were thus stable (Saña *et al.*, 1989).

Table 2.3. Total element contents of the composts on a dry matter basis.

	PM0I		PM5I		PM5		PM0		Optimum ¹ (Maximun) ²
OM (g kg⁻¹ dm)	558.6 ± 8.8	a	390.4 ± 22.4	c	385.2 ± 12.0	c	516.7 ± 14.3	b	>800
Ash (g kg⁻¹ dm)	441.4 ± 8.8	c	609 ± 22.4	a	614.8 ± 12.0	a	483.3 ± 14.3	b	<200
SD (%)	58.18 ± 0.76	a	53.62 ± 1.49	a	63.89 ± 7.60	a	63.30 ± 1.21	a	>50
N (g kg⁻¹ dm)	21.2 ± 0.1	a	18.2 ± 0.1	c	17.1 ± 0.1	d	18.9 ± 0.1	b	
C/N	14.06 ± 0.07	b	11.79 ± 0.07	c	11.81 ± 0.08	c	15.25 ± 0.11	a	20–40
Cd (mg kg⁻¹ dm)	0.05 ± 0.01	b	0.08 ± 0.00	a	0.07 ± 0.00	a	0.07 ± 0.00	a	(<1)
Cr (mg kg⁻¹ dm)	10.36 ± 2.86	b	19.22 ± 2.88	a	18.49 ± 0.56	ab	14.84 ± 1.26	ab	(<100)
Cu (mg kg⁻¹ dm)	17.22 ± 3.56	b	33.24 ± 1.91	a	34.17 ± 0.85	a	21.14 ± 0.56	b	(<100)
Hg (mg kg⁻¹ dm)	0.03 ± 0.01	a	0.03 ± 0.01	a	0.02 ± 0.00	a	0.02 ± 0.00	a	(<1)
Ni (mg kg⁻¹ dm)	8.12 ± 2.17	b	14.66 ± 1.46	a	13.64 ± 0.83	ab	10.28 ± 0.23	ab	(<50)
Pb (mg kg⁻¹ dm)	6.58 ± 1.16	b	11.69 ± 0.62	a	11.14 ± 0.05	a	7.80 ± 0.02	b	(<100)
Zn (mg kg⁻¹ dm)	65.11 ± 11.96	b	120.38 ± 2.07	a	120.55 ± 0.83	a	72.15 ± 0.05	b	(<300)

PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

OM= Organic Matter; SD = Stability Degree.

¹ Recommended values for an ideal substrate (Abad et al., 1993; Saña et al., 1989)

² Limit established as ecological criteria for EU eco-label (EU Commission, 2006)

Mean values and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at $p < 0.05$.

The four composts were acidic and only those containing manure had an appropriate pH in the saturation extract for use as growing media: 5.2–6.3 according to Abad *et al.* (1993). Specifically, their pH values fell in the range recommended by Escudero (1993) for horticultural crops: 5.5–6.8 (see Table 2.4).

Although the salt-sensitivity of plants depends on their age as well as on the particular environmental conditions, plant species and crop management practices, the four composts exhibited a high electrical conductivity (EC). Also, the PM-containing composts were additionally more saline by effect of the increased mineral content of the manure. The presence of excessive amounts of soluble elements is one of the greatest constraints to using compost as a growing media (Abad et al., 2008); therefore, any manure used should be added in small amounts (Burés, 1997). The EC values of the composts as measured in the 1:5 (v/v) extracts (Table 2.5) were in all cases lower than 1.5 dS m⁻¹, which is the limit set by the EU Commission (2006) for award of the eco-label; but they exceeded the maximum level

recommended by Noguera *et al.* (2003): 0.5 dS m^{-1} . The EC values measured in the saturation extracts were too high for any plant species. According to Burés (1997), it should not exceed 3.5 dS m^{-1} and, according to Abad *et al.* (1993) the optimum range is $0.75\text{--}3 \text{ dS m}^{-1}$.

Table 2.4. Analysis of the compost saturation extracts: pH, electrical conductivity (EC) and soluble elements.

	PM0I	PM5I	PM5	PM0	Optimum ¹
pH	3.74 ± 0.10 b	6.09 ± 0.07 a	6.40 ± 0.08 a	4.05 ± 0.06 b	5.2-6.3
EC (dS m^{-1})	3.78 ± 0.16 c	7.87 ± 0.49 a	5.11 ± 0.06 b	3.95 ± 0.05 c	0.75-3.5
NO_3^- (mg L^{-1})	570.0 ± 134.2 b	951.2 ± 56.5 a	723.4 ± 21.5 ab	506.1 ± 0.0 b	100-200
NH_4^+ (mg L^{-1})	45.5 ± 1.3 bc	74.3 ± 8.2 a	53.2 ± 1.5 b	29.7 ± 1.4 c	0-20
P (mg L^{-1})	18.3 ± 0.4 b	28.4 ± 1.1 a	30.7 ± 1.9 a	25.8 ± 2.4 a	6-10
Ca (mg L^{-1})	39.5 ± 0.1 b	96.3 ± 13.9 a	59.1 ± 1.0 b	38.7 ± 3.0 b	>200
Mg (mg L^{-1})	105.3 ± 3.9 a	129.4 ± 19.6 a	97.6 ± 3.4 a	100.0 ± 10.6 a	>70
K (mg L^{-1})	300.5 ± 23.3 c	703.5 ± 112.4 ab	761.2 ± 26.0 a	469.8 ± 4.8 bc	150-250
Na (mg L^{-1})	98.6 ± 0.2 b	240.8 ± 34.6 a	149.0 ± 0.7 b	96.6 ± 7.6 b	
Cu ($\mu\text{g L}^{-1}$)	20.53 ± 0.60 a	31.60 ± 13.46 a	27.27 ± 0.67 a	18.45 ± 1.22 a	1-500
Mo ($\mu\text{g L}^{-1}$)	2.24 ± 0.96 c	9.15 ± 0.91 b	17.38 ± 0.34 a	2.49 ± 0.06 c	10-100
Mn (mg L^{-1})	2.81 ± 0.99 a	0.06 ± 0.02 c	0.08 ± 0.01 bc	2.15 ± 0.24 ab	0.02-3
Fe (mg L^{-1})	0.16 ± 0.02 a	0.04 ± 0.01 c	0.04 ± 0.00 c	0.09 ± 0.02 b	0.3-3
Zn (mg L^{-1})	0.91 ± 0.49 a	0.31 ± 0.07 a	0.37 ± 0.04 a	0.54 ± 0.04 a	0.3-3
B (mg L^{-1})	0.36 ± 0.00 a	0.30 ± 0.17 a	0.36 ± 0.02 a	0.38 ± 0.02 a	0.05-0.5

PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation.

¹ Recommended values for an ideal substrate (Abad *et al.*, 1993)

Mean values \pm standard deviation and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at $p < 0.05$.

The soluble ammonium, phosphorus and potassium contents of the saturation extracts exceeded the optimum values established by Abad *et al.* (1993) in all composts (Table 2.4). The nitrate, ammonium and potassium contents were even higher in the PM-containing composts. On the other hand, the Mg contents in the composts fell within the range recommended by these authors. The Ca contents were low even in the manure-containing composts (PM5 and PM5I) despite the increased levels of this element in the manure (Table

2.1) —which is suggestive of the presence of insoluble Ca forms. Soluble Na content was moderately high, especially in compost with PM, related with it increased EC; it could limit some uses since Na values exceeding 30 ppm in saturated media extract could be harmful for seedlings (Styer and Koranski, 1997) and values over 250 mg L⁻¹ substrate (based on 1:5 extraction) showed a negative effect on cutting propagation (Fornes *et al.*, 2013)

The compost containing poultry manure (PM5I, PM5) showed levels significantly higher of Mo and lower of Mn than those without it (PM0I, PM0). However the contents in Cu, Mn, Mo, B and Zn fell in the recommended ranges (Abad *et al.*, 1993), whereas those in Fe were slightly lower than optimal.

The four composts were suitable as growing media for potting and transplantation, according to ADAS guidelines (1988). Only nitrate among the soluble nutrients in the 1:5 water extracts exceeded the levels proposed for these uses, whichever the treatment (Table 2.5). Potassium levels were also high in all cases, but only in compost PM5I did they exceed the proposed maximum. Phosphorus and ammonium levels were adequate overall, albeit somewhat low in the composts containing no manure (PM0I, PM0); on the other hand, Mg contents were adequate in all composts.

None of the heavy metals studied (Cd, Cr, Cu, Zn, Hg, Ni and Pb) was present at levels exceeding the limits for award of the eco-label (EU Commission, 2006) (Table 2.3). In fact, all were present at levels well below the limit —by exception, the Zn content was nearly one-half the accepted limit, possibly because layer feed is usually supplemented with this micronutrient.

3.3.3. Biological properties

There were no significant differences ($p < 0.05$) in the number of germinated seeds of spring barley between the different compost–peat mixtures (Fig. 2.4a). Also, there were no signs of leaf chlorosis or necrosis (results not shown); therefore, the composts can be deemed plant-tolerated. Also, the plants grown in all mixtures reached at least 90% of the weight they exhibited in the control substrate (Fig. 2.4b), so the composts can be used as soil improvers or fertilizers, and also in mixtures for garden and crop humus (FCQAO, 1994). The

substrates containing compost alone also yielded very high fresh weights relative to peat; therefore, the composts can be used as single-component substrates.

Table 2.5. Analysis of the compost 1:5 (v/v) extracts: pH, electrical conductivity (EC) and soluble elements content referred to substrate volume (mg L substrate⁻¹)

	PMOI	PM5I	PM5	PMO	Optimum ¹ (Maximun) ²
pH	3.90 ± 0.06 b	5.88 ± 0.14 a	6.12 ± 0.21 a	4.32 ± 0.32 b	5.3-6.5
EC (dS m⁻¹)	0.76 ± 0.04 b	1.39 ± 0.02 a	0.81 ± 0.06 b	0.77 ± 0.13 b	0.4-0.9 (1.5)
NO₃⁻ (mg Lsub⁻¹)	231.4 ± 20.6 d	660.0 ± 0.0 a	524.0 ± 15.6 b	390.5 ± 11.6 c	81-200
NH₄⁺ (mg Lsub⁻¹)	42.8 ± 1.2 a	79.6 ± 21.6 a	59.5 ± 3.3 a	46.2 ± 1.3 a	51-150
P (mg Lsub⁻¹)	23.1 ± 1.8 b	40.8 ± 4.2 a	43.3 ± 7.1 a	29.7 ± 0.4 ab	29-100
Ca (mg Lsub⁻¹)	194.0 ± 3.5 ab	277.9 ± 38.6 a	151.2 ± 3.1 b	202.1 ± 19.7 ab	
Mg (mg Lsub⁻¹)	93.3 ± 5.3 ab	113.1 ± 16.7 a	59.1 ± 4.5 b	100.1 ± 4.4 a	16-150
K (mg Lsub⁻¹)	620.0 ± 28.3 ab	792.0 ± 158.4 a	593.0 ± 46.7 ab	434.0 ± 22.6 b	101-650
Na (mg Lsub⁻¹)	79.7 ± 2.1 b	269.7 ± 33.7 a	130.2 ± 12.7 b	111.2 ± 11.4 b	
Cu (µg Lsub⁻¹)	30.66 ± 4.83 a	38.83 ± 6.37 a	31.71 ± 7.51 a	31.59 ± 21.48 a	
Mo (µg Lsub⁻¹)	1.32 ± 0.31 c	17.23 ± 2.55 b	30.85 ± 2.50 a	3.58 ± 0.33 c	
Mn (mg Lsub⁻¹)	1.63 ± 0.24 a	0.10 ± 0.10 b	0.01 ± 0.00 b	1.35 ± 0.13 a	
Fe (mg Lsub⁻¹)	0.31 ± 0.00 a	0.23 ± 0.12 a	0.30 ± 0.02 a	0.23 ± 0.01 a	
Zn (mg Lsub⁻¹)	1.91 ± 0.90 a	0.81 ± 0.70 a	0.90 ± 0.20 a	2.06 ± 0.2 a	
B (mg Lsub⁻¹)	0.64 ± 0.01 a	0.74 ± 0.03 a	0.64 ± 0.05 a	0.57 ± 0.05 a	

PMOI = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PMO = no manure and no irrigation.

¹ Optimun = recommendations for potting and transplanting growing media (based on 1:6 v/v extraction) (ADAS, 1988)

² Maximun = limit established as ecological criteria for growing media eco-label (EU Commission, 2006)

Mean values ± standard deviation and Tukey's post-hoc test. Identical letters for the same parameter indicate not significant differences between treatments at $p < 0.05$.

Based on their high germination index (Fig. 2.5), our gorse composts are mature (GI > 80%) (Zucconi *et al.*, 1981); also, they are germination triggers and boosters (GI > 100%) which may indicate the presence of biostimulant substances frequent in mature compost (Canellas *et al.*, 2015). Belyaeva and Haynes (2010) previously obtained composts consisting of green waste with or without poultry manure whose germination index was slightly lower than 100%. In this work GI was over 100% for all the treatments, so no negative effect of

salinity or Na content on germination was observed; they could be responsible for the slightly lower GI values of the manure-containing composts, but any possible negative impact was surpassed by the biostimulant effect, which has been seen that can alleviate salt stress (Calvo *et al.*, 2014; Canellas *et al.*, 2015)

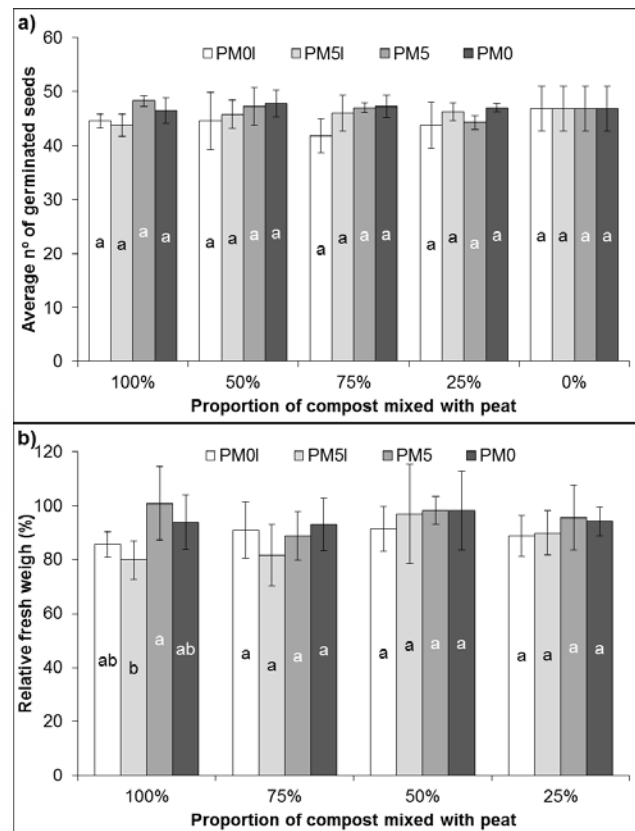


Fig. 2.4. Results of the barley seed germination bioassay. (a) Mean number of germinated seeds and (b) relative fresh weight (%). PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation. Mean values plus SD in error bars. For each proportion, columns with the same letters indicate not significant differences between treatments at $p < 0.05$ (Tukey's post-hoc test).

None of our four composts exceeded the primary pathogen limits set by the EU Commission (2006) for award of its eco-label to growing media. No salmonella was detected in 25 g of material and only 10 MPN of *E. coli* per gram were encountered (the accepted limit

is 1000 MPN). Also, no helminth eggs were found in 1.5 g of material (results not shown). These results are consistent with the variation of temperature in the piles since hygienization is the combined result of a high temperature and a long exposure time. A temperature of 55 °C for 1 h or one of 60 °C for an even shorter time is lethal for these microorganisms (Day and Shaw, 2001); however, the deleterious effect of a high temperature may have been compounded with other factors such as the moisture content or C/N ratio of the materials (Singh *et al.*, 2011). According to US EPA (2003), 55 °C for a minimum of 3 consecutive days suffices to destroy animal and human pathogens not resisting high temperatures in windrow composting systems; the material, however, must be turned over frequently during the thermophilic phase in order to ensure uniform exposure of the whole mass. Gantzer *et al.* (2001) found composting at 50–55 °C in different times of year for 4 weeks —and hence under milder conditions than here— to suffice in order to destroy *Salmonella*, inactivate helminth eggs and dramatically reduce *E. coli* counts.

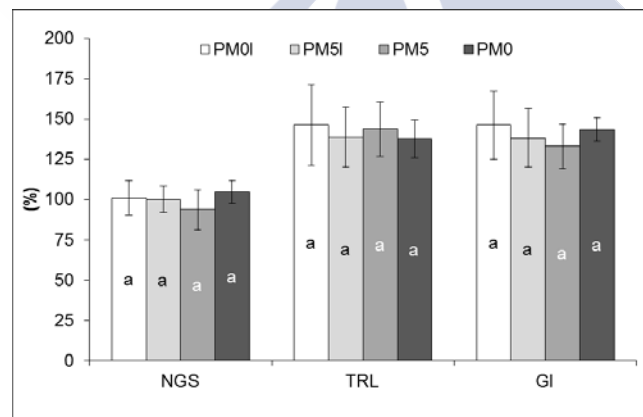


Fig. 2.5. NGS (number of germinated seeds) relative to the control, TRL (total root length of germinated seeds) relative to the control and GI (germination index) of the gorse composts. PM0I = no poultry manure but irrigation before composting; PM5I = manure and irrigation; PM5 = manure but no irrigation; PM0 = no manure and no irrigation. Mean values plus SD in error bars. For each proportion, columns with the same letters indicate not significant differences between treatments at $p < 0.05$ (Tukey’s post-hoc test).

However, except for PM5, which was completely seed-free, all composts contained more than 2 units of weed seeds or vegetative propagation materials per litre, which is the limit set by the EU Commission (2006) for award of its eco-label (results not shown). Weed seeds should not survive a composting process reaching 55 °C over 3 days; also, any seeds surviving will do as a result of localized “cool spots” resulting from inefficient turnover of the windrow or by entering the outer parts of the windrow after the thermophilic phase, especially by wind-blown species (Grundy *et al.*, 1998). The variation of temperature during the composting process, the removal of pathogens and the differences in weed germination between the manure-containing piles, which exhibited a very similar temperature variation pattern, are suggestive of subsequent re-infestation by effect of the piles being outdoors and in contact with the soil —and hence near grasses and other plants. The materials should thus be efficiently isolated from their environment in order to avoid contamination, preserve the hygienization achieved with composting and obtain compost containing no weed propagules

4. Conclusions

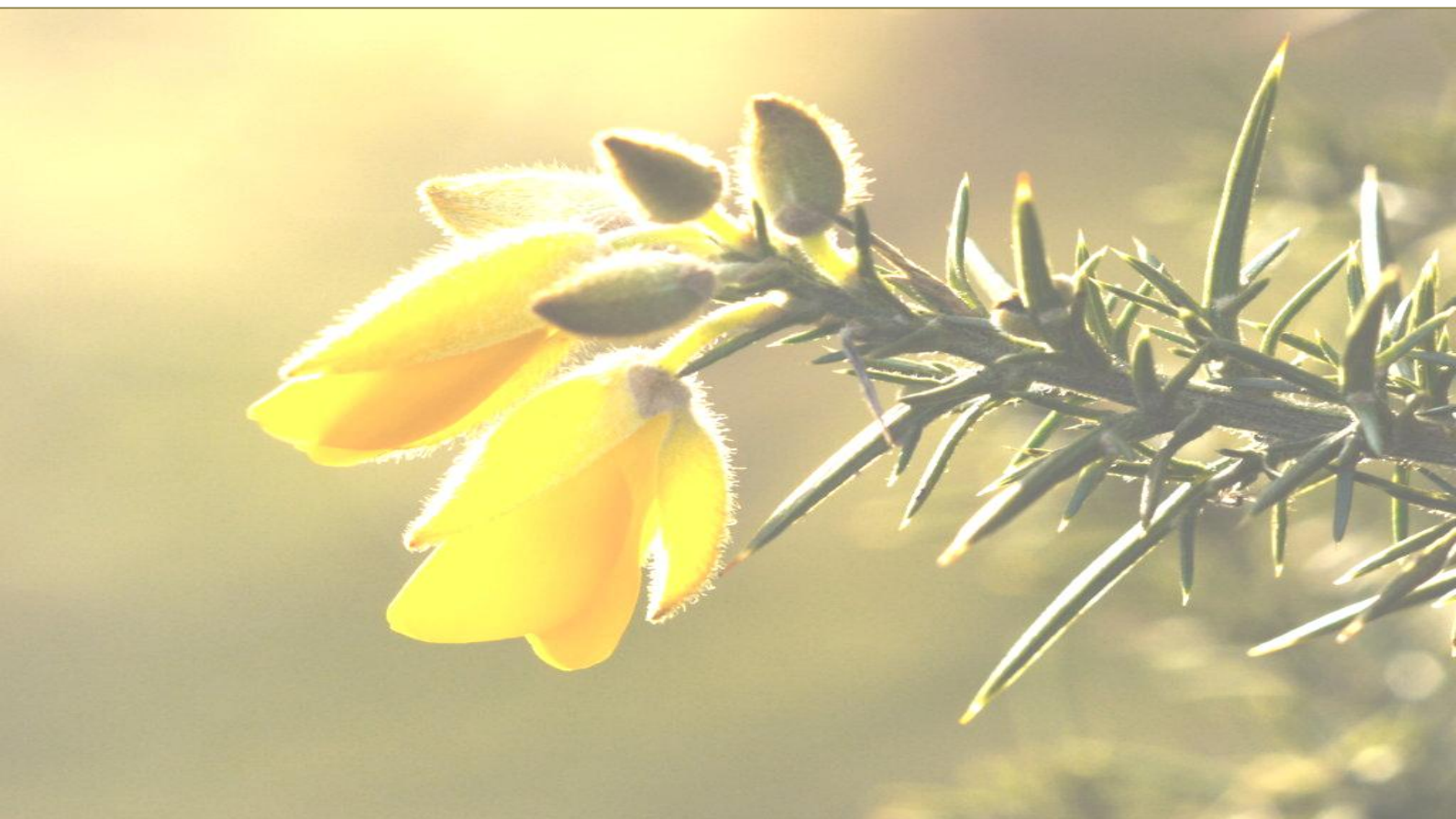
The composts obtained are mature and stable enough. They have a high aeration and drainage capacity and little plant-available water so they will require careful irrigation and also they can be used as aerating component in potting mixtures. The fact that they are all highly saline is no constraint to their obtaining the eco-label and it did not result in negative effect on seed germination or seedling growth, which was promoted. The content of soluble nutrients of the composts was quite high, but it may be unbalanced for some crops and then they would require to be adequately corrected by fertilization.

The addition of poultry manure resulted in substantial changes in the properties of the substrates, which contained less organic matter and had a lower C/N ratio, a nearer-neutral pH, higher contents in soluble elements and an increased salinity.

All the composts fulfil the requirements of the European norm for award of an eco-label except for the content in weed seeds of PM15, PM0 and PM0I owing to contamination after composting. This underlies the importance of strict control in preserving hygienic conditions achieved during the composting process.



CHAPTER III: Gorse Compost as an Ecological Growing Substrate for Strawberry Production.



CHAPTER III: GORSE COMPOST AS AN ECOLOGICAL GROWING SUBSTRATE FOR STRAWBERRY (*FRAGARIA X ANANASSA* DUCH “SELVA”) PRODUCTION: CROP NUTRITION AND FERTILITY STATUS

Abstract

The increasing demand for organic growing media containing no peat has raised the need to find suitable materials for this purpose. Green composts for economically and nutritionally significant crops constitute an attractive choice worth exploring. Agronomically, compost for organic production should be assessed in terms of its nutrient load, fertilizing power and suitability as supplementary fertilizer for specific crops. In this work, we assessed composts from forest cleaning green waste (gorse mainly) as substrates for organic cropping of strawberry (*Fragaria x ananassa* “Dutch”), particularly as regards nutrient availability. Two different composts were examined, namely: gorse composted with poultry manure at a 5 % v/v concentration (PM100) and gorse containing no manure (PM0). The two composts were assessed as such and in three different mixtures, namely: PM25 (25% PM0 + 75% PM100), PM50 (50% PM0 + 50% PM100) and PM75 (25% PM0 + 75% PM100). The cropping tests included a standard peat-based substrate containing slow-release fertilizer for comparison. Determinations involved periodic analyses of substrate solutions and monitoring of the crop nutritional status via chlorophyll and leaf measurements. Fruit production, and final aerial and root biomass, were also determined.

All composts, but especially PM100, had high contents in major nutrients; also, they exhibited acceptable physical properties, but a limited water holding capacity. The nutrient concentrations in the substrate solutions decreased gradually during crop growth; this was particularly so with N and K, which were present at very low levels during fruit production — the individual growth stage where extraction of these two elements typically peaks. The composts exhibited only slight differences from one another but marked differences from the control substrate —the latter released substantially greater amounts of nutrients between the 6th and 9th week of growth. Leaf analyses revealed that N was the scantiest nutrient in the compost-grown plants relative to the control substrate; also, chlorophyll levels were lower in the former. There were no substantial differences in overall production or fruit size, however. Aerial biomass in the compost-grown plants increased with increasing

proportion of PM100 but was greater in the control plants. There were no differences, however, in root biomass. Although the initial nutrient contents of the composts are adequate for strawberry cropping, the substrate must be supplemented with fertilizer during the fruit production stage in order to offset the increased extraction of nutrients.

Keywords: alternative substrate, green waste, poultry manure, peat substitute, renewable resource.

Highlights

Gorse compost had high nutrient contents (especially if containing poultry manure).

Nutrients in the substrate solution (N and K mainly) decreased throughout.

Manure in the compost increased aerial biomass but not root biomass.

There were no differences in overall production or fruit size among composts.

1. Introduction

The increasing demand and rising cost of peat, the most widely used plant-growing medium in recent decades, has promoted a search for alternative high-quality, inexpensive horticultural growing substrates. The need has arisen from ecological concern with the role of peat lands in carbon dioxide sequestration from the atmosphere (Maher *et al.*, 2008) and also with the fact that peat is a non-renewable resource that is being rapidly depleted. In addition, the increasing interest in waste recycling has fostered the re-use of organic wastes and composts as potting substrates.

In fact, composts from some organic wastes have physical, physico-chemical and chemical properties similar to those of peat and may thus be effective substitutes for this substrate (Sánchez-Monedero *et al.*, 2004). Several studies have shown that composted organic residues can be highly successfully used as growing media (Abad *et al.*, 2001; Benito *et al.*, 2005; Pérez-Murcia *et al.*, 2006). Also, organic materials usually possess a high fertility (Altieri *et al.*, 2010) and reducing fertilizer usage is a central aim for sustainable production of many horticultural crops (Tagliavini *et al.*, 1996).

However, the suitability of organic substrates for plant growth is strongly influenced by their ability to supply plants with nutrients (Carmona *et al.*, 2002; Caballero *et al.*, 2007), which may depend not only on their elemental composition, but also on other factors affecting nutrient forms and dynamics such as adsorption capacity, pH, biological stability and the presence of dissolved organic compounds (Caballero *et al.*, 2007). Therefore, the raw material to be used should be stable enough to avoid adverse effects on plant growth through N mineralization, oxygen depletion or the presence of phytotoxic compounds (Iglesias-Jimenez and Pérez García, 1989). Whereas immature compost can immobilize substantial amounts of N, stable compost acts largely as slow-release fertilizer (Raviv *et al.*, 2005).

Correctly diagnosing the status of soilless crops entails assessing substrates in relation to their outer environment (weather, plant material and growth stage, management regime, substrate type) and the dynamics of nutrient uptake, which is essential with a view to adjusting nutrient availability to actual plant requirements (Tagliavini *et al.*, 2005).

Organically cropped acreage has gradually increased in recent years, to an overall 43.7 million ha in 2014 (IFOAM, 2016) in response to the growing consumer demand for organic products. That year, Spain was the 5th greatest contributor to organic farming, with 1.7 million ha (IFOAM, 2016); also, organically grown strawberry crops accounted for 143 ha in 2014 (MAPAMA, 2015). Unsurprisingly, organic producers are requiring appropriate inputs for production and composts, apart from their environmental interest, have the added benefit of suppressing some plant diseases (Noble and Coventry, 2005; Brown *et al.*, 2013; Lopez - Lopez *et al.*, 2016) —an essential ability for organic farming, where using currently widespread synthetic products to protect horticultural crops is banned.

The primary aim of this work was to assess gorse compost as a growing medium for organic strawberry production in containers, with special emphasis on its ability to supply nutrients during the growth cycle and meet the requirements for additional fertilization.

2. Materials and methods

2.1. Composts

The materials studied were obtained by composting for 9 months forest shrub pruning residues consisting mainly of 4–5 year's old gorse (*Ulex europaeus* L) harvested with a flail mower. Two pairs of identical compost stacks were used. Two stacks contained gorse only (PM0, no poultry manure) and the other two gorse to which poultry manure from organic production was added at a 5% (v/v) concentration (PM100, 5% poultry manure) and the approximate composition of which was 70:30 dry weight. The addition of manure was intended to facilitate the process by lowering the C/N ratio to about 30 at the start, and also to increase nutrient levels in the end-product. A proportion of 5 % (v/v) was thought to suffice to fulfil both aims while reducing the risk of too high salinity in the composted material.

2.1.1. Laboratory analyses

Composts were characterized in chemical, physico-chemical and physical terms. Electrical conductivity (EC), pH and soluble elements were assessed in both saturation and 1:5 (v/v) extracts (EN-13652, 2001). Nitrate and ammonium were measured with an ion-selective electrode. Finally, P was determined by ultraviolet spectrophotometry at 880 nm (Olsen and Sommers, 1982), and K, Ca, Mg, Na, Cu, Zn, Fe, Mn, Mo and B by atomic absorption or emission spectrophotometry (USEPA, 1995).

The total contents in C, N and S were determined with a LECO TruSpec CHNS autoanalyzer, and those in Cr, Cu, Cd, Pb, Zn, Hg and Ni by ICP-OES after digestion with HNO₃ (USEPA, 1995). Organic matter and ash in the substrates were also quantified (EN-13039, 1999). The specific physical properties determined were the moisture retention curve (De Boodt et al., 1974); total porosity, bulk density, particle density and shrinkage value (EN-13041, 1999); and packed bulk density (EN-13040, 2007).

2.2. Strawberry crop

Mixing PM0 and PM100 in (v/v) different ratios provided five different substrates, namely: PM0 (0% PM0 + 100% PM100), PM25 (25% PM0 + 75% PM100), PM50 (50% PM0 + 50% PM100), PM75 (25% PM0 + 75% PM100) and PM100 (0% PM0 + 100% PM100). The five materials were tested as growing media for strawberry in an organically managed greenhouse assay. A completely randomized layout with 20 replicates per substrate was designed, each replicate involving growing a plant in a 0.6 L pot. A standard peat-based substrate to which Osmocote® 14-13-13 was added to supply each plant with 3 g N was used as control substrate.

The plant material consisted of strawberry [*Fragaria x Ananassa* (Duch.) 'Selva'] plants that were evenly trimmed and transplanted bare-root. The crop was established on April 29 in Lugo (Spain) and finished five months later. Drip irrigation with one dripper per plant and several daily applications was used. The water dose was adjusted on a frequent basis according to pot weight in order to minimize leaching losses.

2.2.1. Crop monitoring

2.2.1.1. Crop nutrition

Samples of the substrate solutions were taken with a sampler Rhizon equipped with a syringe. To this end, 6 randomly chosen pots per substrate were selected for extraction of the solution and mixing 2-2 to obtain a large enough volume for all analyses. Samples were always collected at least 2 h after irrigation in order to ensure equilibration of added water with the substrate. Sampling was more frequent at the beginning. EC, pH, NH_4^+ , NO_3^- , K, Ca, Mg and P were analysed on all sampling dates. Micronutrients (Mn, Fe, Zn, B, Cu and Mo) were determined twice during the growing period. EC and pH were analysed as described in Section 3.1.1. Nitrate and ammonium were measured with an ion-selective electrode; P by ultraviolet spectrophotometry at 880 nm (Olsen and Sommers, 1982); K, Ca, Mg and Na by atomic absorption or emission spectrophotometry (USEPA, 1995); Cu and Mo by ICP-MS; and Mn, Fe, Zn and B by ICP-OES.

Periodic measurements of chlorophyll index were made with a CCM-200 meter from Opti-Sciences, Inc., on all strawberry plants. Measurements were made on fully developed and young leaves, twice on each plant.

Total element contents in leaves were determined on (a) fully developed and younger leaves; and (b) the aerial portion of the plants. In both cases, harvested material was dried at 60 °C in a stove for 9 days and milled. Then, the material was calcined at 500 °C in an oven and digested with a 2 M HCl solution, the digest being analysed for total Mn, Fe, Zn, Mo, Cu, B, Mg, Na, P, K and N by optical ICP spectroscopy.

2.2.1.2. Crop growth and production

Strawberry fruits were collected periodically at ripeness (that is, immediately after their colour changed to red) to determine the fresh weight of the fruits obtained from each plant and substrate.

At the end of the growth period, the air and root parts of all plants were separated and cleaned to determine the dry weight of each portion after drying in an oven at 60 °C.

2.3. Statistical analysis

Data were processed by univariate analysis of variance (ANOVA). The factor (independent variable) was the presence or absence of poultry manure in the substrate (Section 3.1). In the strawberry crop section (3.2), it was the proportion of poultry manure compost in the compost. Differences at the $p < 0.05$ level between data pairs in Tukey's post-hoc test were deemed statistically significant. Data normality was previously confirmed with the Kolmogorov–Smirnov test and variance homoscedasticity with Levene's comparison test. All statistical calculations were done with the software PASW Statistic v. 18.

3. Results and Discussion

3.1. Composts

Adding poultry manure to gorse resulted in substantial chemical differences among the composts. The differences were less apparent in the 1:5 extract (Table 3.1) than in the saturation extract (Table 3.2). The manure-containing composts (PM100) exhibited higher pH, salinity (EC) and contents in major nutrients (N-NO_3^- , N-NH_4^+ , P and K), but lower contents in Mn, than PM0.

A comparison of the chemical properties of the saturation extract with the values reported by Abad *et al.* (1993) (Table 3.1) reveals that the compost is quite suitable for use as a growing substrate. The pH of PM100 fell at the high end of the range recommended by these authors, whereas that of PM0 was rather low. Overall, the nutrient contents of the compost were high. The EC, NO_3^- , NH_4^+ , P and K values of both composts exceeded the respective optimum values, whereas those of soluble Mg, Cu Zn, Mn and B fell within the optimum ranges. Only the Ca and Fe contents of both composts were below the optimum values, and so was the Mo content of PM0.

Relative to the recommended values for compost to be used as a potting or transplanting substrate (ADAS, 1988), the concentration of soluble NO_3^- in the 1:5 (v/v) extract fell above the optimum range in both composts, and so did the concentration of K in PM100. The concentrations of soluble NH_4^+ and P were within the recommended range in PM100 but slightly below it in PM0, which contradicts the results for the saturation extract. Again, the pH of the 1:5 (v/v) extract from PM0 was very low, whereas that of the extract from MP100 was acceptable. EC in the PM100 extract fell above the optimum range for a 1:6 extract (ADAS, 1988), and was slightly higher than the current limit for award of a growing substrate ecolabel (EU Commission, 2015).

Both substrates thus have high contents in crop-available mineral elements, which is usually the case with compost from nutrient-rich materials (Bustamante *et al.*, 2008; Raviv *et al.*, 2005). Based on the concentrations of soluble nutrients in the saturation extract (Table 3.1), the $\text{N:P}_2\text{O}_5:\text{K}_2\text{O}$ (m/m) proportion in PM0 and PM100 was 1:0.1:0.9 and 1:0.1:1.1, respectively, while ionic relation N:P:K was 1:0.1:0.9 and 1:0.1:1.1 ($\text{mmol}(+) \text{L}^{-1}$) respectively, which are, in principle, adequate for strawberry production (Sarooshi and

Creswell, 1994; Cantliffe *et al.*, 2007). The low levels of Fe in the compost might result in chlorosis and those of Ca detract from fruit firmness and resistance to biotic and abiotic stress (Trejo-Téllez and Gómez-Merino, 2014). However, the effect of calcium depends more markedly on the $K^+ : Ca^{2+}$ ratio —or even the $K^+ / (Ca^{2+} + Mg^{2+})$ ratio— than on the absolute Ca^{2+} concentration in solution (Andriolo *et al.*, 2009). Also, the high salinity of the two composts, but particularly that of PM100, could adversely affect a sensitive crop such as strawberry (Awang, 1995); however, an increased concentration of soluble nutrients does reduce plant growth and production but also improves fruit quality characteristics such as acidity and the contents in soluble solids (Andriolo *et al.*, 2009).

Table 3. 1. Analysis of the compost saturation extracts for pH, EC (electrical conductivity) and soluble elements.

	PM0	PM100	<i>p</i> -value	Optimum ¹
pH	3.89 ± 0.19	6.25 ± 0.19	0.000	5.2–6.3
EC (ds m⁻¹)	3.86 ± 0.13	6.49 ± 1.62	0.018	0.75–3.5
NO₃⁻ (mg L⁻¹)	538.09 ± 85.80	837.30 ± 136.02	0.010	100–200
NH₄⁺ (mg L⁻¹)	37.62 ± 9.20	63.75 ± 13.07	0.017	0–20
P (mg L⁻¹)	22.04 ± 4.58	29.51 ± 1.84	0.023	6–10
Ca (mg L⁻¹)	39.05 ± 1.82	77.68 ± 22.91	0.015	>200
Mg (mg L⁻¹)	102.63 ± 7.19	113.50 ± 21.64	0.377	>70
K (mg L⁻¹)	385.15 ± 98.71	732.35 ± 74.49	0.001	150–200
Na (mg L⁻¹)	97.63 ± 4.54	194.88 ± 56.62	0.014	
Cu (mg L⁻¹)	0.02 ± 0.00	0.02 ± 0.01	0.303	0.001–0.5
Zn (mg L⁻¹)	0.73 ± 0.36	0.34 ± 0.06	0.139	0.3–3
Fe (mg L⁻¹)	0.12 ± 0.04	0.04 ± 0.01	0.634	0.3–3
Mn (mg L⁻¹)	2.48 ± 0.70	0.07 ± 0.01	0.002	0.02–3
Mo (mg L⁻¹)	0.00 ± 0.00	0.01 ± 0.00	0.013	0.01–0.1
B (mg L⁻¹)	0.37 ± 0.11	0.38 ± 0.03	0.600	0.05–0.5

PM0 = composts with no poultry manure; PM100 = composts containing poultry manure

¹ Recommended values for an ideal substrate (Abad *et al.*, 1993)

Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter

The composts had a low content in organic matter (OM) as a result of the characteristics of the raw materials and the composting method used. Also, the OM content

of PM100 was much lower than that of PM0 (Table 3.3), which is consistent with the increased mineral content of the former by effect of its containing poultry manure. The decreased OM content of PM100 is also consistent with its lower total N content; this result is apparently contradictory with the high N content of an N-rich material such as poultry manure but consistent with the low C/N ratio of organic matter containing abundant N. Despite their differences, both composts had a low C/N ratio falling below the limit recommended by Abad *et al.* (1993), 20, but within the broader range proposed by Burés (1997). This was a result of efficient composting of N-rich raw materials and is suggestive of also efficient maturation (Golueke, 1981) —a necessary condition for compost to be used as a growing substrate. Similarly low values were previously obtained for mixtures of poultry litter with hardwood chips or pine sawdust as bulking agents (Preusch *et al.*, 2004), and also with a mixture of gorse and the solid fraction of pig slurry (Brito *et al.*, 2010). By contrast, gorse-only compost had slightly higher values (Iglesias-Díaz *et al.*, 2009).

The contents in five of the seven heavy metals studied (*viz.*, Cr, Cu, Ni, Pb and Zn) were substantially higher in the manure-containing compost (PM100). In any case, such contents were all low and well below the limits for award of a growing substrate ecolabel (EU Commission, 2015); also, they amply met the requirements for class A, which is the most demanding compost class in Spanish substrate regulations (BOE, 2010).

As can be seen from Table 3.4, the compost containing poultry manure (PM100) had significantly higher bulk density and particle density than that containing none (PM0) by effect of the increased mineral content of the former. As a result, total porosity in PM100 was significantly lower —but still high and adequate— than in PM0. The difference was only apparent in the pore fraction holding the most strongly retained water (UW), with the compost containing no manure (PM0) having the lower values. Both composts had bulk density, particle density, total porosity and shrinkage values within the optimum ranges for ideal growing substrates reported by Abad *et al.* (1993). However, easily available water (EAW) and water buffer capacity (WBC) were underoptimal, and aeration capacity excessive (up to 15% higher than desirable), these two characteristics being consistent with other substrate components such as green residues (Fornes *et al.*, 2013), switchgrass (Altland and Krause, 2009) or bracken (Pitman and Webber, 2013). Because of their low EAW values,

these materials require careful irrigation with small, frequent applications. In practice, the differences between the physical properties of the two composts justify no different management or need lead to a different crop response.

Table 3.2. Analysis of the compost 1: 5 (v/v) extracts for pH, EC (electrical conductivity) and soluble elements in relation to substrate volume (mg L substrate⁻¹).

	PM0	PM100	<i>p</i> -value	Optimum ¹ (Maximum) ²
pH	4.11 ± 0.31	6.00 ± 0.20	0.000	5.3–6.5
EC (ds m⁻¹)	0.76 ± 0.08	1.10 ± 0.33	0.097	0.4–0.9 (1.0)
NO₃⁻ (mg Lsub⁻¹)	310.95 ± 92.88	591.99 ± 79.04	0.004	81–200
NH₄⁺ (mg Lsub⁻¹)	44.49 ± 2.23	69.57 ± 17.13	0.027	51–150
P (mg Lsub⁻¹)	26.38 ± 3.95	42.03 ± 4.99	0.003	29–100
Ca (mg Lsub⁻¹)	198.03 ± 12.47	214.55 ± 76.49	0.685	
Mg (mg Lsub⁻¹)	96.68 ± 5.61	86.08 ± 32.76	0.547	16–150
K (mg Lsub⁻¹)	527.00 ± 109.40	692.50 ± 149.30	0.124	101–650
Na (mg Lsub⁻¹)	95.43 ± 19.35	199.95 ± 83.18	0.050	
Cu (mg Lsub⁻¹)	0.07 ± 0.03	0.07 ± 0.01	0.703	
Zn (mg Lsub⁻¹)	1.99 ± 0.54	0.86 ± 0.42	0.060	
Fe (mg Lsub⁻¹)	0.27 ± 0.05	0.26 ± 0.08	0.977	
Mn (mg Lsub⁻¹)	1.49 ± 0.23	0.06 ± 0.07	0.001	
Mo (mg Lsub⁻¹)	0.00 ± 0.00	0.02 ± 0.01	0.008	
B (mg Lsub⁻¹)	0.61 ± 4.85	0.69 ± 0.07	0.574	

PM0 = compost with no poultry manure; PM100 = compost containing poultry manure

¹Optimum = recommended for potting and transplanting of growing media (based on 1:6 v/v extraction) (ADAS, 1988)

²Maximum = limit for award of a growing substrate ecolabel (EU Commission, 2015)

Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter

Table 3.3. Total element contents of the composts on a dry matter basis.

	PM0	PM100	<i>p</i> -value	Optimum ¹ (Maximum) ²
OM (g kg ⁻¹ dm)	53.76 ± 2.53	38.78 ± 1.63	0.000	
Ashes (g kg ⁻¹ dm)	46.24 ± 2.53	61.22 ± 1.63	0.000	
N (g kg ⁻¹ dm)	2.01 ± 0.12	1.76 ± 0.06	0.002	
C/N	14.62 ± 0.12	11.80 ± 0.07	0.000	20–40
Cd (mg kg ⁻¹ dm)	0.06 ± 0.01	0.07 ± 0.00	0.077	(1)
Cr (mg kg ⁻¹ dm)	12.60 ± 3.15	18.86 ± 1.74	0.013	(100)
Cu (mg kg ⁻¹ dm)	19.18 ± 3.07	33.71 ± 1.32	0.000	(100)
Hg (mg kg ⁻¹ dm)	0.03 ± 0.01	0.03 ± 0.01	0.882	(1)
Ni (mg kg ⁻¹ dm)	9.20 ± 1.77	14.15 ± 1.14	0.003	(50)
Pb (mg kg ⁻¹ dm)	7.19 ± 0.97	11.41 ± 0.48	0.000	(100)
Zn (mg kg ⁻¹ dm)	68.63 ± 8.01	120.46 ± 1.29	0.000	(300)

PM0 = compost with no poultry manure; PM100 = compost containing poultry manure
OM = Organic Matter

¹ Recommended values for an ideal substrate (Abad *et al.*, 1993)

² Limit for award of an EU ecolabel (EU Commission, 2015)

Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter

Table 3.4. Physical properties of the composts.

	PM0	PM100	<i>p</i> -value	Optimum ¹
BD (g cm ⁻³)	0.19 ± 0.01	0.26 ± 0.01	0.000	<0.4
PD (g cm ⁻³)	1.92 ± 0.02	2.08 ± 0.02	0.000	1.45–2.65
TP (% v/v)	90.29 ± 0.37	87.47 ± 0.68	0.000	>85
AC (% v/v)	48.74 ± 1.45	47.22 ± 2.84	0.269	10–30
EAW (% v/v)	10.77 ± 0.93	11.43 ± 1.84	0.449	20–30
WBC (% v/v)	2.52 ± 0.15	2.35 ± 0.18	0.103	4–10
UW (% v/v)	28.27 ± 1.17	26.47 ± 1.39	0.037	
R (kPa)	0.93 ± 0.03	0.93 ± 0.06	0.931	1–3
S (% v/v)	16.86 ± 1.43	19.28 ± 3.40	0.140	<30

PM0 = compost with no poultry manure; PM100 = compost containing poultry manure

BD = bulk density, PD = particle density, TP = total porosity, S = shrinkage value, AC = aeration capacity, EAW = easily available water, WBC = water buffer capacity, UW = unavailable water; R = suction equilibrating the water and air contents

¹ Optimum values for an ideal substrate (Abad *et al.*, 1993; Abad *et al.*, 2001; Noguera *et al.*, 2003).

Mean ± standard deviation and *p*-value (ANOVA significance level) for each parameter.

3.2. Crop nutrition

As can be seen from Fig. 3.1, the chemical properties of the substrate solutions from the composts differed already on the first sampling date, namely: 26 days after transplantation (26 d.a.t.). Thus, the pH was near-neutral (6 for PM0) and scarcely influenced by the presence of poultry manure. This was the individual parameter differing most markedly between the extracts and the solutions from the substrates as obtained with suction samplers. The increased difference may in part have been spurious as a result of the solution being altered by degassing through suction during the sampling operation; the resulting reduction in the concentration of dissolved CO₂ (Morell and Sánchez, 1998) may have shifted equilibrium to carbonic acid and raised the solution pH as a result. The control sample was always acidic, probably by effect of its increased buffer capacity.

Electrical conductivity (CV) was lower than 1 dS m⁻¹ in all samples on the first sampling. This result suggests a decreased concentration of elements in the substrate solution relative to the saturation extract from the raw materials. Also, the concentrations of all nutrients in the substrate solutions were markedly lower (particularly those of K⁺, Mg²⁺ and NO₃⁻). Since leaching losses were minimized, this result suggests absorption of these three nutrients over the 26 first days preceding the first sampling. However, no substantial extraction of nutrients was to be expected at this early stage of growth (Molina *et al.* 1993), but rather after flowering (Choi *et al.*, 2013), with a peak at the fruit production stage (Albregts and Howard, 1980) —fruits were harvested 6 weeks after transplantation.

As can be seen from the variation of EC in Fig. 3.1, all composts exhibited sustained dilution of the substrate throughout the experiment. Overall, the concentrations of soluble elements were slightly higher in the composts containing the highest proportions of poultry manure (PM100, PM75) than in the others; all, however, exhibited a decrease in EC throughout. In fact, the decline in electrical conductivity was apparent already on the first sampling date (26 d.a.t.) but diminished as EC values fell. The fact that the overall and individual ionic concentrations evolved identically was a result of the release of soluble elements by the material (compost or pat containing slow-release fertilizer) being offset by crop extraction largely in the absence of leaching losses. The concentrations of some nutrients in the substrate solution gradually decreased to very low levels (Fig. 3.1); this was

especially with case with NO_3^- and K, which were the most abundant initially but also the most strongly extracted by the crop, their concentrations falling rapidly to rather low levels from the second half of the cropping cycle. In addition, the differences in the way the concentrations of the ions changed altered their equilibria.

Virtually all soluble N present was in the form of N-NO_3^- throughout the sampling period because NH_4^+ ion was scarcely present in solution in all samplings. A near-neutral pH and good aeration by effect of the favourable physical properties of the compost led to efficient nitrification. As a result, virtually all mineral N remained in solution and N extractions were only countered —albeit inadequately— by mineralization of the compost. The N requirements during the vegetative growth stage and start of the fruit formation stage caused a drop in nitrate until 42 d.a.t. and then to even lower levels 75 d.a.t., coinciding with the highest demand typical of the fruit production stage (Molina *et al.* 1993).

The fruit production stage boosted extraction of K (Molina *et al.* 1993), the concentration of which also fell gradually and remained at very low levels beyond 89 d.a.t. Mobilizing K^+ stocks in the exchange complex usually offsets solution losses of this ion; however, losses were incompletely countered here and the K concentration in solution was lower than that extracted by the crop. P levels also decreased during the sampling period, albeit less markedly than K levels. The greatest decline was observed 42 d.a.t, and was followed by a less marked decrease. The difference from N and K was a result of more reduced extraction of P but also of more complex mobilization by desorption and solubilization, and also of more difficult leaching (Ansorena, 1994).

Other elements such as Ca and Mg remained at virtually unchanged concentrations in solution throughout the growing period, which suggests that they were gradually released from the exchange complex of the compost or even solubilized (particularly Ca, which is more strongly extracted by strawberry) (Tagliavini *et al.*, 2005). By contrast, the concentration of Na remained constant or even increased slightly throughout the experiment (results not shown).

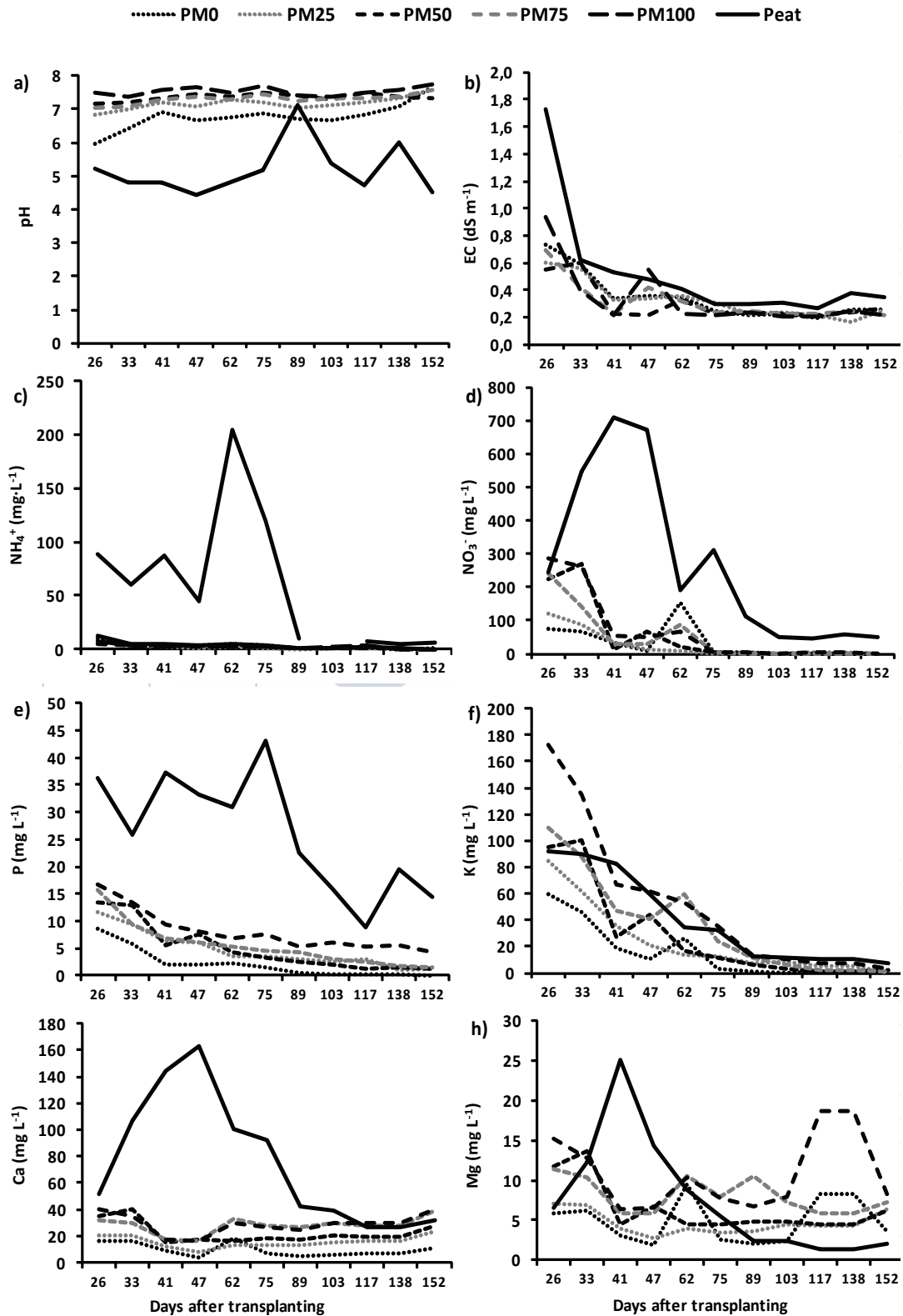


Fig.3.1. Changes in selected properties of the substrate solution during strawberry cropping under greenhouse conditions as a function of the proportion of poultry manure in the mixed composts: (a) pH, (b) CE (dS m⁻¹), (c) NH₄⁺ (mg L⁻¹), (d) NO₃⁻ (mg L⁻¹), (e) P (mg L⁻¹), (f) K (mg L⁻¹), (g) Ca (mg L⁻¹) and (h) Mg (mg L⁻¹).

Unlike the compost-based substrates, the nutrient concentrations in the solution from the control material, which consisted of fertilized peat, increased roughly over the first two months and then decreased more or less gradually — unlike the composts, however, no nutrients were depleted in most cases. N and P availability exhibited the greatest differences from the composts; by contrast, K availability was similar to that in the composts containing the greatest amounts of poultry manure (PM75 and PM100). The Ca and Mg concentrations in the solution from the control material exceed those in the compost extracts at the early growth stages but were similar (Ca) or even lower (Mg) by the end. Mobilization of nutrients from the slow-release fertilizer took less than the expected 3–4 months as a result of a high temperature and moisture.

Table 3.5 shows the micronutrient concentrations in the substrate solution at two different times during the strawberry growth period. There was no clear-cut trend for the gorse composts as a whole; by exception, the B concentration differed between successive samplings in all composts. The concentrations of Cu, Mo, Mn and Zn in the control substrate decreased, whereas those of Fe and B increased, during the growth cycle.

Regarding plant mineral contents (Table 3.6), N was the individual element most strongly dependent on the particular substrate. Thus, it was present in greater amounts in the plants grown in peat than in those grown in the composts, the difference increasing with decreasing content of poultry manure in the composts. This result was obtained on both sampling dates; however, the differences among composts decreased whereas those from the control substrate increased at the end of the process. This finding is consistent with the changes in solution concentrations, which were higher in the control substrate than in all composts beyond 33 d.a.t. (Fig. 3.1), the initial differences among composts gradually vanishing with time. Also, the N contents of the plants were invariably low; in fact, even those of the peat-grown plants fell below the acceptable ranges.

The differences in P contents among plants grown in the different substrates were similar to those in N. However, none of the P values was below the optimum range and some even exceeded the upper limit. This suggests that the decreased availability of P in the composts throughout the sampling period resulted in less marked —though not necessarily

inadequate— absorption by the plants relative to the control substrate. However, the differences in P among substrate solutions were not echoed by plant leaves.

Table 3.5. Changes in selected micro nutrients in the substrate solution 106 and 145 days after transplanting (d.a.t.) of strawberry plants by substrate.

	106 d.a.t.	145 d.a.t.	106 d.a.t.	145 d.a.t.
	Mn (mg L⁻¹)		Fe (mg L⁻¹)	
PM0	0.022 ± 0.038 a	0.006 ± 0.006 a	0.059 ± 0.035 a	0.051 ± 0.036 a
PM25	0.003 ± 0.002 a	0.006 ± 0.005 a	0.064 ± 0.051 a	0.123 ± 0.093 a
PM50	0.002 ± 0.001 a	0.002 ± 0.001 a	0.033 ± 0.010 a	0.038 ± 0.019 a
PM75	0.004 ± 0.004 a	0.010 ± 0.020 a	0.031 ± 0.012 a	0.035 ± 0.029 a
PM100	0.005 ± 0.003 a	0.003 ± 0.001 a	0.029 ± 0.013 a	0.033 ± 0.021 a
Peat	0.146 ± 0.126 b	0.039 ± 0.015 b	0.062 ± 0.027 a	0.115 ± 0.091 a
	Zn (mg L⁻¹)		B (mg L⁻¹)	
PM0	0.172 ± 0.130 a	0.073 0.034 a	0.045 ± 0.037 a	0.089 ± 0.013 a
PM25	0.118 ± 0.144 a	0.173 0.105 ab	0.042 ± 0.041 a	0.119 ± 0.024 a
PM50	0.055 ± 0.043 a	0.076 0.062 a	0.039 ± 0.034 a	0.100 ± 0.016 a
PM75	0.036 ± 0.031 a	0.036 0.020 a	0.054 ± 0.036 a	0.092 ± 0.020 a
PM100	0.216 ± 0.416 a	0.084 0.080 a	0.070 ± 0.054 a	0.111 ± 0.033 a
Peat	1.915 ± 1.278 b	0.274 0.095 b	0.030 ± 0.053 a	0.092 ± 0.020 a
	Cu (µg L⁻¹)		Mo (µg L⁻¹)	
PM0	4.551 ± 2.972 a	3.161 ± 1.711 a	0.608 ± 0.285 a	0.722 ± 0.258 a
PM25	5.779 ± 3.862 a	8.807 ± 6.524 a	0.990 ± 0.594 a	1.525 ± 0.845 ab
PM50	4.484 ± 1.544 a	5.024 ± 2.853 a	1.302 ± 0.615 a	1.680 ± 0.802 ab
PM75	4.453 ± 2.764 a	3.276 ± 1.625 a	1.866 ± 0.919 a	1.507 ± 0.841 ab
PM100	7.341 ± 3.021 a	6.373 ± 4.387 a	4.034 ± 1.439 b	4.561 ± 3.288 b
Peat	8.342 ± 2.613 a	5.842 ± 3.129 a	4.003 ± 1.749 b	3.774 ± 3.313 ab

Mean ± standard deviation and Tukey's post-hoc test. Identical letters for the same parameter and date indicate non-significant differences at $p < 0.05$ between treatments.

Unlike the previous elements, K was present in smaller amounts in the peat-grown plants than in the compost-grown plants; also, the composts differed little in K irrespective their proportion of poultry manure. This result may have arisen from the high initial K contents of the compost-based substrates and the K concentrations in the corresponding

solutions being comparable to those for the control substrate despite the reduction in soluble K in solution during crop growth. The differences in plant-available soluble K^+ concentrations observed during most of the growing period were not echoed by the total K content in leaf.

Because fruits are major sinks of N, P, K, the levels of these elements can be expected to fall during the fruit production stage (Bottoms *et al.*, 2013). This expectation is consistent with the reduction in soluble element concentrations in the substrate solutions during that stage (Fig. 3.1); however, no similar reduction in leaf levels was observed in comparing the results for the two sampling dates. In fact, only the N concentration was lower on the second date in all substrates, P and K exhibiting similar or even high levels at the end of the growing period than mid-way the harvesting period.

The Ca and Mg levels were largely adequate for all substrates, and somewhat higher on the second sampling date than on the first. The plants grown in the compost-based substrates were similar in this respect but differed from those grown in the control substrate, the latter having the lowest concentrations on the first sampling date even though the Ca levels in solution were much higher in the preceding period.

All micronutrient levels fell within the acceptable range but differed among substrates. Thus, B and Cu levels were especially low in the peat-grown plants, whereas the Zn and Fe levels were similar in all. Mn levels peaked in the compost containing no poultry manure (PM0) and decreased gradually with increasing manure content. By contrast, Mo levels exhibited the opposite trend, which is consistent with differences in these elements between composts (see Table 3.2).

Table 3.7 illustrates the variation of the chlorophyll index for the gorse composts as a function of their manure content as compared to the control (peat) substrate. The chlorophyll index is widely used to assess the N nutritional status of plants more simply and rapidly than with tissue analyses (Cambouris *et al.*, 2016). All substrates had similar N values on the first sampling date (22 d.a.t.), which coincided with a period of good availability of mineral N in the solutions from all substrates (Fig. 3.1). Nitrogen levels were subsequently slightly higher in all materials, but especially in the control substrate, as a result of the N concentrations in the solutions from the compost-based substrates gradually decreasing

Table 3.6. Total element contents of strawberry tissue on two different dates: 104 and 153 days after transplanting (main harvest and end of cropping period).

104 d.a.t.	PEAT	PM0	PM25	PM50	PM75	PM100	Opt¹
N (g kg⁻¹)	22.44 a	13.18 d	13.74 cd	14.09 bcd	15.72 bc	16.49 b	24–40
P (g kg⁻¹)	3.76 a	2.28 b	3.34 ab	3.06 ab	3.43 ab	3.18 ab	2–4
K (g kg⁻¹)	13.09 b	15.82 ab	19.11 a	18.72 ab	17.40 ab	17.43 ab	11–25
Ca (g kg⁻¹)	5.79 b	8.75 ab	10.63 a	9.77 a	8.68 ab	8.53 ab	4–23
Mg (g kg⁻¹)	1.69 b	3.19 a	2.97 a	2.54 a	2.62 a	2.60 a	2–4.5
Na (g kg⁻¹)	34.75 a	68.31 a	84.71 a	41.22 a	41.60 a	31.03 a	
B (mg kg⁻¹)	25.51 b	47.67 a	50.67 a	44.75 a	48.42 a	48.11 a	20–77
Zn (mg kg⁻¹)	33.45 a	22.61 a	24.79 a	13.15 a	28.75 a	23.18 a	12–50
Mn (mg kg⁻¹)	73.53 a	280.90 b	114.58 a	37.69 a	46.59 a	48.90 a	25–300
Fe (mg kg⁻¹)	55.67 a	93.12 a	78.46 a	54.09 a	73.50 a	55.14 a	50–300
Cu (mg kg⁻¹)	2.54 b	3.36 ab	3.87 ab	4.64 ab	7.89 a	5.10 ab	2.5–15
Mo (mg kg⁻¹)	0.79 b	0.85b	1.21 b	1.79 b	1.31 b	3.38 a	
153 d.a.t.	PEAT	PM0	PM25	PM50	PM75	PM100	Opt¹
N (g kg⁻¹)	22.11 a	12.07 b	12.72 b	13.26 b	14.10 b	14.37 b	24–40
P (g kg⁻¹)	6.85 a	2.91 b	4.59 b	4.36 b	4.73 b	4.43 b	2–4
K (g kg⁻¹)	16.42 b	20.09 ab	22.63 a	22.94 a	23.81 a	22.43 a	11–25
Ca (g kg⁻¹)	19.42 a	15.70 c	17.30 bc	17.13 bc	17.98 ab	16.26 bc	4–23
Mg (g kg⁻¹)	3.21 c	4.14 a	3.60 abc	3.53 bc	3.79 ab	3.78 ab	2–4.5
Na (g kg⁻¹)	218.31 a	246.19 a	226.73 a	220.52 a	229.37 a	223.85 a	
B (mg kg⁻¹)	39.46 b	64.12 a	63.77 a	66.77 a	68.70 a	71.15 a	20–77
Zn (mg kg⁻¹)	29.97 a	23.51 a	33.95 a	26.52 a	22.36 a	24.29 a	12–50
Mn (mg kg⁻¹)	233.70 b	445.66 a	156.45 b	67.52 b	69.10 b	79.09 b	25–300
Fe (mg kg⁻¹)	133.70 a	168.79 a	180.33 a	145.87 a	129.12 a	146.30 a	50–300
Cu (mg kg⁻¹)	1.99 b	4.12 a	5.08 a	4.82 a	5.07 a	5.80 a	2.5–15
Mo (mg kg⁻¹)	1.96 a	1.62 a	2.20 a	3.28 a	2.36 a	2.54 a	

¹ Compiled from data of Bottoms et al. (2013) (full harvest, limb); Hochmuth and Albrechts (1994) (full harvest, full leaves); Campbell and Miner (2000) (full harvest, full leaves); and Ulrich *et al.* (1980) (unspecified time, limb)

Mean and Tukey's post-hoc test. Identical letters for the same parameter and date indicate non-significant differences at $p < 0.05$ between treatments.

with time. In fact, the poorest substrates showed symptoms of inadequate N availability 94 d.a.t.; thus, the plants grown on peat exhibited the highest N levels and only those grown on

the composts containing the largest amounts of manure (PM100 and PM75) had comparable levels. Beyond that point in time, the chlorophyll index of the peat-grown plants remained constant, whereas that of the compost-grown plants decreased gradually in response to the low N availability. In fact, the chlorophyll values for the composts 104 d.a.t. were all similar and lower than those for the control substrate; on the other hand, the values for leaves on that sampling date exposed slight differences in total N content among composts (Table 3.7). The availability of inorganic N from the slow-release fertilizer decreased until 103 d.a.t. and then levelled off at low values but still higher than those for the composts and seemingly adequate to prevent chlorophyll levels from declining —which suggests that no deficiency occurred. In fact, the greatest difference in chlorophyll levels between the composts and the control substrate was observed at the end of the growing period, which is consistent with the result of the second plant analysis.

3.3. Crop growth and production

Nutrient accumulation in strawberry has two critical stages, namely: (1) active growth, and (2) stolon formation and fructification (Cooper and Vaile, 1945). The gradual reduction in available nutrient levels, which was faster in the compost-based substrates, restricted vegetative growth in the strawberry plants and delayed leaf development relative to the control substrate after the seventh week (results not shown), concurrently with faster growth. As can be seen from Fig 3.2, the peat-grown strawberry plants exhibited more marked growth in the form of substantially increased amounts of aerial biomass relative to the gorse composts (28.38 vs 13.73 g). Also, aerial biomass increased with increasing proportion of poultry manure in the composts. These results can be related to the variation of the availability of N in the form of NH_4^+ and NO_3^- , the changes being more marked in the control substrate than in the compost-based substrates, and also in the composts containing some poultry manure (PM100) than in those containing none (PM0) (see Tables 3.1 and 3.2) —which is bound to have delayed restrictions on plant growth.

Table 3.7. Chlorophyll index for strawberry leaves on six different dates during the crop cycle (d.a.t. = days after transplanting).

	22 d.a.t.	36 d.a.t.	94 d.a.t.
PM0	17.40 ± 3.23 a	18.50 ± 2.52 ab	18.53 ± 3.68 b
PM25	17.80 ± 2.75 a	18.04 ± 2.51 ab	18.38 ± 3.32 b
PM50	17.59 ± 2.47 a	16.86 ± 2.72 b	19.13 ± 4.38 b
PM75	18.47 ± 2.75 a	17.27 ± 2.67 b	20.51 ± 3.01 ab
PM100	17.33 ± 4.09 a	16.74 ± 2.22 b	21.77 ± 5.29 ab
Peat	17.31 ± 2.91 a	18.70 ± 2.94 a	21.82 ± 4.68 a
	104 d.a.t.	119 d.a.t.	146 d.a.t.
PM0	17.33 ± 3.69 b	15.78 ± 2.06 b	16.09 ± 1.51 bc
PM25	17.98 ± 2.98 b	17.36 ± 3.64 b	17.51 ± 2.85 ab
PM50	17.11 ± 4.37 b	16.03 ± 4.55 b	15.75 ± 3.06 bc
PM75	16.25 ± 2.75 b	14.65 ± 3.57 b	14.71 ± 2.10 c
PM100	17.80 ± 4.18 b	16.58 ± 6.00 b	16.54 ± 4.03 bc
Peat	22.61 ± 7.02 a	21.63 ± 6.51 a	21.56 ± 5.72 a

Mean values ± standard deviation and Tukey's post-hoc test. Identical letters for each date indicate non-significant differences at $p < 0.05$ between treatments.

There were, however, no significant differences among substrates as regards root growth in the form of root dry weight. The average dry weight for all substrates was approximately 5 g, which is somewhat smaller than previously reported values (e.g., 7.4 g by Yavari *et al.*, 2008).

There were no significant differences in strawberry fruit weight or total production among substrates (Fig. 3.3). The average fruit weight ranged from 8.3 to 9 g and was thus very similar to previously reported values: 10 g by Ameri *et al.* (2012) for the Selva variety and also 10 g by Yavari *et al.* (2008) for various mixed substrates made from residues. Total strawberry production averaged 70–90 g/plant and was thus lower than the value reported by Ameri *et al.* (2012), 170 g/plant, but much higher than that reported by Yavari *et al.* (2008), 45 g. Although strawberry production spanned the period from June to September, biomass accumulation peaked in the last month with most compost-based substrates —by contrast, more than 50% of biomass production in the control substrate occurred in June.

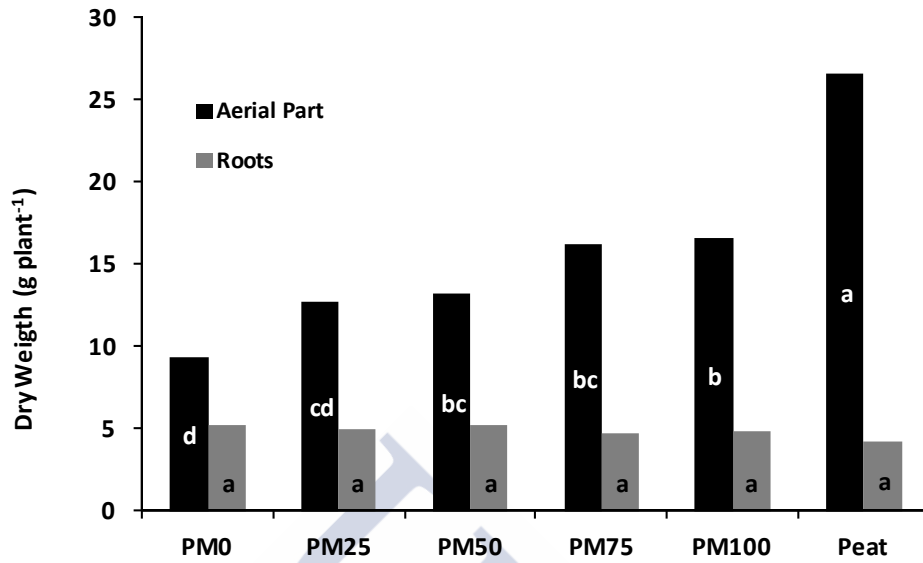


Fig.3.2. Average dry weight of the aerial part and roots of strawberry plants by substrate. Identical letters for the same parameter indicate non-significant differences between treatments (Tukey's Post Hoc test at $p < 0.05$).

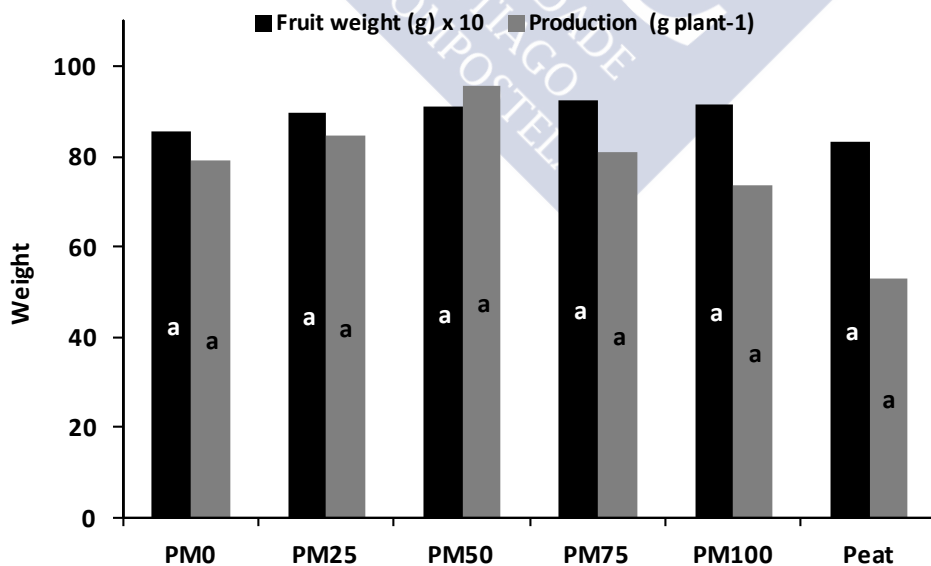
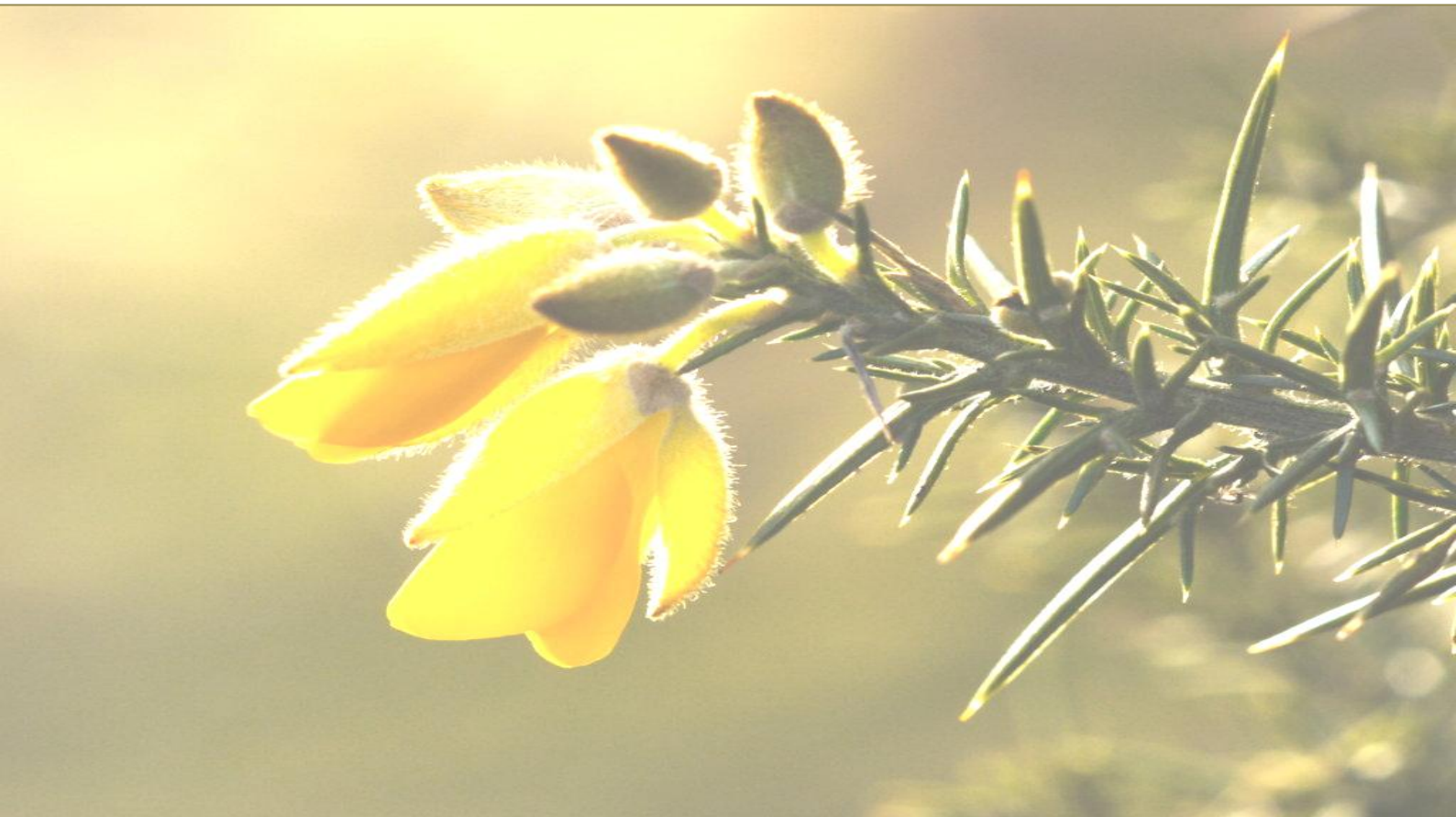


Fig.3.3. Average fruit weight by substrate and total production per plant. Identical letters for the same parameter indicate non-significant differences between treatments (Tukey's Post Hoc test at $p < 0.05$).

4. Conclusions

The two types of gorse compost studied, but particularly that containing poultry manure (PM100), exhibited high contents in major nutrients. Also, their physical properties were acceptable except for a relative low water holding capacity. Nutrient concentration in the solution of the compost-based substrates decreased gradually during strawberry growth (particularly those of N and K, which remained at very low levels during the fruit production stage). The differences in soluble element concentrations of the substrate solutions among composts were fairly small; by contrast, the control substrate exhibited substantial release of nutrients between the 6th and 9th week of cropping. Leaf analyses revealed that N was the scantiest nutrient in the compost-grown plants relative to the control substrate. The chlorophyll contents echoed this result. Aerial biomass in compost-grown plants increased with increasing proportion of poultry manure in the substrate, but plants grown in the control substrate exhibited greater figures. There were no substantial differences in root biomass, overall production or fruit size, however. Although the initial nutrient contents of the composts are adequate for strawberry growing, they require additions of supplementary fertilizer to offset extractions during the growth period.

CHAPTER IV: Natural Suppressive Compost from Forest Cleaning Green Waste.



*Addapted from

López-López, N., Segarra, G., Vergara, O., López-Fabal, A., Trillas, M.I., 2016. Compost from forest cleaning green waste and *Trichoderma asperellum* strain T34 reduced incidence of *Fusarium circinatum* in *Pinus radiata* seedlings. *Biol Control* 95: 31-39.

CHAPTER IV: NATURAL SUPPRESSIVE COMPOST FROM FOREST CLEANING GREEN WASTE AND *TRICHODERMA ASPERELLUM* STRAIN T34 REDUCE THE INCIDENCE OF *FUSARIUM CIRCINATUM* DISEASE IN *PINUS RADIATA* SEEDLINGS.*

Abstract

Fusarium circinatum is a quarantine pathogen that causes important economical losses in forest nurseries throughout the world. Alternatives to chemical control of plant diseases such as suppressive composts and the use of biological control agents in growing media can reduce the incidence and spread of disease. In this work, four gorse composts obtained from forest cleaning green wastes and a reference compost prepared from the organic fraction of solid urban waste were studied as environmentally sustainable peat substitutes. Their suppressiveness against mating types M1 and M2 of the pathogen *F. circinatum* affecting *Pinus radiata* was evaluated in the presence or absence of the biocontrol agent *Trichoderma asperellum* strain T34. One of the gorse composts was more suppressive than the reference compost (15% and 55% of disease incidence, respectively). The former had a low EC, moderate contents of P, Ca, Mg and K, and high contents of NH_4^+ , as well as moderate levels of Ca, B and oligotrophic actinomycetes, the highest levels of total fungi, moderate levels of *Trichoderma* spp. and the lowest levels of *Fusarium* spp. Adding T34 to the moderately suppressive and non-suppressive composts decreased pre- and post-emergence incidence of the disease by up to 50%.

In conclusion, one gorse compost exhibited natural suppressiveness as a growing medium for *Pinus radiata* seedlings by decreasing the incidence of *F. circinatum* disease. Also, *T. asperellum* strain T34 further reduced the incidence and improved the health of pine seedlings grown in moderately non-suppressive composts.

Key words: Cattle slurry, *Gibberella circinata*, gorse, pine, poultry manure.

Highlights

Gorse composts exhibit natural suppressiveness against *F. circinatum* in pine

T34 decreases incidence of *F. circinatum* on moderately suppressive composts.

Seedlings on suppressive composts exhibited greater sizes and higher photosynthesis.

$\text{NH}_4^+/\text{NO}_3^-$ ratio was unrelated to incidence of *F. circinatum* disease in seedlings.

Composts produced at a small scale had high incidence of the disease.

1. Introduction

Pitch canker, which is caused by the fungus *Gibberella circinata* (anamorph *Fusarium circinatum*) Nirenberg & O'Donnell is a serious disease affecting pine plantations and nurseries around the world. Cankers are often associated with conspicuous, occasionally spectacular resin exudates ("pitch"). Multiple-branch infections may cause severe crown dieback and eventually lead to tree death (Dwinnell *et al.*, 2001; Storer *et al.*, 2002). The pitch canker pathogen can also infect seedlings and cause them to exhibit pre- and post-emergence damping off (Storer, 1998). Pitch canker was first reported in North Carolina, United States (Hepting and Roth, 1946) but has since spread throughout the southeast of the country and within California (Dwinnell *et al.*, 2001), Japan (Muramoto and Dwinell, 1990), Mexico (Guerra-Santos, 1999), South Africa (Viljoen *et al.*, 1994), Chile (Wingfield *et al.* 2002) and Spain (Landeras *et al.*, 2005) —the latter country was the first to report the presence of this pathogen in Europe. The European and Mediterranean Plant Protection Organization (EPPO, 2012) considers *F. circinatum* a quarantine pest present in the Mediterranean region but not widely distributed there; also, the disease is officially controlled. Pitch canker infects 57 species of pines (*Pinus* spp.) and Douglas fir (*Pseudotsuga menziesii*) (Quesada *et al.*, 2010; Wingfield *et al.*, 2008; Gordon *et al.*, 2006). Among the pine species, *Pinus radiata* D. Don is considered to be one of the most susceptible to this pathogen (Gordon *et al.*, 2001), the presence of which in nurseries and plantations results in crop and yield losses, high monitoring and control costs, and bans on exports (Pérez-Sierra *et al.*, 2007). Barnard and Blakeslee (1987) recommended growing the *Pinus* species and provenance that is best suited for a specific site. For sites with historically high levels of pitch canker, a more resistant *Pinus* species or genetically resistant genotype can be planted.

Sphagnum peat is the most widely used growth medium in tree nurseries, either alone or as a component of mixed media (Bunt, 1988; Heiskanen, 2013; Landis *et al.*, 1990).

However, finding effective alternatives is desirable because peat is obtained from peatlands, which are being rapidly depleted (Chong, 2005; Guerrero *et al.*, 2002; Ingelmo *et al.*, 1998; Ostos *et al.*, 2007; Wilson *et al.*, 2006). The increasing costs (particularly transportation costs) and declining availability of imported sphagnum peat in many countries have promoted a search for organic substitutes worldwide (Heiskanen, 2013). Thus, seedling growers are searching for more local growth medium components such as compost (Landis and Morgan, 2009). Also, there is a political and environmental drive to reduce the environmental burden of waste production and to increase the use of composts in growth media. In the EU, for example, the eco-label has established a quality assurance system that promotes the use of compost as a soil improver and a component of growth media.

One of the most important incentives to using composts as growth media is their commonly observed suppressive effect against a variety of soil-borne pathogens, as first suggested by Hoitink *et al.* (1975) and later confirmed by many authors (Hoitink and Fahy, 1986; Cotxarrera *et al.*, 2002; Litterick *et al.*, 2004; Noble and Coventry, 2005; Borrero *et al.*, 2006; Castaño *et al.*, 2013). This property is especially important for organic farming, where the use of synthetic pesticides is banned. The use of microorganisms, whether individually or in combination with other measures of disease control, to replace pesticides has grown steadily in recent years (Moraga-Suazo *et al.*, 2011). Biological control provides another effective alternative to chemicals and helps to minimize their adverse impact on human health and the environment (Kim *et al.*, 2003). Moreover, EU Directives (Regulation EC 1107/2009) promote the use of integrated pest and disease management measures against plant diseases.

Trichoderma spp. are free-living fungi, the effectiveness of which has been ascribed to various modes of action including competition with other soil microorganisms for nutrients (Chet *et al.*, 1987), and production of antibiotics and lytic enzymes to parasitize or inhibit other fungi (Harman *et al.*, 1981; Zimand *et al.*, 1996; Howell, 2003). Recent studies have shown that *Trichoderma* spp. can also colonize plant roots and trigger plant defense mechanisms (Olson and Benson, 2007; Segarra *et al.*, 2007, 2009; Trillas and Segarra, 2009). Moraga-Suazo *et al.* (2011) found that three *Trichoderma* spp. strains reduced mortality in *P. radiata* seedlings inoculated with *F. circinatum* to less than 50% if the antagonists were

incorporated into the substrate prior to inoculation. Martínez-Álvarez *et al.* (2012) also succeeded in reducing *F. circinatum* disease by inoculating *Trichoderma viride* in vitro a few days before the pathogen.

Whereas mature compost can sustain biological control agents, immature compost does not support them, so may have an adverse impact on growth in crop plants and may even contain pathogen populations (De Ceuster and Hoitink, 1999; Litterick *et al.*, 2004). This makes using mature, stable compost to test suppressiveness against major pathogens such as *F. circinatum* essential. Compost from gorse (*Ulex europaeus* L.) is a stable material with good physical and chemical properties that make it an effective substitute for peat (Gómez *et al.*, 2009; Iglesias-Díaz *et al.*, 2009). Furthermore, harvesting gorse bush material is essential to prevent forest fires (Badia *et al.*, 2002).

The aim of the study was to evaluate the natural suppressiveness against *F. circinatum* in *P. radiata* seedlings of (i) different gorse composts and compost from the organic fraction of solid urban waste (SUW) mixed with peat and perlite, and (ii) the effect of the presence of *Trichoderma asperellum* strain T34, which was previously shown to be effective against *Fusarium oxysporum*.

2. Materials and methods

2.1. Physical, chemical and physico-chemical properties of the composts

Four different gorse composts were studied, namely: compost produced at a small scale and containing poultry manure (C1), compost obtained at a small scale (C2), compost produced at a large scale and containing cattle slurry (C3) and compost obtained at large scale and allowed to ferment in the wood, where it was collected for transfer to the composting plant to end the process (C4). Additional compost obtained from the organic fraction of SUW containing 25% perlite and 25% peat (C5) was also studied.

All composts were characterized in physical, chemical and physico-chemical terms. Water retention was measured at different suction levels (1, 2.5, 5, 7.5 and 10 kPa) in a sandbox (De Boodt *et al.*, 1974). Bulk density was calculated from volume and dry weight measurements made after oven-drying at 105 °C. Particle density was calculated from the organic matter (OM) and ash contents (EN-13039, 1999) as determined by ashing at 540 °C.

Total porosity was calculated from particle and bulk densities (EN-13041, 1999 and EN-13040, 2007). Electrical conductivity (EC), pH and soluble macronutrients were determined in a 1:5 (v/v) extract (EN-13652, 2001); nitrate and ammonium with an ion-selective electrode; P by UV spectrophotometry at 880 nm (Olsen and Sommers, 1982); and K, Ca, and Mg by atomic absorption/emission spectrophotometry (USEPA, 1995). The samples (replicates) were used per compost.

2.2 Microbial characterization of the composts

Cellulolytic actinomycetes (CA), *Bacillus* spp. (B), oligotrophic actinomycetes (OA) and total fungi (F) were determined by dilution plating on semi-selective media, using the procedure described by Tuitert *et al.* (1998) as modified by Borrero *et al.* (2004). Populations of *Fusarium* spp. (FUS) were measured using a semi-selective medium (Komada, 1975). Three samples (replicates) were studied per compost. Two plates were used for each medium and dilution of each sample.

2.3. Microorganisms used

T. asperellum strain T34 was grown in an agitated liquid medium containing 10 g/L malt for 5 days at 30°C. The culture was filtered to remove the mycelium and centrifuged at 10 000 g. The pellet was washed twice in distilled water to obtain medium-free conidia.

One isolate (the most pathogenic) of each mating type (MAT1 and MAT2) of *F. circinatum* were obtained from the Areeiro Phytopathological Station (Pontevedra, Spain) and cultivated in the same way as T34.

2.4. *Trichoderma* spp. concentration in the composts

To study the population density of *Trichoderma* spp. at the beginning and end of the experiments, two samples from each compost were randomly selected from each of the three blocks (see following section) and subjected to dilution plating on semiselective media designed for *Trichoderma* spp. (Chung and Hoitink, 1990).

2.5. Assessment of disease incidence

Disease suppression by the composts was assessed via a *F. circinatum* (Fc) bioassay. In order to standardize the initial moisture conditions, the composts were saturated in culture trays for 24 h and then drained for 3 days. The trays were covered to prevent evaporative loss during the process. Subsequently, the composts were placed in plastic bags for inoculation with the pathogens or biocontrol agent in accordance with the experimental design.

The bioassay was established in response to three factors, namely: composts, pathogen inoculum and biocontrol agent. The Fc strains MAT1 (M1) and MAT2 (M2) were used as pathogens and *T. asperellum* strain T34 (T34) as biocontrol agent. Thus, each compost was subject to six different treatments, namely: (1) no pathogen or biocontrol agent (Control, -T34); (2) T34 no pathogen but (Control, +T34); (3) M1 but no T34 (M1, -T34); (4) M1 and T34 (M1, +T34); (5) M2 but no T34 (M2, -T34) and (6) M2 and T34 (M2, +T34). First, T34 was inoculated at a rate of 10^4 conidia mL⁻¹ compost. Then, M1 or M2 were inoculated at 10^3 conidia mL⁻¹ 1 day later. Inoculated composts were stored in bags and shaken every day for a week.

Seeds were supplied by the official tree nursery of Xunta de Galicia and imbibed in distilled water for 48 h before planting. Then, one seed per cell was placed in forest size trays (220 cm³ each). For each treatment, 10 seeds were planted in each tray cell. The bioassay was replicated three times per treatment and treatments were arranged in a randomized block design.

Trays remained in an EGC walk-in chamber under controlled conditions of temperature (25 °C), relative humidity (60%) and photoperiod (12 h, 150 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) throughout the bioassay. Plants were irrigated on a daily basis with Peters Professional® solution [(27:15:12) + B, Cu, Fe, Mn, Mo and Zn) supplemented with CaCl₂ and MgSO₄.

Disease incidence was monitored at 1-day intervals for 51 days after sowing. Germination was assumed to end 30 days after sowing, which signalled the end of pre-emergence and start of post-emergence. Disease incidence was scored on a symptom scale with 0 for asymptomatic plants and 1 to symptomatic or dead plants. Those plants not germinating by the end of the pre-emergence stage were considered to be dead.

2.6. Biomass and physiological analysis of plants

At the end of the study, two healthy plants per treatment and per block (six plants per treatment) were randomly selected for assessing photosynthesis, stomatal conductance and transpiration. These parameters were determined on a model LI-6400 infrared gas analyser from Li-Cor, Inc. (Lincoln, NE, USA) equipped with a special camera to measure conifers (LI-05-6400). Twelve plants were used to estimate total plant leaf area before drying by using a GT-5000 flat-bed scanner from Epson (Nagano, Japan) to obtain images that were processed with imaging software (Nogués *et al.*, 2001). Plant height and root length measurements were followed by measurements of dry weight of the aerial parts and roots of all seedlings in combination. Plants were dried to constant weight in an oven at 105 °C. Leaf, shoot and root dry weights roots were measured in two plants per block per treatment.

2.7. Statistical analysis

The three principal components (independent variables) examined were (a) type of compost, (b) presence or absence of *T. asperellum* strain T34 and (c) presence or absence of *F. circinatum* inoculum. Data were processed by multivariate analysis of variance (MANOVA) for statistical analysis and the LSD test for post-hoc analysis. Differences between data pairs with $F < 0.05$ were assumed to be significant. Data normality was previously confirmed via the Kolmogorov–Smirnov test and variance homogeneity via Levene’s comparison test. All statistical calculations were done with the software PASW Statistics v. 18.

3. Results

3.1. Characterization of the composts

There were significant differences in physical, chemical and physico-chemical properties between gorse composts and the compost obtained from the organic fraction of USW, and also between composts obtained on a small and large scale (Table 4.1). Thus, gorse composts had lower BD values than USW compost (particularly that produced on a large scale). Gorse composts also had higher AC and OM values, but lower pH values, than USW compost. Small scale-produced composts (C1, C2 and C5) had higher EC and Ca concentrations than large scale-produced composts (C3 and C4). The best composts (C4, C2

and C3) had higher TP values than the others. Small scale-produced gorse composts had the highest NO_3^- and Mg contents, whereas C3 had the lowest NH_4^+ content, and C1 and C5 the highest K contents. Compost C5 had the highest pH and AW values, but the lowest OM, NO_3^- , P and Mg contents. P levels, however, were widely variable and could not be ranked by composition or production scale. C4 had a moderate pH and low EC values, in addition to moderate levels of P, Ca, Mg and K, and high levels of NH_4^+ (Table 4.1).

Table 4.1. Physical, chemical and physico-chemical properties of the composts^X.

C ^Y	BD	TP	AC	AW	UW	OM	pH
C1	0.27 b	85.34 c	43.20 b	13.43 c	28.70 c	65.18 c	4.70 b
C2	0.18 c	90.85 b	45.81 b	14.95 c	30.08 c	52.61 d	3.50 c
C3	0.14 d	91.33 b	37.06 c	17.33 b	37.01 a	84.04 a	4.02 c
C4	0.13 e	92.82 a	56.35 a	10.73 d	25.74 d	68.92 b	4.68 b
C5	0.32 a	84.86 c	25.67 d	24.60 a	34.59 b	34.20 e	7.95 a
C ^Y	EC	NH_4^+	NO_3^-	P	Ca	Mg	K
C1	1.66 a	107.51 c	3,834.41 b	98.35 a	641.70 a	193.60 a	945.00 a
C2	1.03 c	135.02 b	4,405.30 a	39.30 d	318.35 b	188.55 a	545.00 b
C3	0.53 d	31.05 d	1,054.33 c	59.80 c	49.85 e	58.05 b	475.00 b
C4	0.35 e	206.50 a	1,030.10 c	70.36 b	87.35 d	61.90 b	487.00 b
C5	1.10 b	103.95 c	543.91 d	20.45 e	225.70 c	28.75 b	1010.00 a

Mean values and post-hoc LSD. Values followed by different letters in each column are significantly different at $P < 0.05$ as per the LSD test.

^XBD, bulk density (g cm^{-3}); TP, total porosity (%); AC, aeration capacity (%); AW, available water (%); UW, unavailable water (%); OM, total organic matter (%). pH; EC, electrical conductivity (dS cm^{-1}); NH_4^+ , NO_3^- , P, Ca, Mg, K (mg L^{-1} substrate) in 1:5 (v/v) extract.

^YCompost: C1, gorse compost produced at a small scale and containing poultry manure; C2, gorse compost produced at a small scale; C3, gorse compost produced at a large scale and containing cattle slurry; C4, gorse compost produced at a large scale; C5, 50% compost of organic fraction of USW + 25% perlite + 25% peat, produced at a small scale.

Based on microbial populations, C1 and C5 had the highest levels of CA (Table 4.2). All gorse composts contained similar levels of *Bacillus* spp. that were significant lower than those in C5. OA levels were lower for small scale-produced than for large scale-produced gorse composts and peaked in C5. Finally C4 had the highest levels of (F) and lowest of *Fusarium* spp., whereas C5 and C2 had the highest levels of *Fusarium* spp. (Table 4.2).

Table 4.3 illustrates the correlations between physico-chemical/chemical and microbial properties in the composts. As can be seen, OM correlated negatively with the populations of actinomycetes, B and FUS; EC correlated with increased CA and negatively with F populations and pH correlated positively with the populations of actinomycetes and B and

correlated negatively with T. On the other hand, NO₃⁻ levels correlated negatively with B, OA and F and correlated positively with T. NH₄⁺ levels favoured overall fungal growth. Also, high levels of Ca correlated negatively with populations of fungus; Mg correlated negatively with B and OA and positively with T; K correlated positively with the populations of actinomycetes and B and P correlated negatively with B, OA and FUS.

Table 4.2. Initial microbiological properties of the composts^X.

C ^Y	CA	B	OA	F	FUS
	× 10 ⁵ CFU/mL compost				
C1	70.313 a	18.805 b	1.7169 c	1.7169 b	0.1308 c
C2	2.0969 d	26.185 b	6.8081 c	0.3025 c	0.6958 a
C3	11.490 c	32.238 b	46.004 b	2.0677 bc	0.3446 b
C4	32.390 b	4.7263 b	37.279 bc	19.780 a	0.0001 c
C5	124.83 a	110.86 a	98.899 a	6.2186 b	0.7441 a

Values followed by different letters in each column are significantly different at $P < 0.05$ as per the LSD test.

^XCA = cellulolytic actinomycetes, B = *Bacillus* spp., OA = oligotrophic actinomycetes, F = fungi, FUS = *Fusarium* spp.

^YComposts: C1, gorse compost produced at a small scale and containing poultry manure; C2, gorse compost produced at a small scale; C3, gorse compost produced at a large scale and containing cattle slurry; C4, gorse compost produced at a large scale; C5, 50% compost of organic fraction of USW + 25% perlite + 25% peat, produced at a small scale.

Table 4.3. Pearson correlation coefficients of physico-chemical and chemical properties with microbiological properties of the plant growth media as evaluated in bioassays.

	OM	EC	pH	NO ₃ ⁻	NH ₄ ⁺	Ca	Mg	K	P
CA	-0.497**	0.379*	0.723**	-0.191	0.062	0.280	-0.164	0.683*	-0.108
B	-0.599**	0.146	0.700**	-0.385*	-0.216	-0.102	-0.426*	0.498**	-0.598**
OA	-0.399*	-0.041	0.544**	-0.510**	-0.110	0.235	-0.506*	0.303*	-0.489*
F	0.107	-0.483**	0.002	-0.343*	0.586**	-0.361*	-0.293	-0.256	0.124
T	0.428	0.043	-0.585**	0.412*	-0.312	0.108	0.423*	-0.341	0.238
FUS	-0.627**	0.187	0.318	0.045	-0.312	-0.058	-0.037	0.221	-0.768**

OM, total organic matter (%). pH; EC, electrical conductivity (dS cm⁻¹) and NH₄⁺, NO₃⁻, P, Ca, Mg, K (mg L⁻¹ substrate) in 1:5 (v/v) extract. CA = cellulolytic actinomycetes,

B = *Bacillus* spp., OA = oligotrophic actinomycetes, F = fungi, T = *Trichoderma* spp., FUS = *Fusarium* spp.

* Significant correlation at $P < 0.05$.

** Significant correlation at $P < 0.01$.

3.2. Assessment of disease incidence

There were significant differences ($P < 0.05$) in disease incidence between pine seedlings at the pre-emergence stage, particularly in factors (Fc) and (T34) (Fig. 4.1). Isolate M2 (30%) caused more deaths than M1 (25%) at the pre-emergence stage (Fig. 4.1a), but the differences were not significant; also, it led to increased disease incidence in the composts receiving no T34 inoculum (Fig. 4.1b).

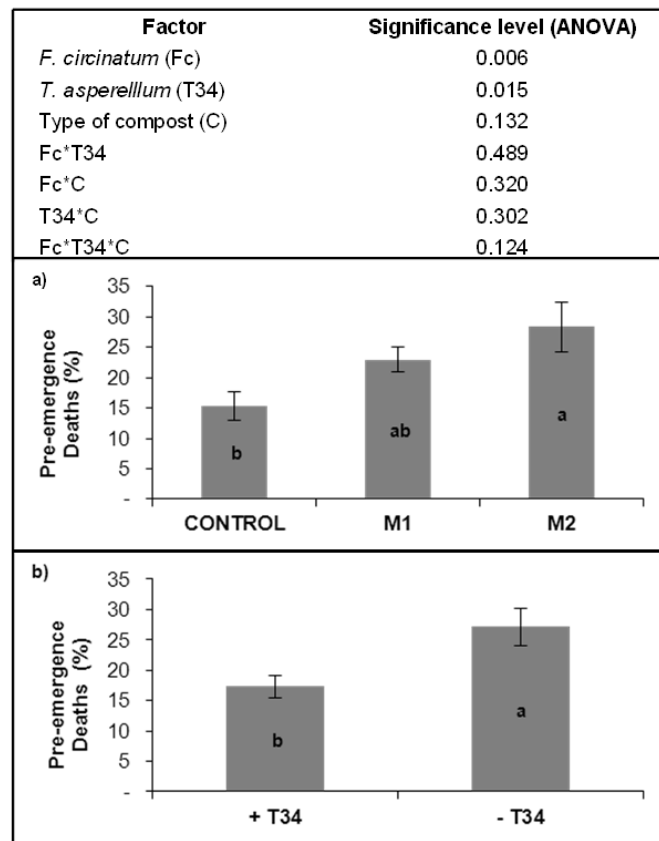


Fig. 4.1. Disease incidence at the pre-emergence stage in *Pinus radiata* D. Don seedbeds. Significance level (ANOVA) for *Fusarium circinatum* (Fc), *Trichoderma asperellum* (T34), type of compost (C) and their main interactions. (a) Preemergence deaths according to factor T34 (-T34 = without *Trichoderma* and +T34 = with *Trichoderma* at 10^4 conidia cm^{-3}); (b) pre-emergence deaths according to factor Fc (Control = without Fc; M1 and M2 = with *Fusarium circinatum* MAT 1 and MAT 2, respectively, at 10^3 microconidia cm^{-3}). Mean values, S.E. in error bars and post hoc LSD. Different letters in each column are significantly different at $P < 0.05$ as per the LSD test.

There were also significant differences ($P < 0.05$) in disease incidence between pine seedlings at the post-emergence stage, especially in factors Fc and T34, and also between composts (C) (Fig. 4.2). Isolates M1 and M2 led to similar levels of incidence at this stage; also, such levels were significantly higher than those in the control (uninoculated) composts (Fig. 4.2a). Post-emergence deaths were also significantly greater in number in those composts receiving no T34 inoculum (Fig. 4.2b). C4 was the most suppressive compost against Fc (15% post-emergence deaths), followed by C2 (25%), C3 (30%) and C5 (35%); on the other hand, C1 (55%) was the most conducive (Fig. 4.2c).

The highest correlations of pre- and post-emergence deaths with physical properties of the composts were those for bulk density, which influenced total porosity and aeration in the composts and high UW levels were directly correlated with a high pre-emergence incidence of disease (Table 4.4). Moreover, high EC levels correlated positively with disease incidence but only at the post-emergence stage. NH_4^+ correlated negatively with disease incidence in *P. radiata* at pre- and post-emergence. Finally, Ca correlated positively with disease incidence at the post-emergence stage while K correlated positively with disease both at pre and post-emergence (Table 4.4).

Table 4.4. Pearson correlation coefficients of physical and physico-chemical properties of the plant growing media as evaluated in bioassays and disease incidence at the pre- and postemergence stages.

	BD	TP	AC	AW	UW	OM	EC	pH	NO_3^-	NH_4^+	Ca	Mg	K	P
PRE	0.307*	-0.304*	-0.342**	0.608	0.284*	-0.193	0.238	0.205	0.001	-0.271*	0.128	0.009	0.277*	-0.154
POST	0.425**	-0.501**	-0.299*	0.228	0.170	-0.069	0.515**	0.143	0.182	-0.337**	0.456**	0.197	0.472**	0.196

BD, bulk density (g cm^{-3}); TP, total porosity (%); AC, aeration capacity (%); EAW, easily available water (%); WCB, water buffering capacity (%); UW, unavailable water (%); OM, total organic matter (%). pH; EC, electrical conductivity (dS cm^{-1}) and NH_4^+ , NO_3^- , P, Ca, Mg, K (mg L^{-1} substrate) in 1:5 (v/v) extract.

PRE = disease incidence at the pre-emergence stage; POST = disease incidence at the post-emergence stage.

* Significant correlation at $P < 0.05$. ** Significant correlation at $P < 0.01$.

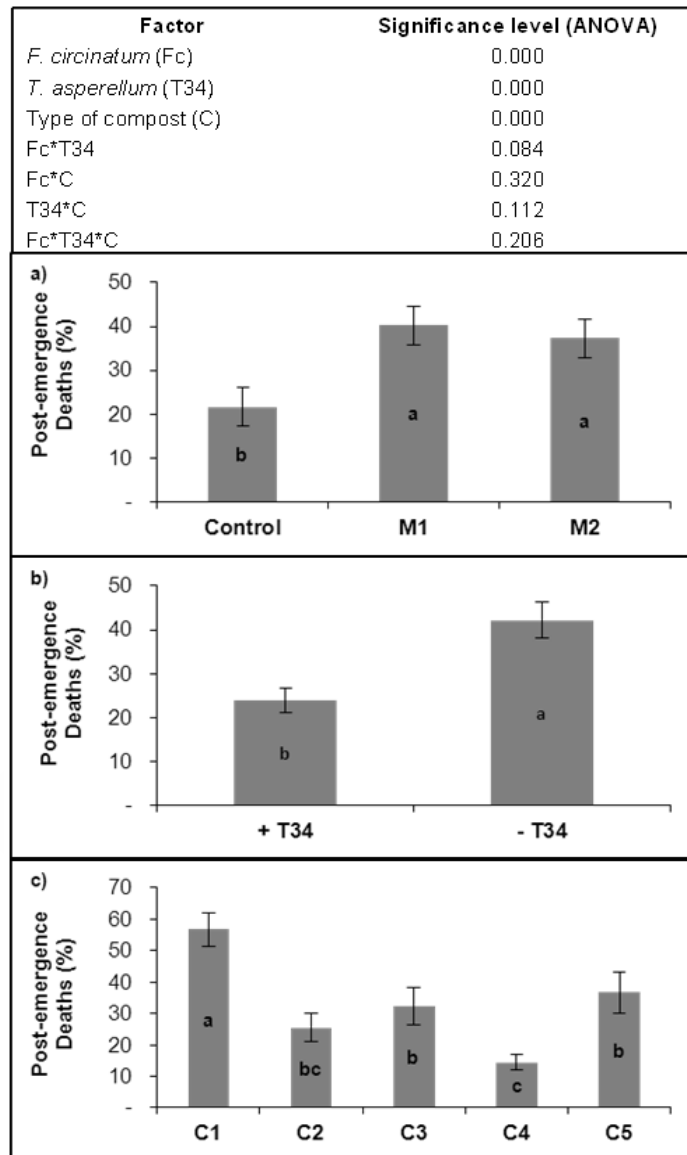


Fig. 4.2. Disease incidence at the post-emergence stage in *Pinus radiata* D. Don seedbeds. Significance level (ANOVA) for *Fusarium circinatum* (Fc), *Trichoderma asperellum* (T34), type of compost (C) and their main interactions. (a) Postemergence deaths according to factor T34 (-T34 = without *Trichoderma*; +T34 = with *Trichoderma* at 104 conidia cm⁻³); (b) post-emergence deaths according to factor F (Control = without *Fusarium circinatum*; M1 and M2 = with *Fusarium circinatum* MAT 1 and MAT 2, respectively, at 10³ microconidia cm⁻³); (c) postemergence deaths according to factor C (C1 = gorse compost produced on a small scale and containing poultry manure; C2 = gorse compost produced on a small scale; C3 = gorse compost produced on a large scale and containing cattle slurry; C4 = gorse compost produced on a large scale; C5 = reference substrate consisting of 50% compost from organic fraction of USW (Urban Solid Waste) + 25% perlite + 25% peat. Mean values, S.E. in error bars and post hoc LSD. Different letters in each column are significantly different at P < 0.05 as per the LSD test.

3.3. Plant biomass and physiological analysis

There were significant differences ($P < 0.05$) in aerial height and dry weight (Fig. 4.3); thus, plants grown in composts receiving no T34 inoculum were on average 20 mm longer than those grown with T34 (Fig. 4.3a). There were also significant differences ($P < 0.05$) in aerial and root biomass between seedlings at the end of the study depending on the compost used (C) (Fig. 4.3). Thus, plants grown on C4, C3 and C2 had significantly greater height, dry weight and root length than those grown on C5 or C1 (Fig. 4.3). The interactions Fc*T34 and Fc *T34 *C were also significantly different ($P < 0.05$) on aerial dry weight (Fig. 4.3).

The physiological factors examined varied significant differences ($P < 0.05$) according to factor (Fc) and photosynthesis in *P. radiata* seedlings, as well as in factor C (Fig. 4.4). Thus, there were significant differences in photosynthesis-related measurements between healthy *P. radiata* seedlings inoculated with the pathogen (M1 or M2) and the control plants at the post-emergence stage (Fig. 4.4a). Seedlings grown on C4 had the highest photosynthetic rates and stomatal conductance (Figs 4.4b and 4.4d), and, together with those grown on C2, the highest transpiration rates (Fig. 4.4c). Composts C2 and C3 had intermediate values in the other physiological properties studied, and C1 and C5 the lowest (Figs 4.4b–4.4d).

Disease incidence in pine seedlings was significantly correlated, both pre- and post-emergence, with aerial and root growth, and also with all physiological properties (results not shown).

3.4. Evolution of *Trichoderma* spp.

Composts C2 and C3, which contained the highest levels of natural *Trichoderma* spp., exhibited the lowest levels upon inoculation with T34 (Table 4.5). Conversely, the composts with the lowest levels of natural *Trichoderma* spp. had the highest levels of *Trichoderma* spp. upon inoculation with T34 (particularly C5). In the presence of pathogen (M2), *Trichoderma* spp. levels were maintained throughout the study in the composts with the largest initial populations. Worth special note here are the low levels of natural *Trichoderma* spp. in compost C4, which became the highest upon inoculation with M2 and T34.

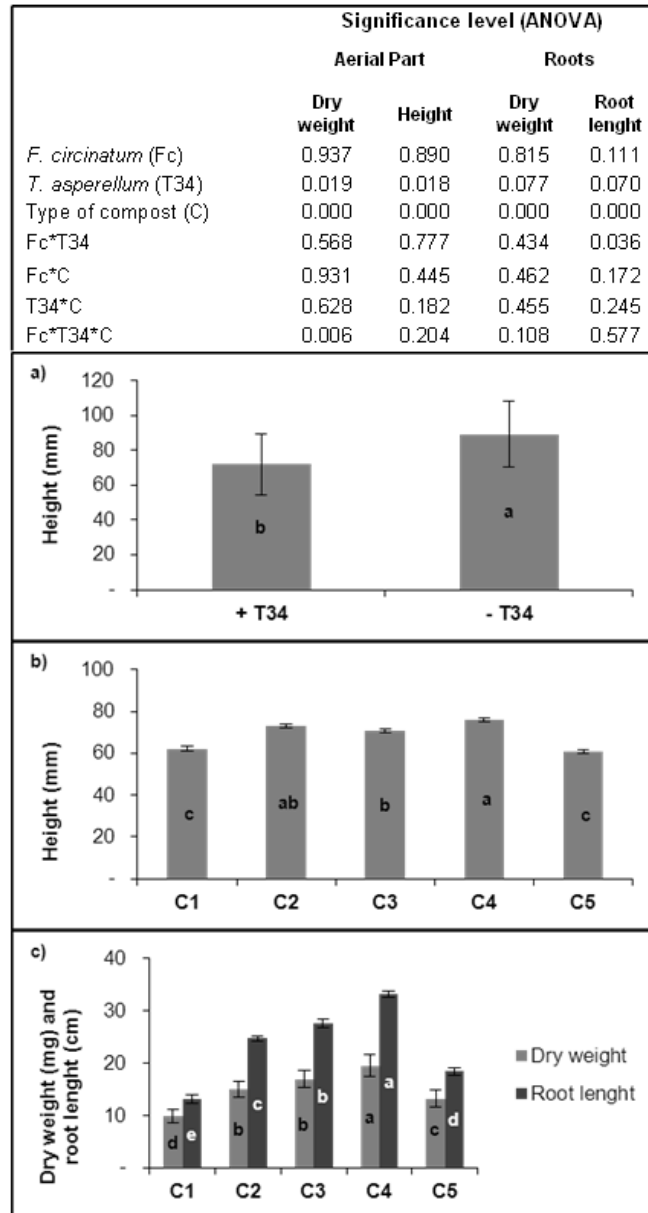


Fig. 4.3. Biomass measurements of *Pinus radiata* D. Don seedlings at the end of the bioassay. Significance level (ANOVA) for *Fusarium circinatum* (Fc), *Trichoderma asperellum* (T34), type of compost (C) and their main interactions. (a) Height of the aerial part of seedlings according to factor T34 (-T34 = without *Trichoderma*; +T34 = with *Trichoderma* at 10^4 conidia cm^{-3}); (b) height of the aerial part of seedlings according to factor C; (c) dry weight and root length of the root part of seedlings according to factor C (C1 = gorse compost produced on a small scale and containing poultry manure; C2 = gorse compost produced on a small scale; C3 = gorse compost produced on a large scale and containing cattle slurry; C4 = gorse compost produced on a large scale; C5 = reference substrate consisting of 50% compost from the organic fraction of USW (Urban Solid Waste) + 25% perlite + 25% peat. Mean values, S.E. in error bars and post hoc LSD. Within each column of the same color tone, different letters in each column of the same color are significantly different at $P < 0.05$ as per the LSD test.

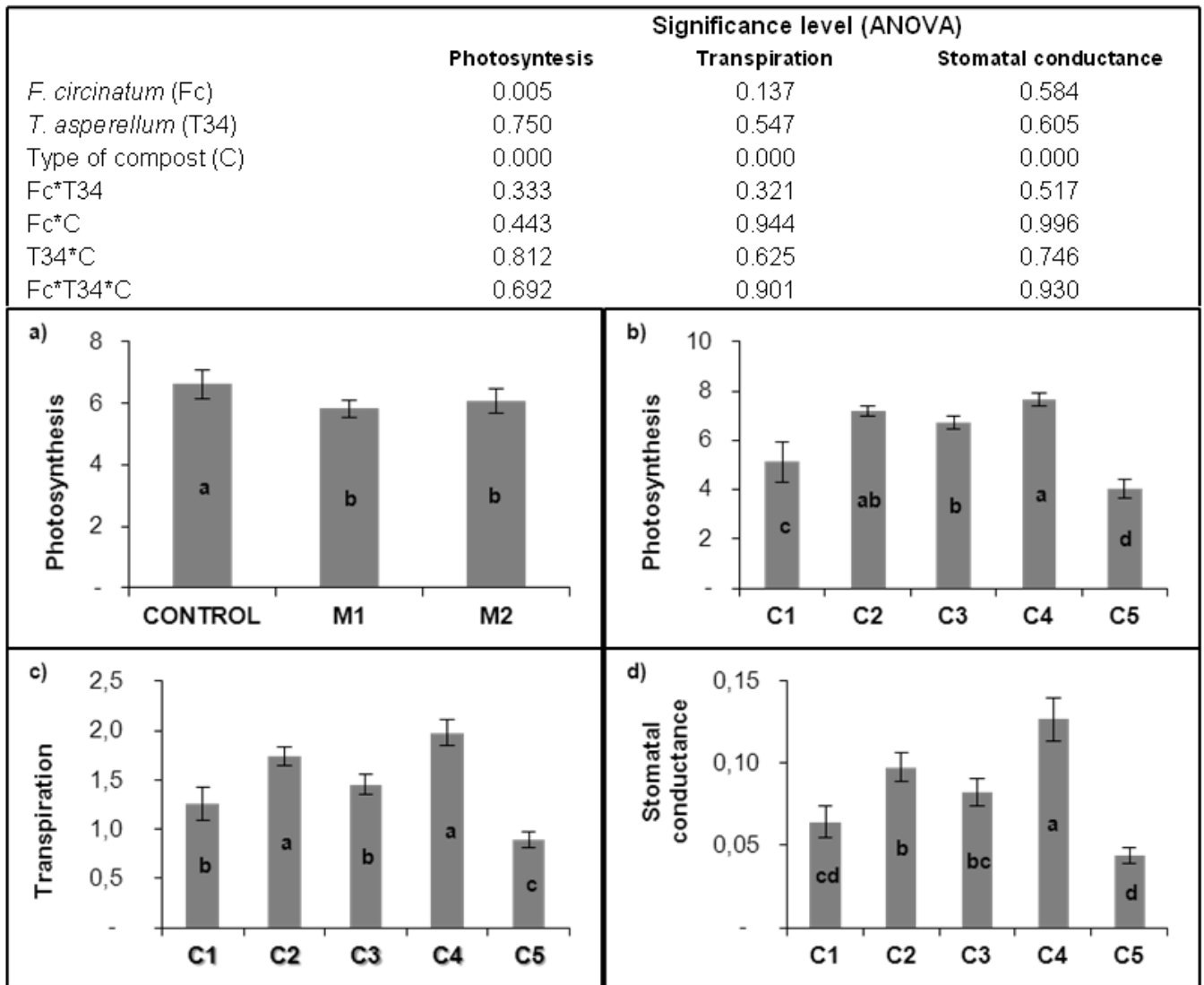


Fig. 4.4. Physiological properties of *Pinus radiata* D. Don seedlings at the end of the bioassay.

Significance level (ANOVA) for *Fusarium circinatum* (Fc), *Trichoderma asperellum* (T34), type of compost (C) and their main interactions. (a) Rate of photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) according to factor Fc (Control = without *Fusarium circinatum*; M1 and M2 = with *Fusarium circinatum* MAT 1 and MAT 2, respectively, at 10^3 microconidia cm^{-3}); and (b) rate of photosynthesis ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), (c) stomatal conductance ($\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) and (d) transpiration rate ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) according to factor C (C1 = gorse compost produced on a small scale and containing poultry manure; C2 = gorse compost produced on a small scale; C3 = gorse compost produced on a large scale and containing cattle slurry; C4 = gorse compost produced on a large scale; C5 = reference substrate consisting of 50% compost from the organic fraction of USW (Urban Solid Waste) + 25% perlite + 25% peat. Mean values, S.E. in error bars and post hoc LSD. Different letters in columns of the same color are significantly different at $P < 0.05$ as per the LSD test.

Table 4.5. *Trichoderma* spp. concentration of the five plant growth medium at the end of the bioassay x 10⁴ CFU/cm³ of plant growth medium^y

C ^x	CONTROL						M2					
	-T34			+T34			-T34			+T34		
C1	40.880	ab	D	116.460	ab	A	1.848	b	C	8.355	d	B
C2	52.370	a	A	41.882	b	B	39.600	a	B	51.774	c	B
C3	55.583	a	A	35.578	b	B	57.557	a	B	165.940	b	B
C4	15.361	bc	B	121.060	ab	AC	71.347	a	C	395.790	a	A
C5	0.151	c	A	224.140	a	B	1.071	b	A	83.760	b	A

^x C1, gorse compost produced on a small scale with poultry manure; C2, gorse compost produced on a small scale; C3, gorse compost produced on a big scale with cattle slurry; C4, gorse compost produced on a big scale; C5, 50% compost of organic fraction of USW+ 25% perlite + 25% peat.

^y Control= without *Fusarium circinatum*; M2 = with *Fusarium circinatum* MAT 2 at 10³ microconidia cm⁻³; -T34= without *T. asperellum* T34; +T34= with *T. asperellum* T34 at 10⁴ microconidias cm⁻³. Media values and LSD post hoc. Within each row, values followed by different capital letters; and within each column, values followed by different small letters, are significantly different based on LSD's test at P < 0.05.

4. Discussion

Most of the physical, chemical and physico-chemical properties studied were correlated with the sources of the raw materials, whether primary (gorse and USW) or secondary (poultry manure, cattle slurry), as well as with the scale of the composting process (small or large) (Zamora-Nahum *et al.*, 2007). Fisher *et al.* (1981) and Blakeslee *et al.* (1999) previously found high levels of fertilizer made plants more susceptible to pitch canker disease. Our results are consistent with theirs: disease incidence was correlated with K, Ca and EC levels. Also, high pH values have been associated with large populations of bacteria and actinomycetes (Waksman, 1927), and used as a predictive factor against *Fusarium* wilt in tomato grown on various kinds of compost (Borrero *et al.*, 2004). Our results are consistent with a link between pH and microbial populations, but not with suppression of *F. circinatum*; in fact, the most conducive compost (C5) exhibited the highest levels of actinomycetes and bacillus. Also, *F. circinatum* disease could not be predicted from the NH₄⁺/NO₃⁻ ratio because the most suppressive and conducive composts (C4 and C5, respectively) had similar ratios — which contradicts previous results for *F. oxysporum* disease (Borrero *et al.*, 2012).

The levels of *Fusarium* spp. found in C2, C3 and C5 cannot be assumed to correspond to non-pathogenic saprophytic *Fusarium* spp. exclusively because the control plants

exhibited a slight disease incidence even though they were not inoculated with *F. circinatum*. The incidence of the disease was significantly reduced in the control plants treated with T34 but receiving no pathogen. For example, composts C3 control –T34 and +T34 had a disease level of 0.33 ± 0.03^a and 0.00 ± 0.0^b , respectively, and composts C5 control –T34 and + T34 one of 0.13 ± 0.07^a and 0.07 ± 0.03^{ab} , respectively. These composts may have contained other pathogenic *Fusarium* spp. besides *F. circinatum* or other soil-borne plant pathogens not removed during the thermophilic phase of the composting process (Noble and Roberts, 2004). The presence of disease in the control plants may also have originated in the seeds.

C4 was the most suppressive compost pre- and post-emergence with both M1 and M2. Although T34 failed to reduce disease incidence in this compost, it proved effective in moderately and non-suppressive composts (up to 50% in C2 and C5 post-emergence with M2). Similar results were previously obtained for T34 against *Rhizoctonia solani* by using composts of variable suppressiveness (Trillas *et al.*, 2006). Other studies also showed strains UDC-280, UDC-351 and UDC-404 of *Trichoderma* spp. to reduce death in *P. radiata* seedlings by up to 50% after enrichment of the growing media prior to inoculation with *F. circinatum* (Moraga-Suazo *et al.*, 2011). *Trichoderma asperellum* strain T34 also proved effective against *F. oxysporum* f. sp. *dianthus* (Sant *et al.*, 2010), f. sp. *lycopersici* (Cotxarrera *et al.*, 2002; Segarra *et al.*, 2010; Borrero *et al.*, 2012) and other soil pathogens (Segarra *et al.*, 2013). There have been many studies on the application of antagonistic microbes for biological control of *Fusarium* wilts including *Bacillus* spp., nonpathogenic *Fusarium* spp., *Pseudomonas* spp., *Penicillium* spp, *Trichoderma* spp., *Paenibacillus* spp., etc. (Fuchs *et al.*, 1999; Sabuquillo *et al.*, 2006; Hervas *et al.*, 1998; Dijksterhuis *et al.*, 1999)

With regards microbial populations in the composts, C4 exhibited the highest levels of total fungi, the lowest concentrations of *Fusarium* spp. and moderate levels of natural *Trichoderma* spp. compared to the other composts. As previously found in other suppressive composts (Hoitink *et al.* 1993), allowing C4 to remain in the forest during the first stage of the composting process may have facilitated natural colonization by beneficial antagonistic microorganisms. This compost exhibited the highest levels of *Trichoderma* spp. —not necessarily T34— in the presence of pathogen (M2). However, the presence of T34 in C2 and C5 reduced disease incidence but increased the population of *Trichoderma* in C5. In previous studies on *F. oxysporum* disease, the presence of the pathogen also increased T34

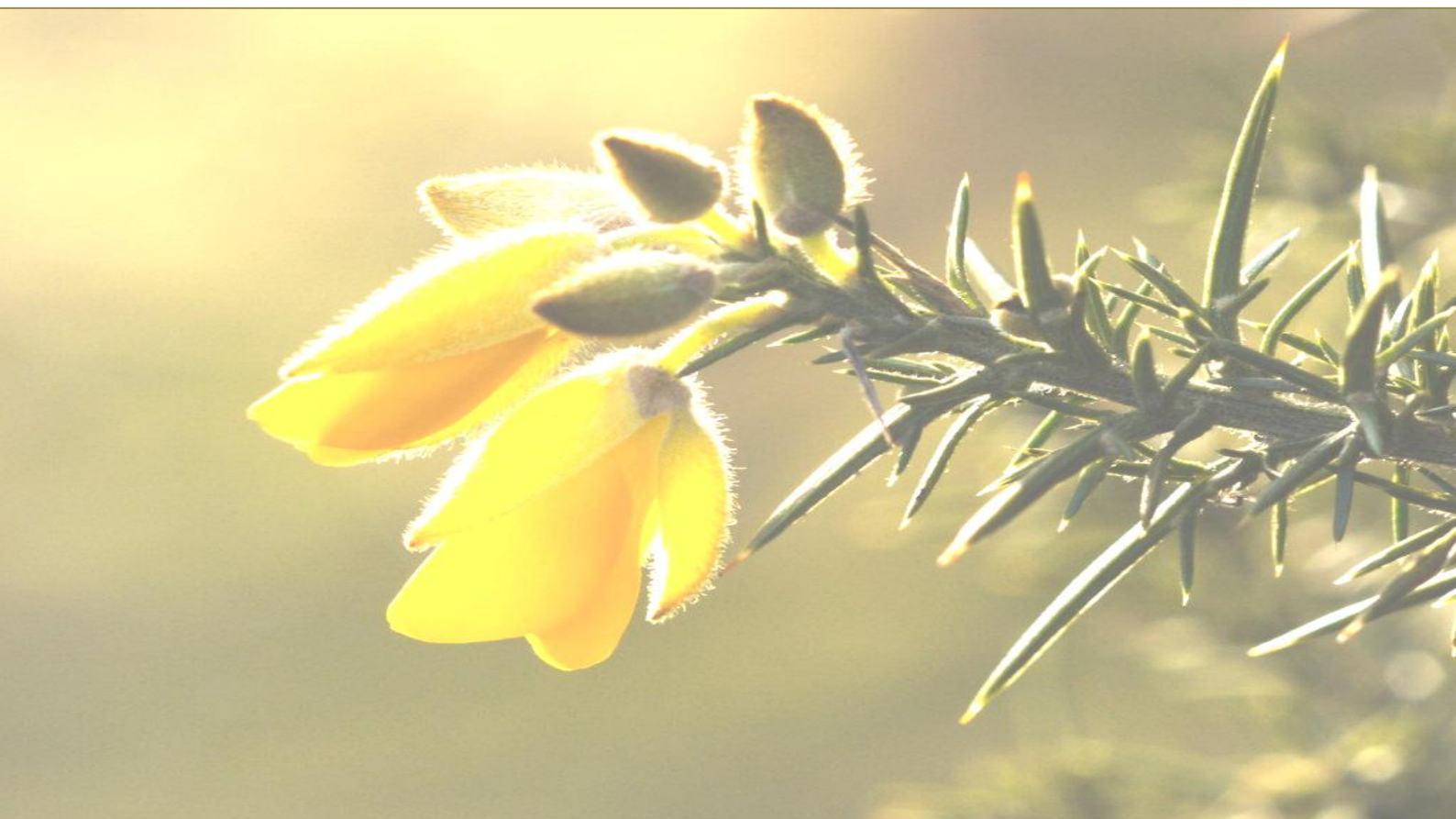
populations (Borrero *et al.*, 2012; Sant *et al.*, 2010). The populations of *Trichoderma* spp. found in C5 must have been exclusively or largely due to T34. In C2, however, *Trichoderma* populations changed very little, whether the pathogen M2 was present or absent.

Some *Trichoderma* spp. strains not only triggered plant defence responses, but also enhanced growth through rhizosphere competition (Shoresth *et al.*, 2005 and Verma *et al.*, 2007). This was also echoed by the results: the plants grown on the composts containing T34 exhibited greater aerial growth in terms of dry weight and vigor —pines exhibited greater dry weights but lower heights (results not shown). Hohmann *et al.* (2012) obtained similar results for *P. radiata* seedlings inoculated with *Trichoderma hamatum* strain LU592, which increased the height of aerial shoots and stem diameter by 16% and 8%, respectively. In this work, C4 led to the greatest aerial and root length, and also greatest weight. These results are consistent with all physiological parameters measured with pine seedlings grown on Fc inoculated compost C4 as control plants. Surviving plants grown on compost C4 were healthier than those grown on the other composts. Finally, the plants grown on C5, which had the lowest photosynthesis rates, exhibited some metabolic deficiencies suggesting that they might be overcoming the disease.

5. Conclusions

All studied composts exhibited suitable physical and physico-chemical properties for use as nursery growing media for *P. radiata*. Furthermore, gorse compost produced at a large scale exhibited natural suppressive properties against the *F. circinatum* disease. The naturally suppressive compost had high AC, low EC, high NH_4^+ , and low Ca and K levels. The biological control agent *T. asperellum* strain T34 reduced pre- and post-emergence incidence of the disease in the moderately suppressive composts, which testifies to its potential as an effective alternative to chemical treatment against *F. circinatum* in *P. radiata* seedling production.

CHAPTER V: General Discussion and Conclusions



CHAPTER V: GENERAL DISCUSSION AND CONCLUSIONS

1. General discussion

The previous three chapters present the results and main conclusions on the suitability of gorse compost as a plant-growing substrate for organic agriculture. All experiments conducted in this work were intended to be not only reproducible, but also comprehensive, so that they could be used as references for the processing, management and valorization of currently unexplored but potentially useful resources.

Prioritizing the exploitation of local resources honours the potential and richness of the Galician territory by valorizing what a large-scale economy has hidden from our agricultural view in the past few decades (Pearce and Moran, 1994). Also, it has facilitated the recovery of natural biological cycles by integrating them into more sustainable, harmonic and environmentally friendly management schemes (Altieri, 2004). Both aims are consistent and in line with the production system supported by organic agriculture, which seeks to preserve soil, ecosystems and personal health by promoting ecological processes, biodiversity and locally adapted cycles instead of inputs with adverse effects. In fact, organic agriculture combines tradition, innovation and science for the invariable benefit of the environment and to foster fair relations and quality of life for all stakeholders (IFOAM, 2009).

The primary aim of this work was to meet the increasing demand for nursery plant production in Galicia. Plant growers need suitable, more inexpensive materials for use as growing substrates in organic farming. This need prompted a search for a raw material potentially fulfilling these requirements that started with the analysis and evaluation of gorse clearing residues (*Ulex europeaus* L.).

Gorse has elicited great interest in Galicia on account not only of its abundance in the region, but also of its high sprouting capacity (Willians, 1997), its potential for use in variable degrees of lignification (Masaguer *et al.*, 2015) and its widespread occurrence worldwide. In fact, although gorse originated in central and western Europe, and in the British Isles (Allen and Allen, 1981), it is also present in North America, South America, India, New Zealand and Australia (Gaynor and MacCarter, 1981; Holm *et al.*, 1977; Hoshovsky, 1986). In fact, gorse is a bushy legume spanning large areas whose pioneering, invasive potential has facilitated

colonization of degraded land, improvement of soil fertility (MacCarter and Gaynor, 1980), and reduction of soil erosion and its associated loss of organic matter (De Luis *et al.*, 2003).

In regions such as Galicia, gorse has traditionally been exploited and valorized. For centuries, this species was used as a fertilizer, source of energy, and cattle bedding or feed (Webb, 1998). In fact, younger gorse was formerly used as animal bedding and then exploited as manure, whereas older gorse was used as fuel (Miramontes, 2001). After the 1960s, however, collection and usage of gorse declined to a point where the plant was only used for extensive grazing (Masaguer *et al.*, 2015), mainly as a result of the introduction of mineral and synthetic fertilizers, increased labour costs and bedless cattle stabling, which led to decreased manure production.

Galicia has 414 849 ha of wood forests (MAPA, 2010) comprising dwarf European and holm oaks, and rockrose, gorse, mastic, broom and heather bushes, among others —a vast source of unexploited resources for purposes other than extensive grazing. In addition, Galicia is the Spanish region with the largest area of municipal communal woodland: 620 313 ha out of 840 755 ha according to a report by MAGRAMA (2013). Most is in a non-productive status (Soliño, 2003) and has been one of the main sources of forest fires for decades (Pérez and Delgado, 1995). Such vast expanses of underexploited land can provide a good opportunity for the proposed exploitation scheme; also, recovering forest clearing practices would have the added benefit of helping prevent forest fires —a frequent occurrence in some Galician areas (Copena and Simón, 2014). In addition, the proposed exploitation scheme is compatible with grazing uses, which it can favour by facilitating regrowth of highly palatable, tender sprouts (Luginbuhl and Castagni, 2007); under appropriate conditions, the scheme may be viable even in young forest plantations requiring bush clearing during their earliest establishment years (Villanueva and Riesco, 2015).

It should be noted that valorizing gorse for use as a substrate is not a residue management policy proper as it differs from the replacement of peat with alternative, residual materials such as green residues from trimming operations (Benito *et al.*, 2005), wood nurseries (Veijalainen *et al.*, 2007) or gardening (Estévez-Shwarz *et al.*, 2012). Rather, the aim is to exploit biomass that would be collected exclusively for producing substrates as is the case with ferns (Pitman and Webber, 2013) or even crops such as kenaf (Giménez *et*

al., 2008), poplars or even thistles (Burés, 1997). Obviously, the materials to be harvested should possess appropriate characteristics allowing all obtainment costs to be assigned to the end-product to enable valorization of a residue which must inevitably be managed in some way.

In practice, the materials should be exploited with provision for the associated costs and expected yields. Thus, they should be collected with mechanical means, which is not always possible on steep slopes or uneven terrain (Masaguer *et al.*, 2015). The yield of mechanically harvested gorse on favourable sites has been estimated to range from 0.5 to 1 $\text{ha}\cdot\text{h}^{-1}$; with gorse bushes approximately 1 m tall more or less uniformly covering the land, the yield would amount to about 15 $\text{t}\cdot\text{ha}^{-1}$ (Masaguer *et al.*, 2015). Vega-Hidalgo *et al.* (2001) estimated a harvesting yield of ca. 10 $\text{t}\cdot\text{ha}^{-1}$ for gorse shrubs 70 cm tall at 40% coverage, and one of 45 $\text{t}\cdot\text{ha}^{-1}$ for plants 160 cm tall at 100% coverage. Also, Seijas *et al.* (2009) estimated yields up to 95.14 $\text{t}\cdot\text{ha}^{-1}$ for shrubs more than 3.10 m tall.

In this work, gorse yield after composting was approximately 38% (results not shown). This value was calculated by estimating the reduction in stack size from the start to the end of the process. Based on the reduction in organic matter during composting, the material yield was 36%. These two results are quite consistent despite their being obtained in a different manner. Veeken *et al.* (2002) also obtained very similar volume and mass yields by composting wheat straw in passively aerated static piles. Other authors reported also similar volume yields such as 36% from winter composting of cattle manure (Larney *et al.*, 2000) or 42% from grass hay and spoiled corn silage (Breitenbeck and Schellinger, 2004); a windrow system with mechanical turnover was used in both cases. Mass yields in the region of 40% were obtained by composting mixtures of dairy manure and sawdust with a windrow system (Michel *et al.*, 2004). Also, Brito *et al.* (2010) obtained mass yields close to 50% by composting cattle slurry and gorse as bulking agent in stacks. It should be noted that static stacks provide greater yields than the windrow system with mechanical turnover, which is the least efficient choice (Breitenbeck *et al.*, 2004; Yue *et al.*, 2008; Brodie *et al.*, 2010).

The proportion of material exceeding 6 mm in grain size that was rejected in screening the starting materials prior to agronomic evaluation was estimated to be 15% (results not shown). A combination with the previous estimates provides a yield of 31% for gorse from

source to compost ready for use as a growing substrate. Based on it, on a bulk density of $442 \text{ kg}\cdot\text{m}^{-3}$ for compacted gorse compost and a minimum yield of $10 \text{ t}\cdot\text{ha}^{-1}$, obtaining 1 m^3 of gorse substrate would require harvesting an area of 1228 m^2 .

Since Galicia spans $29\,474 \text{ km}^2$, of which 21% ($620\,313 \text{ ha}$) accounts for municipal communal woodland (MAGRAMA, 2013), if at least 10% could be exploited and a minimum of 5 years were needed to allow forests to regenerate between successive clearings, the region could produce $100\,000 \text{ m}^3$ of gorse compost-based substrates each year. If a composting plant operating under average conditions could harvest the raw material across a range of 30 km (R. Lourido and J.A. Neira, private communication), then up to 10 plants producing about $10\,000 \text{ m}^3$ of compost each year could coexist in Galicia. The ability to mix gorse with other raw materials in order to make substrates for specific purposes would further increase the potential turnover of marketable substrate. This gives a fairly good idea of the dimension of degree of professionalization that could be reached by producing substrates from compost based on land clearing residues and their potential for replacing peat substrates.

The raw material (gorse) was composted for conversion into a plant-growing substrate. Although the composting green residues is not new (Aleandri *et al.*, 2015; Benito *et al.*, 2005; Ribeiro *et al.*, 2007), it continues to be a highly effective choice for obtaining organic growing substrates (Abad *et al.*, 2008), partly because compost is a major source of organic matter and fertilizing elements (Raviv, 2005) —which is especially important because the use of synthetic fertilizers in organic farming is banned by law. Compost has the added advantage of its suppressive properties (Hoitink and Fahy, 1986); such properties are also essential for organic agriculture, where artificial phytosanitary products are also banned. In addition, composting provides mature, stable substrates (Dimitrios and Ioannis, 2009) in physical, physico–chemical and biological terms.

Based on the results of this work, gorse compost-based substrates can be efficiently obtained by using a small-scale composting system with a 9-month production cycle. In fact, the resulting substrates were mature and stable enough to meet the requirements for award of the organic ecolabel for growing substrates (EU Commission, 2006). However, some exceeded the set limit for the number of weed propagules and/or seeds per volume unit.

Most of the compost properties were comparable to those required for an ideal growing substrate (Abad *et al.*, 1993; ADAS, 1988). However, some physical properties may be an exception because the high aeration and drainability of the compost, in combination with its low water-retention capacity, may restrict its use for specific purposes in greenhouse containers. In any case, estimating the water and air supply to plant roots from substrate properties can lead to erroneous conclusions (Masaguer *et al.*, 2015) because substrates may account for as little as 25% of such supply, the other 75% being contributed by irrigation (Fonteno, 1999). Also, irrespective of the optimum or desirable air–water ratio (De Boodt *et al.* 1974; Abad *et al.* 1993), substrates should possess a high aeration capacity (especially with a view to avoiding fungal diseases). As a result, drainability can be regarded as another advantage of compost-based substrates (Masaguer *et al.*, 2015).

Our results suggest the needs to carefully manage irrigation and select appropriate containers for the substrates, and to use them with crops bound to exploit their properties. Also, they suggest that the substrates can be used in mixtures with other materials with a higher retention capacity in order to overcome their main limitations and expand their use.

As regards irrigation, dripping is unsuitable for potted gorse compost because its high hydraulic conductivity results in adequate wetting of the bulb at the bottom but not at the top. As a result, part of the container volume is rendered useless for root exploration and growth, and the substrate surface is highly dry. In addition, dryness in the material by effect of the lack of water hinders subsequent rewetting owing to the high hydrophobicity of the compost (Valat *et al.*, 1991; Michel *et al.*, 2001). This is also the case with other organic materials (Michel *et al.*, 2001), particularly ligneous materials such as pine bark (Naasz *et al.*, 2008), where a substantial fraction of pores never reaches saturation (Raviv *et al.*, 2002, 2004). On the other hand, gorse compost responds very well to microaspiration irrigation, which allows water to be uniformly delivered across the substrate surface and avoids the restrictions imposed by the high permeability or saturated hydraulic capacity (Raviv *et al.*, 2002) usually arising from a high aeration capacity and drainability or even a low pore tortuosity factor (Gruda and Shnitler, 2004). The substrates should be irrigated frequently and adequately to fulfil the water requirements of the crops, and excessive surface dryness avoided —particularly in the hottest months— as a result.

Using container types suited to the substrate properties and irrigation requirements is also very important. The high aeration capacity, together with an R point (i.e., the point where the air and water contents equilibrate) lower than 1 kPa, suggest that the substrate should be used in shallow containers (Ansorena, 1994) to avoid waterlogging. The substrate is thus quite suitable for seedbed growing but should be used in gutters or bags for longer production cycles. Bags can additionally reduce surface dryness, thereby alleviating the hydrophobicity of the material and facilitating dripping irrigation.

The range of materials that can be mixed with gorse compost is limited by the requirements for award of an EU organic ecolabel. In fact, the applicable regulation for growing media (EU Commission, 2015a) only allows materials such as processing or recycled residues—which excludes peat—to be used. The acceptable materials include coir peat (Evans and Konduru, 1996), compost from scarcely ligneous green residues (Abdelrahman *et al.*, 2012; Benito *et al.*, 2005; Bakry *et al.*, 2010), compost from urban solid waste (Hargreaves *et al.*, 2008) or vermicompost (Campos *et al.*, 2007). These materials usually exhibit high water retention but poor aeration, so they require mixing with other materials possessing complementary properties such as gorse compost.

The feasibility of producing gorse-based substrate mixtures for various purposes can open up new business opportunities by increasing the diversification of gorse compost and expanding its uses. The production of dedicated substrates tailored to specific needs is a growing trend on the professional and amateur markets (Quispe, 2007). Also, few plant-growing substrates have been awarded an ecolabel and commercial manufacturers are firmly committed to expanding in this new direction (EU Commission, 2015b)—a new potential avenue for furthering business in this sector.

The physical properties of gorse compost can be improved for use without mixing by modifying the composting process or even the end-product. Thus, as found in previous studies (Amboaje *et al.*, 2009), using less lignified raw materials could facilitate stronger composting and lead to a product with a lower C/N ratio. Also, extending the composting time from 4 to 6.5 months and using younger, less ligneous material reduces the aeration capacity of mixed substrates containing poultry manure by 15% and that of gorse-only

substrates by up to 25% (Amboaje *et al.*, 2009; López-López *et al.*, 2008), at the expense of reduced harvesting and composting yields.

Screening the raw materials to narrow their particle size range would decrease the distance between particles, and hence total porosity and aeration capacity, thereby increasing water retention in the least absorbing pore fraction (Abad *et al.*, 2004; Abad *et al.*, 2005). One problem with mechanical screening is that it usually requires the material to be fairly dry in order to facilitate the passage of particles through the mesh. On the other hand, too dry material is easy to screen but particles may break and produce fines that will be swept to the bottom of pots or cropping bags by irrigation or rain water and eventually cause waterlogging (Miller and Jones, 1995). As a rule, screening reduces aeration—to what extent is difficult to predict because the effect is non-linear (Burés, 1997) and must be assessed through testing. Also, the test results may be too poorly reproducible for practical purposes—the grain size range to be used for adequate reproducibility is too narrow. Other materials have also been found to possess a high aeration capacity. Such is the case with pine bark, where only the grain size fraction from 0.2 to 0.5 mm exhibits adequate water retention capacity (Arrieta *et al.*, 1992; López-Fabal *et al.*, 2009). One other problem with heavy screening is that it diminishes material yield.

Usually, the physical properties of the substrates are deemed more important than their chemical properties because the latter can be more easily altered through irrigation and fertilization during plant growth (Ansorena, 1994). However, the chemical properties of organic substrates are also important because synthetic fertilizers are usually banned in organic farming (IFOAM, 2009). It is therefore advisable to produce substrates adapted to specific products and crops in terms of fertility and chemical properties.

The high nutrient contents of the studied materials (particularly those containing poultry manure) allow their use for short-cycle cropping (e.g., seedbed growing) without the need for additional fertilizer. In fact, these substrates were found to produce amounts of biomass similar to or even greater than those of fertilized peat-based substrates in organic seedbed grown crops of horticultural and aromatic plants such as lettuce, basil and parsley (López-Fabal *et al.*, 2011; López-López *et al.*, 2011; López-López and López-Fabal, 2012). With longer growing cycles such as those of strawberry, however, the fertilizing capacity of

the substrates was reduced by their ability to mobilize nutrients beyond their soluble contents being inadequate to meet the cropping requirements and necessitating supplementary fertilization (ideally, in the form of fertirrigation).

The suitability of gorse compost as a substrate for conventionally grown ornamental plants was also examined. Gorse compost is an effective replacement for peat as a growing medium for propagation by thuja (Iglesias-Díaz *et al.*, 2008; Iglesias-Díaz *et al.*, 2009) or cotoneaster cuttings (Iglesias-Díaz *et al.*, 2004b). Also, it has proved an acceptable substitute for peat in mixtures with other materials for pot or container growing of spindletree, thuja and boxtree cuttings (Iglesias-Díaz *et al.*, 2004a).

High-quality compost has variable effects on plant growth and health status (Fuchs, 2002). Thus, the few efficient synthetic phytosanitary products available for treating most of the diseases that decimate nursery production are very expensive; also, they take a long time to act and rapidly elicit resistance responses (Van den Bosch *et al.*, 2011). In addition, a number of allegedly active materials have been deemed detrimental to health and the environment in recent times (FAO, 2003; IPCS, 2006; EPA, 2011). Widely used growing substrates such as peat and coir fibre are ready vectors for edaphic pathogen diseases (Hoitink and Fahy, 1986; Borrero *et al.*, 2006). Adding a biological control agent is usually effective (Masaguer *et al.*, 2015) but increases substrate costs considerably. The suppressive properties of gorse-based compost makes it an interesting, economically competitive choice for use in mixtures with other materials. In fact, one of the composts studied here, which is produced on a large scale, exhibited substantial suppression of *Fusarium circinatum*. This compost differed from the others in that it initially fermented while in the forest, which not only reduces transportation costs through the resulting reduction in volume, but also boosts suppressive properties as a result of the processes involved mimicking natural mechanisms (Hoitink *et al.*, 1993) and hence respecting natural biological cycles. It would be interesting to further examine the natural suppressive properties of this compost against other diseases and with other crops.

Overall, the moisture content of the raw materials used is directly related to the void space in the micropore network of the composted material (Madejón *et al.*, 2002). The wetting factor affected the composting process but not the physical or chemical properties

of the resulting substrates. Also, initially washing the raw materials failed to reduce salinity in the resulting compost to the desired extent, which required the additional contribution of rainfall. As a result, this factor was ignored in subsequent tests.

The presence of poultry manure was indeed strongly influential. Thus, the compost stacks containing manure reached the thermophilic stage faster and the resulting compost exhibited substantially different chemical properties. Also, plant growth in terms of strawberry biomass increased with increasing content in manure, similarly to previous experiments on seedbed growing of vegetables and aromatic plants (López-Fabal *et al.*, 2011; López-López *et al.*, 2011; López-López and López-Fabal, 2012). In addition, composting gorse in combination with poultry manure provided substrates with a strong post-emergence suppressive effect on *Fusarium circinatum* and increased seedling growth of *Pinus radiata* in seedbeds, as well as to an increased natural concentration of *Trichoderma* spp. It is therefore advisable to mix gorse with poultry manure or another suitable type of manure for composting.

Gorse compost is therefore an effective substitute for peat as a growing substrate for greenhouse and organic production. Using renewable resources of local origin reduces production costs, the environmental impact of agricultural activities and the dependence on external inputs. Also, expanding gorse composting as a rural economic activity can have major socio-economic and environmental implications. In fact, an increasing demand for gorse compost can encourage entrepreneurs to exploit new forest areas and create direct or indirect jobs in disfavoured regions. In addition, valorizing marginal and/or abandoned land to exploit gorse would lower the risk of forest fires and improve the quality of rural landscape. Finally, introducing gorse in degraded land would facilitate its reclamation, and increase its fertility, productivity, and economic and environmental value.

2. Conclusions

Charter 1

- The composts obtained are mature and stable enough. They have a high aeration and drainage capacity and little plant-available water so they will require careful irrigation and also they can be used as aerating component in potting mixtures.

- They are all highly saline but it is no constraint to their obtaining the EU eco-label and it did not result in negative effect on seed germination or seedling growth, which was promoted.
- The content of soluble nutrients of the composts was quite high, but it may be unbalanced for some crops and then they would require to be adequately corrected by fertilization.
- The addition of poultry manure resulted in substantial changes in the properties of the substrates, which contained less organic matter and had a lower C/N ratio, a nearer-neutral pH, higher contents in soluble elements and an increased salinity.
- All the composts fulfill the requirements of the European norm for award of an eco-label except for the content in weed seeds of PMI5, PM0 and PM0I owing to contamination after composting. This underlies the importance of strict control in preserving hygienic conditions achieved during the composting process.

Charter 2

- The two types of gorse compost studied, but particularly that containing poultry manure (PM100), exhibited high contents in major nutrients.
- Nutrient concentration in the solution of the compost-based substrates decreased gradually during strawberry growth, particularly those of N and K, which remained at very low levels during the fruit production stage. The differences in soluble element concentrations of the substrate solutions among composts were fairly small; by contrast, the control substrate exhibited substantial release of nutrients between the 6th and 9th week of cropping.
- Leaf analyses revealed that N was the scantiest nutrient in the compost-grown plants relative to the control substrate. The chlorophyll contents echoed this result.
- Aerial biomass in compost-grown plants increased with increasing proportion of poultry manure in the substrate, but plants grown in the control substrate exhibited

greater figures. There were no substantial differences in root biomass, overall production or fruit size, however.

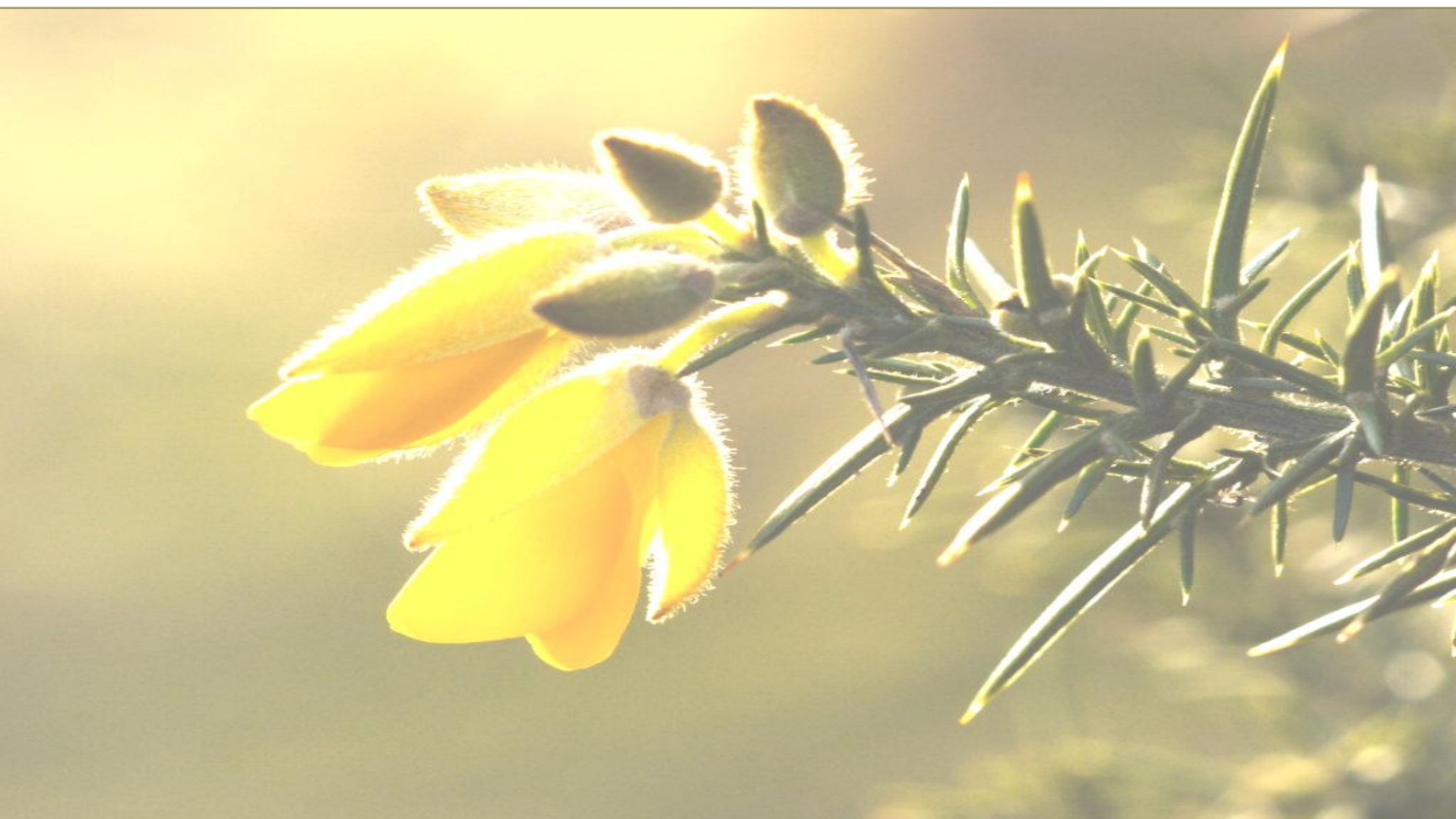
- Although the initial nutrient contents of the composts are adequate for strawberry growing, they require additions of supplementary fertilizer to offset extractions during the growth period.

Charter 3

- All studied composts exhibited suitable physical and physicochemical properties for use as nursery growth media for *Pinus radiata*.
- Gorse compost produced on a large scale exhibited natural suppressive properties against *Fusarium circinatum* disease. The naturally suppressive compost had high AC, low EC, high NH_4^+ , and low Ca and K levels.
- The biological control agent *Trichoderma asperellum* strain T34 reduced pre- and post-emergence incidence of the disease in the moderately suppressive composts, which testifies to its potential as an effective alternative to chemical treatment against *Fusarium circinatum* in *Pinus radiata* seedling production.



APPENDIX I: Extended Abstract



APPENDIX I: RESUMEN EXTENDIDO

La reducción de turba en los sustratos y el uso de compost como sustrato

En Europa se producen una amplia gama de materiales susceptibles de ser usados como sustratos de cultivo, pero es la turba la que se usa mayoritariamente en los viveros de producción para semilleros y para planta en contenedor (Bohlin, 2002; Schilewski, 2009). De hecho, de los 37 millones de m³ de sustratos que se consumen al año en Europa, solamente estaría totalmente libre de turba un pequeño porcentaje del 0,1-1,0 % (Schilewski, 2005). La turba sigue liderando el mercado de los sustratos en buena parte debido a sus excelentes características físicas, químicas y biológicas para ser usada como sustrato de cultivo (Bragg 1990; Robertson, 1993; Krucker *et al.*, 2010; Schilewski, 2008). Y es que, aún teniendo en cuenta la gran variedad de materiales existentes, estos a veces no cumplen tan acertadamente los requerimientos de cultivo como la turba, no están disponibles en la cantidad necesaria o suponen una dificultad de uso para los viveristas por sus diferentes requerimientos de manejo.

Sin embargo, en los últimos años, el sector del cultivo sin suelo ha optado por la búsqueda de materiales alternativos y más sostenibles para ser usados como sustratos de cultivo (Heisnaken, 2013). Esto se debe principalmente a que el precio de la turba de calidad que se consume en países como España, más alejados de los lugares de extracción, ha ido encareciéndose progresivamente sobre todo por el incremento de los costes de transporte. Además, la presión medioambiental asociada al impacto que su extracción supone en los ecosistemas naturales y sus consecuentes emisiones de C a la atmósfera viene alejando los puntos de suministro (Ribeiro *et al.*, 2007; Ostos *et al.*, 2008; Larcher y Scariot, 2009; Mäkiranta *et al.*, 2010; Bullock *et al.*, 2012). Entre los materiales alternativos a la turba destacan por ser ampliamente usados, el sustrato de coco (Arenas *et al.*, 2002), la corteza de pino (Burés, 1997; Bilderback *et al.*, 2013) y la fibra de madera (Barrett *et al.*, 2016); pero también los composts (Landis y Morgan, 2009), cuyo uso ha ido incrementándose progresivamente a lo largo de los últimos 40 años (Raviv, 2013).

El compostaje es el método más extendido para estabilizar e higienizar subproductos orgánicos con la finalidad de valorizar los residuos o materiales orgánicos mediante su empleo como fertilizantes, enmiendas de suelo o componentes de sustratos de cultivo (Bertoldi *et al.*, 1983; Ansorena *et al.*, 2014). Cuando el compost va a ser utilizado directamente como sustrato de cultivo el concepto de calidad y su evaluación cobran una mayor importancia (Moreno *et al.*, 2008), pues los requerimientos son más exigentes que para otros usos. Existen muchos estudios que muestran que los residuos orgánicos transformados mediante compostaje pueden ser usados como sustratos de cultivo con muy buenos resultados (Abad *et al.*, 2001; Benito *et al.*, 2005; Pérez-Murcia *et al.*, 2006). Además, los materiales orgánicos destacan normalmente por una alta fertilidad (Altieri *et al.*, 2010) y, reducir el uso de fertilizantes químicos es un importante objetivo de cara a una producción hortícola más sostenible (Tagliavini *et al.*, 1996). En Europa el compost de residuos o materiales verdes es el que más ampliamente se utiliza para sustratos de cultivo comerciales (Barrett *et al.*, 2016), aunque también a lo largo de los años han ido adquiriendo importancia los procedentes de otras materias primas como del sustrato agotado de la producción de champiñones (Zhang *et al.*, 2012), los subproductos de la industria del corcho (Carmona *et al.*, 2004) o el alperujo de la vid (Baran *et al.*, 2001).

Aunque no como solución única, el compost de residuos verdes está llamado a jugar un papel importante en la sustitución de la turba y en la transición hacia sustratos de cultivo más sostenibles. Sin embargo, muchos productores de planta nunca han llegado a mostrar una verdadera confianza en ellos y otros la tienen mermada por el uso de compost de baja calidad (Knight, 2012). Por tanto el aseguramiento de su calidad es un factor clave para promover la inclusión de los compost en los sustratos y progresar en la reducción del uso de turba. Los mayores desafíos con los que se encuentran los productores de compost para ser usado como sustrato de cultivo son la falta de uniformidad (Raviv, 2013), la alta densidad aparente y los altos costes de transporte asociados (Benito *et al.*, 2005; Rainbow, 2009), inestabilidad biológica (Burger *et al.*, 1997), fitotoxicidad (Lumis y Johnson, 1982; Hartz *et al.*, 1996), alta salinidad (Raviv, 2013), relaciones aire-agua desequilibradas derivadas de la distribución granulométrica (Abad *et al.*, 2008) y el elevado pH (Prasad y Maher, 2001; Benito *et al.*, 2005). Pero desde una perspectiva comercial, los problemas más importantes se refieren a la contaminación de las materias primas, principalmente a partir

de herbicidas (WRAP, 2010), presencia de inertes punzantes y cortantes y patógenos humanos (Tognetti *et al.*, 2007; Weber y Scholman, 2011).

En respuesta a las inquietudes ambientales respecto de la extracción de la turba y la necesidad de reciclaje de residuos, la Comisión Europea estableció los criterios ecológicos para la concesión de la ecoetiqueta europea a sustratos de cultivo. La ecoetiqueta europea es un sistema voluntario destinado a promover la excelencia ambiental. Puede ser concedida a productos y servicios que tienen un reducido impacto ambiental en su ciclo de vida, incluyendo la extracción de las materias primas, su producción, uso y eliminación. En el caso de los sustratos los criterios ecológicos incluyen aspectos relacionados con las materias primas, la presencia de contaminantes físicos, químicos y biológicos, la estabilidad, algunas características químicas y la respuesta de las. Existen compost de muchos materiales que son usados como medios de cultivo y fuente de nutrientes, y algunos de los mejores podrían cumplir los requisitos para la concesión de la etiqueta ecológica a sustratos de cultivo.

Una de las características más relevantes a estudiar en un sustrato a base de composts es su supresividad (Hoitink *et al.*, 1975). Algunos composts de gran calidad, al igual que ciertos suelos, pueden reducir de manera natural la incidencia y/o severidad de las enfermedades de las plantas (Noble y Coventry, 2005; Castaño *et al.*, 2013). La turba y la fibra de coco, ampliamente utilizados como sustratos de cultivo por sus excelentes propiedades físicas y baja actividad microbiológica, acostumbran a ser materiales conductores para la mayoría de las enfermedades producidas por patógenos edáficos (Hoitink *et al.*, 1986; Borrero *et al.*, 2006). Por otra parte, los agentes de control biológico suponen una alternativa efectiva al uso de fitosanitarios de síntesis y ayudan a minimizar los impactos en la salud humana y en el medioambiente (Kim *et al.*, 2003)

La motivación que impulsó al desarrollo de este trabajo fue principalmente dar respuesta a una demanda de producción viverística que se estaba manifestando en Galicia. Los productores de planta necesitaban un material que sirviera como sustrato de cultivo, que abaratase costes de producción, con características adecuadas y que pudiera servir para su uso en agricultura ecológica. Fue el tojo (*Ulex europeus* L.) la materia prima que suscitó interés, no solamente por su abundancia en los montes gallegos (MAPA, 2010; MAGRAMA,

2013), sino también por su alta capacidad de rebrote (Willians, 1997), por su posibilidad de uso en diferentes grados de lignificación (Masaguer *et al.*, 2015), y por su dispersión y extensión a nivel mundial.

En zonas como Galicia, el tojo ha sido ya tradicionalmente aprovechado y valorizado. Durante siglos fue usado como fertilizante, como fuente de energía o de cama y/o alimento para el ganado (Webb, 1998). El tojo más joven servía para cama de ganado y permitía así obtener estiércol; el más leñoso se utilizaba para combustible (Miramontes, 2001). Sin embargo, a partir de los años 60 la recogida y utilización del tojo fue reduciéndose hasta prácticamente desaparecer el interés por su aprovechamiento más allá del pastoreo extensivo (Masaguer *et al.*, 2015). Las principales razones fueron la aparición de fertilizantes minerales y/o de síntesis, el encarecimiento de la mano de obra requerida para su recolección y la generalización del uso de las estabulaciones sin cama para el ganado, con la consecuente reducción en la generación de estiércol.

La vuelta al aprovechamiento del tojo, y su transformación mediante compostaje para la obtención de sustratos de cultivo tendría numerosos beneficios económicos y ambientales. La explotación de superficies abandonadas mediante desbroce ayudaría en la prevención de incendios forestales, tan frecuentes en zonas gallegas (Copena *et al.*, 2014), y se pondrían en valor terrenos marginales y/o abandonados aumentando su capacidad productiva y su fertilidad. Además es compatible y favorece el aprovechamiento por el ganado, que da lugar al rebrote de tallos tiernos que favorecen el pastoreo. El uso de recursos renovables y de origen local permitiría reducir el impacto ambiental de la actividad agrícola, bajar los costes de producción y limitar la dependencia de insumos de procedencia lejana. Por otra parte, la demanda del compost de tojo puede generar aparición de productores que aprovechen diferentes zonas de monte, con la consiguiente creación de puestos de trabajo directos e indirectos en zonas rurales.

Objetivos

El objetivo general de este trabajo doctoral es la revalorización y transformación del tojo para su uso como sustrato de cultivo en agricultura ecológica. Este objetivo general se

concreta en tres objetivos específicos que a su vez se desarrollan en los tres capítulos siguientes:

1.- Obtención de compost de tojo utilizable como sustrato

- realización y seguimiento del compostaje de tojo, atendiendo a diferentes variables que pudieran afectar al proceso y a las características del producto final
- caracterización de los composts obtenidos para su uso como sustrato en agricultura ecológica
- evaluación del cumplimiento de los criterios para la concesión de la etiqueta ecológica comunitaria a sustratos de cultivo

2.- Evaluación de los compost como sustrato para el cultivo ecológico

- evaluación del comportamiento de los composts durante un cultivo ecológico en contenedor
- estudio de la capacidad de suministro de nutrientes para el cultivo
- cuantificación de la respuesta del cultivo en cuanto a estado nutricional, crecimiento y producción

3.- Evaluación de la capacidad supresora de los compost de tojo

- evaluación de la capacidad supresora de diferentes sustratos a base de compost de tojo frente a un patógeno de cuarentena en semillero
- evaluación de la respuesta supresora en diferentes sustratos a base de compost de tojo en semillero tras la inoculación de un agente de control biológico.

Proceso de compostaje y caracterización de los composts

Se recolectó material de monte consistente principalmente en tojo de unos 4-5 años de edad con una segadora de mayales. El diseño experimental incluyó dos factores con dos niveles cada uno. Estos fueron el riego de los materiales al inicio del proceso de compostaje (I) y la adición de gallinaza procedente de una granja ecológica de puesta en una proporción

del 5% v/v (PM). Así resultaron un total de 4 tratamientos diferentes: PM0I (mojado al inicio sin adición de gallinaza), PM5I (mojado con adición de gallinaza), PM5 (adición de gallinaza sin mojado previo del material), PM0 (material no mojado y sin adición de estiércol). Se estudió el factor gallinaza con el objetivo de disminuir a cerca de 30 la C/N inicial e incrementar el nivel de nutrientes del producto final. La proporción del 5% (v/v) se consideró suficiente para cumplir ambos objetivos sin elevar excesivamente la conductividad eléctrica. Por su parte el riego buscó aumentar la humedad del tojo de partida y reducir en lo posible su contenido de sales

El proceso de compostaje comenzó en el mes de julio y tuvo una duración de 9 meses. Las pilas tuvieron un tamaño de unos 6 m³, con forma troncocónica y una altura de 2 m. El material se volteó mecánicamente una vez al mes al principio, y cada dos meses después. Se monitoreó el proceso de compostaje obteniendo datos de evolución de temperatura, humedad, pH y C/N. Además los composts resultantes fueron caracterizados física, química y biológicamente, y evaluados conforme a los requerimientos para la concesión de la etiqueta ecológica comunitaria a sustratos de cultivo (EU Commission, 2006).

El compostaje fue adecuado en todos los tratamientos, con una fase termófila que duró al menos dos meses y en la que se mantuvieron temperaturas por encima de los 50°C en el interior de las pilas, suficiente para una correcta higienización. Las pilas inicialmente no mojadas mostraron pronto una ralentización del proceso por falta de agua, que se tradujo en temperaturas máximas más bajas; posteriormente todas las pilas se regaron regularmente para mantener la humedad en valores aceptables. Los tratamientos con gallinaza experimentaron un compostaje más intenso en las primeras etapas que los respectivos sin gallinaza, alcanzando temperaturas máximas más altas, para entrar más pronto en fase de enfriamiento. Durante el proceso se consumió entorno al 70 % de la materia orgánica inicial.

Los sustratos a base de compost de tojo obtenidos estuvieron suficientemente maduros, estabilizados y libres de patógenos. La caracterización de las propiedades físicas mostró materiales con una alta capacidad de aireación y drenaje, pero limitada capacidad de retención de agua disponible. Esto último hace aconsejable prestar especial atención al riego, así como usarlos en mezclas con otros materiales con escasa aireación. La salinidad

fue elevada, sobre todo en los que contuvieron gallinaza, pero no supuso ningún efecto negativo en la germinación ni en el crecimiento de plántulas en los test realizados, ni tampoco una limitación de cara a la obtención de la etiqueta ecológica a sustratos de cultivo. El contenido en nutrientes solubles fue bastante elevado en los cuatro tratamientos, especialmente de N y K; para algunos cultivos podría resultar desequilibrado, en cuyo caso requerirían ser adecuadamente corregidos antes de su uso con fertilización.

La adición de gallinaza resultó en cambios sustanciales en las propiedades de los sustratos; mostrando estos menor contenido en materia orgánica, menor C/N, valores de pH más cercanos a la neutralidad y un mayor contenido en elementos solubles y mayor salinidad. El factor mojado no tuvo repercusiones importantes en las propiedades finales de los composts, por lo que se desestimó en las fases posteriores del estudio. Todos los composts cumplieron con los requerimientos para la concesión de la etiqueta ecológica a sustratos de cultivo (EU Commission, 2006), a excepción del contenido en semillas de malas hierbas para los tratamientos PMI5, PM0 y PM0I, lo que se relacionó con una reinfestación durante la maduración. Esto último remarca la importancia de un control más estricto en el mantenimiento de las condiciones higiénicas y de aislamiento durante el proceso de compostaje.

Evaluación agronómica durante un cultivo ecológico en contenedor

En un cultivo ecológico de fresa se evaluó el comportamiento como sustrato de dos de los composts anteriormente obtenidos, atendiendo especialmente a los aspectos relacionados con la capacidad de suministro de nutrientes y el estado nutricional del cultivo. Se usaron dos composts a base de tojo que fueron caracterizados previamente en laboratorio de acuerdo a sus características físicas y químicas; PM0: compost de tojo sin adición de gallinaza y, PM100: compost de tojo con 5% v/v de gallinaza. Estos dos y sus mezclas PM25 (25% PM0 + 75% PM100), PM50 (50% PM0 + 50% PM100), PM75 (25% PM0 + 75% PM100) fueron testados en un ensayo de cultivo de fresa (*Fragaria x ananassa* Duch "Selva") en contenedor, utilizando como control un sustrato estándar de turba fertilizado con abono de liberación lenta. Durante el cultivo se hicieron análisis periódicos de la

solución del sustrato y se hizo el seguimiento del estado nutricional del cultivo con medidas periódicas de clorofila y análisis de tejidos. Además se controló la producción y al final del cultivo se midió la biomasa aérea y radicular de las plantas.

Ambos composts de tojo mostraron propiedades físicas adecuadas aunque con limitada capacidad de retención de agua fácilmente disponible, por lo que durante el cultivo el riego se manejó con dosis pequeñas y frecuentes. Su contenido de nutrientes solubles fue elevado, especialmente de N y K, lo que también redundó en alta salinidad. El compost con gallinaza (PM100) presentó un pH menos ácido, un nivel de salinidad más alto y un mayor contenido de los principales nutrientes como N-NO_3^- , N-NH_4^+ , P y K; sólo su contenido de Mn fue inferior al de PM0.

En general a lo largo del cultivo de fresa el nivel de nutrientes en la solución de los sustratos de compost fue bajando progresivamente. Esto fue especialmente marcado para el N y el K, que inicialmente eran los más abundantes pero también los más demandados por el cultivo, de modo que su concentración se mantuvo en valores muy bajos durante la fase de producción de frutos. Otros elementos como el Ca y el Mg mantuvieron su concentración en la solución del sustrato a lo largo del cultivo; mientras que la de P experimentó una reducción moderada. Por tanto la capacidad de suministro de nutrientes fue variable, lo que se relacionó con la diferente dinámica de cada elemento. Las diferencias entre los tratamientos de compost fueron reduciéndose a medida que avanzó el cultivo, mientras que el control con abono de liberación lenta mostró un comportamiento distinto, con una importante liberación de nutrientes entre las semanas 6 y 9 de cultivo.

Los análisis de hoja revelaron que el N fue el nutriente que estuvo más escaso en las plantas cultivadas en compost respecto del control, mientras que el P lo estuvo en menor medida. Por su parte el K resultó más abundante en las plantas cultivadas en los compost a pesar de la progresiva bajada de su concentración en la solución. Las mediciones de clorofila indicaron síntomas de mayor disponibilidad de nitrógeno en las plantas cultivadas en el control respecto de las cultivadas en los compost desde los 94-104 días de cultivo según tratamientos.

En los tratamientos de compost la biomasa aérea de las plantas aumentó con la proporción de PM100 en la mezcla, pero el control ofreció el mayor valor; no hubo

diferencias en la biomasa radicular. No hubo diferencias en cuanto a la producción total por planta, que fue de 70-90 g de fresa; tampoco en cuanto al tamaño medio de los frutos, que fue los 8.3 - 9 g.

A pesar del buen contenido inicial de nutrientes solubles en el compost la capacidad de movilización de reservas para un suministro continuado al cultivo es limitada. Por ello para la adecuada producción de fresa en estos compost se debe aplicar fertilización complementaria en el momento de mayores extracciones.

Evaluación de la capacidad supresora de los composts

Se consideró importante evaluar la capacidad supresora de los composts obtenidos a pequeña escala en la primera parte del trabajo. Estos se compararon además con dos sustratos a base de composts de tojo obtenidos en procesos de mayor escala y que actualmente se comercializan y también son producidos en la comunidad gallega. Resultaron así cuatro tratamientos a base de compost de tojo: C1 (compost obtenido a pequeña escala con estiércol de gallinaza), C2 (compost obtenido a pequeña escala sin estiércol), C3 (compost obtenido a gran escala con estiércol de vacuno) y C4 (compost obtenido a gran escala sin estiércol). Además también fue testado un compost obtenido de la fracción sólida de residuos sólidos urbanos en mezcla con un 25% de perlita y un 25% de turba (C5).

El ensayo de cultivo se llevó a cabo en semillero de *Pinus radiata* D. Don, uso que se adapta a las características de los sustratos obtenidos. Se estudió la supresividad de los compost frente a *Fusarium circinatum* (Fc), como uno de los patógenos de cuarentena que mayores pérdidas económicas y de cultivo generan en la comunidad gallega y que supone ser una de las más importantes problemáticas para viveristas forestales (EPPO, 2012). Además, este patógeno de cuarentena supone un interés a nivel mundial, puesto que afecta en una importante superficie a través de todo el globo (Muramoto and Dwinell, 1990; Viljoen *et al.*, 1994; Guerra-Santos, 1999; Dwinell *et al.*, 2001; Wingfield *et al.*, 2002 y Landeras *et al.*, 2005).

Todos los composts fueron caracterizados física, química y biológicamente. Además también fueron caracterizados microbiológicamente atendiendo a poblaciones de actinomicetos celulolíticos, actinomicetos oligotróficos, *Bacillus* spp., recuento total de hongos y poblaciones de *Fusarium* spp.

El ensayo de cultivo con semilleros de pino se estableció teniendo en cuenta tres factores: composts, patógeno inoculado y agente de biocontrol. Se usaron dos cepas patogénicas de Fc; MAT 1 (M1) y MAT 2 (M2) y *Trichoderma asperellum* strain T34 (T34) como agente de control biológico. La combinación de estos dos últimos factores dio lugar a seis tratamientos diferentes: 1) sin patógeno y sin agente de biocontrol (Control, -T34); 2) sin patógeno pero con agente biocontrol (Control, +T34); 3) M1 sin biocontrol (M1, -T34); 4) M1 con agente de biocontrol (M1, +T34); 5) M2 sin agente de biocontrol (M2, -T34) y 6) M2 con agente de biocontrol (M2, +T34).

Con este ensayo de cultivo se monitoreó la incidencia de la enfermedad todos los días durante un periodo de 51 días. Se asumió que el periodo de germinación acababa a los 30 días desde la siembra y este momento marcó los dos periodos diferenciados de pre-emergencia y post-emergencia. La incidencia de la enfermedad fue evaluada con una escala de sintomatología con valor 0 para las plantas asintomáticas y con valor de 1 para las plantas con sintomatología o muertas. Las plantas que no germinaron al final del periodo de pre-emergencia se consideraron plantas muertas.

Al final del estudio, dos plantas sanas por tratamiento y por bloque fueron escogidas al azar para evaluar su fotosíntesis, conductancia estomática y transpiración. Además 12 plantas fueron escogidas al azar para estimar el área foliar total por planta. También se midieron la altura y la longitud de las raíces de dos plantas por tratamiento y por bloque, así como el peso seco tanto de la parte aérea como de la parte radicular.

Todos los composts estudiados mostraron propiedades físicas y físico-químicas adecuadas para ser usados como sustrato de cultivo en semilleros de *P.radiata*. Los composts producidos a gran escala mostraron una mayor supresividad natural frente a Fc. El compost que contó con mayor supresividad (C4) natural contó con mayor capacidad de aireación, conductividad eléctrica más baja, concentración alta de NH_4^+ y bajos niveles de Ca y K. Por otra parte, el tojo compostado a pequeña escala con gallinaza (C1) mostró un mayor

efecto supresor en post-emergencia que aquel compostado a pequeña escala sin gallinaza (C2); además de mayores crecimientos de las plántulas; así como una mayor concentración natural de *Trichoderma* spp. El agente de control biológico T34 redujo la incidencia de la enfermedad tanto en pre como en post-emergencia en los composts con moderada supresividad natural (sobre todo C1 y C5); confirmando esto último el gran potencial del uso de tratamientos alternativos en el control de Fc en semilleros de *P. radiata*.





APPENDIX II: Bibliography



APPENDIX II: BIBLIOGRAPHY

- Abad, M., 2002. Sustratos de cultivo en alveolus, macetas y contenedores, en: J.F. Ballester-Olmos (ed.), Nuevas tecnologías en la viverística de plantas ornamentales. Generalitat Valenciana. Consellería de Agricultura, Pesca y Alimentación, Valencia. 147-164 pp.
- Abad, M., Fornes, F., Mendoza-Hernández, D., García de la Fuente, R., 2008. Uso de compost como sustrato o componente de sustratos en viveros y semilleros. Tendencias futuras. *Actas de Horticultura*. 53: 17-31.
- Abad, M., Martínez, P.F., Martínez, M.D., Martínez, J., 1993. Evaluación agronómica de los sustratos de cultivo. *Actas de Horticultura* 11: 141-154.
- Abad, M., Noguera, P., Carrión, C. 2005. Sustratos para el cultivo sin suelo y fertirrigación. En: C. Cadahía (Coord. y Dir.) *Fertirrigación. Cultivos Hortícolas, Frutales y Ornamentales*. 3ªed. 299-354. Ediciones Mundi-Prensa. Madrid.
- Abad, M., Noguera, P., Burés, S., 2001. National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain. *Bioresour Technol* 77: 197-200.
- Abad, M., Noguera, P., Carrión, C. 2004. Los sustratos en los cultivos sin suelo. En: M. Urrestarazu (Coord. y Dir.). *Tratado de Cultivo sin Suelo*. 3ªed. 113-158. Ediciones Mundi-Prensa, Madrid.
- Abad., M., Fornes, F., Carrión, C., Noguera, V., Noguera, P., Maquieira, A., Puchades, R., 2005. Physical properties of various coconut coir dusts compared to peat. *Hort Sci* 40 (7): 2138-2144.
- Abdelrahman, H.M., Coccozza, C., Miano, T., 2012. Posidonia-based compost as a peat substitute for lettuce transplant production. *Hort Science* 47 (10): 1-7.
- ADAS, 1988. *Guide to the Interpretation of Analytical Data for Loamless Compost*. UK Ministry of Agriculture, Fisheries and Food, Circ. Nº 25. London. UK.
- Albregts, E. E., Howard, C. M., 1980. Accumulation of nutrients by strawberry plants and fruit grown in annual hill culture. *J Am Soc Hortic Sci* 105(3): 386-388.
- Aleandri, M.P., Chilosi, G., Muganu, M., Vettraino, A., Marinari, S., Paolucci, M., Luccioli, E., Vannini, A., 2015. On farm production of compost from nursery green residues and its use to reduce peat for the production of olive pot plants. *Sci. Hortic* 193: 301-307.
- Allen, O.N., Allen, E.K., 1981. *The leguminosae: a source book of characteristics, uses and nodulation*. Univ. of Wisconsin Press, Madison, WI.

- Altieri, M.A., 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. *Front Ecol Environ* 2 (1): 35-42.
- Altieri, R., Esposito, A., Baruzzi, A., 2010. Use of olive mill waste mix as peat surrogate in substrate for strawberry soilless cultivation. *Int Biodeter Biodegr* 64: 670-675.
- Altland, J.E., Krause, C., 2009. Use of switchgrass as a nursery container substrate. *HortScience* 44(7): 1861-1965.
- Amboaje, J.L., López-Fabal, A., López-López, N., 2009. Compostaje de biomasa forestal y gallinaza para la obtención de un sustrato de cultivo para agricultura ecológica. En: Neira, X., Cuesta, T.S., Cervera, A. (Coords). *Compostaje: la salud de la tierra. Utilización en la agricultura ecológica*. 145-160 pp.
- Ameri, A., Tehranifar, A., Shoor, M., Hossein-Davarynejad, G., 2012. Study of the effect of vermicompost as one of the substrate constituents on yield indexes of strawberry. *J Hortic Sci Orn Plants* 4 (3): 241-246.
- Andriolo, J.L., Jänisch, D.I., Schmitt, O.J., Vaz, M.A.B., Cardoso, F.L., Erpen, L., 2009. Concentração da solução nutritiva no crescimento da planta, na produtividade e na qualidade de frutas de morangueiro. *Ciência Rural* 39(3): 648-690.
- Anon, 1987. Our common future, report of the world commission on environment and development, world commission on environment and development, 1987. Published as Annex to General Assembly document A/42/427, Development and International Co-operation: Environment August 2, 1987.
- Anon, 2005. United Nations General Assembly 2005. 2005 world Summit outcome, resolution A/60/1, adopted by the general assembly on 15 September.
- Anon, 2010. Consultation on reducing the horticultural use of peat in England. (http://archive.defra.gov.uk/Document.aspx?Document=SPo8019_FRP.pdf; last accessed 10/11/2011)
- Ansorena, J., 1994. *Sustratos. Propiedades y Caracterización*. Ediciones Mundi-Prensa. Madrid.
- Ansorena, J., Batala, E., Merino, D., 2014. Evaluación de la calidad y usos del compost como componente de sustratos, enmiendas y abonos orgánicos. Laboratorio Agroambiental Fraisoro y Diputación Foral de Guipúzkoa, País Vasco, España. (www.fraisoro.net/FraisoroAtariaDoku/Evaluacion_de_la_calidad_y_usos.pdf; last accessed 17/02/2017)
- Arenas, M., Vavrina, C.S., Cornell, J.A., Hanlon, E.A., Hochmuth, G.J., 2002. Coir as an alternative to peat in media for tomato transplant production. *HortScience* 37(2), 309–312.

- Arrieta, V., Terés, V., Olabarría, I., Esnaola, I., 1992. Relación entre granulometría y algunas propiedades físicas en la corteza de pino (*P. insignis*). I reunión científica sobre aprovechamiento agrícola y forestal de residuos industriales de carácter orgánico. Universidad de Valladolid. Escuela Politécnica de Valencia.
- Atland, J., 2010. Use of processed biofuel crops for nursery substrates. *Jour Environ Hor* 28(3): 129-134.
- Aviani, I., Laor, Y., Medina, Sh., Krasnovsky, A., Raviv, M., 2010. Co-composting of solid and liquid olive mill wastes: Management aspects and the horticultural value of the resulting composts: *Bioresour Technol* 101 (17): 6699-6706.
- Badia, A., Saur, D., Cerdan, R., Llurdes, J.C., 2002. Causality and management of forest fires in Mediterranean environments: an example from Catalonia. *Environ Hazards* 4 (1): 23-32.
- Bakry, M., Lamhamedi, M. S., Caron, J., Margolis, H., El Abidine, A. Z., Bellaka, M., Stowe, D.C., 2011. Are composts from shredded leafy branches of fast-growing forest species suitable as nursery growing media in arid regions? *New Forest* 43 (3): 267-286.
- Ballester-Olmos, J.F., 1993. Sustratos para el cultivo de plantas ornamentales. Spanish Ministry of Agriculture Fisheries and Food. *Hojas divulgadoras* 11: 1-42.
- Baran, A., Çaycı, G., Kütük, C., Hartmann, R., 2001. Composted grape marc as growing medium for *hypostases* (*Hypostases phyllostagya*). *Bioresour Technol* 78(1): 103-106.
- Barnard, E.L., Blakeslee, G.M., 1987. Pitch Canker of Southern Pines. Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Gainesville (Plant Pathology Circular nº 302).
- Barrett, G.E., Alexander, P.D., Robinson, J.S., Bragg, N.C., 2016. Achieving environmentally sustainable growing media for soilless plant cultivation systems-A review. *Sci Hort-Amsterdam* 212: 220-234.
- Belyaeva, O.N., Haynes, R.J., 2010. A comparison of the properties of manufactured soils produced from composting municipal green waste alone or with poultry manure or grease trap/septage waste. *Biol Fert Soils* 46: 271-281.
- Belyaeva, O.N., Haynes, R.J., Sturm, E.C., 2012. Chemical, physical and microbial properties and microbial diversity in manufactured soils produced from co-composting green waste and biosolids. *Waste Manage* 32: 2248-2257.
- Benito, M., Masaguer, A., De Antonio, R., Moliner, A., 2005. Use of pruning waste compost as a component in soilless growing media. *Bioresour Technol* 96: 597-603.

- Bertoldi, M.; Vallini, G., Pera, A., 1983. The biology of composting: A review. *Waste Manage Res* 1: 157-176.
- Bilderback, T.E., Riley, E.D., Jackson, B.E., Kraus, H.T., Fonteno, W.C., Owen Jr., J.S., Altland, J., Fain, G.B., 2013. Strategies for developing sustainable substrates in nursery crop production. *Acta Hort* 1013: 43–56.
- Black, B.L., Zimmerman, R.H., 2002. Mixtures of coal ash and compost as substrates for highbush blueberry. *J Amer Soc Hort Sci* 125(5): 869-877.
- Blakeslee, G.M., Jokela, E.J., Hollis, C.H., Wilson, D.S., Lante, W.D., Allen, J.E., 1999. Pitch canker in young loblolly pines: influence of precommercial thinning and fertilization on disease incidence and severity. *South J Appl For* 23: 139-143.
- Blythe, E.K., Merhaut, D.J., 2007. Grouping and comparison of container substrates based on physical properties using exploratory multivariate statistical methods. *Hort Sci-England* 42(2): 353- 363.
- BOE 2010. Royal Decree 865/2010, 2 July, about growing media. Official Bulletin of the Spanish State nº 170: 61831-61859.
- Bohlin, C., 2002. Data on the use of growing medium constituents. Proc. Intl. Peat Symposium Peat in Horticulture- Quality and Environmental Challenges. Pärnu, Estonia, 3-6 Sep. 144-150 pp.
- Boldrin, A., Hartling, K.R., Laugen M., Christensen, T.H. 2010. Environmental inventory modelling of the use of compost and peat in growth media preparation. *Resources, Conserv Recycling* 54:1250-1260.
- Borrero, C., Ordovás, J., Trillas, M.I., Avilés, M., 2006. Tomato Fusarium wilt suppressiveness. The relationship between the organic plant growth media and their microbial communities as characterized by Biolog®. *Soil Biol Biochem (US)* 38: 1631-1637.
- Borrero, C., Trillas, M.I., Delgado, A., Avilés, M., 2012. Effect of ammonium/nitrate ratio in nutrient solution on control of Fusarium wilt of tomato by *Trichoderma asperellum* T34. *Plant Pathol* 61: 132-139.
- Borrero, C., Trillas, M.I., Ordovás, J., Tello, J.C., Avilés, M., 2004. Predictive factors for the suppression of Fusarium Wilt of tomato in plant growth media. *Phytopathology* 94: 1094-2004.
- Bottoms, T.G., Bolda, M. P., Gaskell, M.L., Hartz, T.K., 2013. Determination of Strawberry Nutrient Optimum Ranges through Diagnosis and Recommendation Integrated System Analysis. *HorTechnology* 23(3): 312-318.
- Bragg, N., 1990. A Review of Peat Reserves and Peat Usage in Horticulture and Alternative Materials – Report for the Horticultural Development Company(HDC). Petersfield, UK.

- Breitenbeck, G.A., Shellinger, D., 2004. Calculating the reduction in material mass and volume during composting. *Compost Sci Util* 12: 365-371.
- Brewer, L.J., Sullivan, D.M., 2001. A quick look at quick compost stability test. *Biocycle* 42: 74-76.
- Brewer, L.J., Sullivan, D.M., 2003. Maturity and stability evaluation of composted yard trimmings. *Compost Sci Util* 11: 96-112.
- Brito, L.M., Mourão, I., Coutinho, J., Smith, S.R. 2010. Physicochemical dynamics of composting screw pressed cattle slurry amended with italian ryegrass straw or gorse bulking agents. *Compost Sci Util* 18(2): 119-126.
- Brodie, H.L., Carr, L.E., Condon, P. 2000. A comparison of static pile and turned windrow methods for poultry litter compost production. *Compost Sci Util* 8: 178-189.
- Brown, K., Ghoshdastidar, A.J., Hanmore, J., Frazee, J., Tong, A. Z., 2013. Membrane bioreactor technology: a novel approach to the treatment of compost leachate. *Waste manage* 33(11): 2188-2194.
- Bueno, P., Tapias, R., López, F.,Díaz, M.J. 2008. Optimizing composting parameters for nitrogen conservation in composting. *BioresourTechnol* 99: 5069-5077.
- Bullock, C.H., Collier, M.J., Convery, F., 2012. Peatlands, their economic value and priorities for their future management – The example of Ireland. *Land Use Policy* 29: 921-928.
- Bunt, A.C., 1988. Media mixes for container-grown plants, Unwin Hyman ed., Cross Ref, London.
- Burés, S. 1997. *Sustratos*. Ediciones Agrotécnicas S.L. Madrid.
- Burger, D.W., Hartz, T.K., Forister, G.W., 1997. Composted green waste as a container medium amendment for the production of ornamental plants. *HortScience* 32 (1): 57–60.
- Bustamante, M. A., Paredes, C., Marhuenda-Egea, F. C., Pérez-Espinosa, A., Bernal, M. P., Moral, R., 2008. Co-composting of distillery wastes with animal manures: carbon and nitrogen transformations in the evaluation of compost stability. *Chemosphere* 72(4): 551-557.
- Caballero, R., Ordovás, J., Pajuelo, P., Carmona, E., Delgado, A., 2007. Iron chlorosis in gerber as related to properties of various types of compost used as growing media. *Commun Soil Sci Plant Anal* 38: 2357-2369.
- Cáceres, R., Flotats, X., Marfà, O., 2006. Changes in the chemicals and physicochemical properties of the solid fraction of cattle slurry during composting using different aeration strategies. *Waste Manage* 26: 1081-1091.
- Calvo, P., Nelson, L., Kloepper, J.W. 2014. Agricultural uses of plant biostimulants. *Plant Soil* 383: 3-41

- Cambouris, A.N., Ziadi, N., Perron, I., Alotaibi, K. D., St. Luce, M., Tremblay, N., 2016. Corn yield components response to nitrogen fertilizer as a function of soil texture. *Can J of Soil Sci* 96(4): 386-399.
- Campos, L., van Meeteren, V., Blok, C., 2007. Comparison of the physical properties of vermicompost from paper mill sludge and green compost as substitutes for peat-based potting media. *Acta Hort* 819: 227-234.
- Canellas, L.P; Olivares, F.L., Aguiar, N.O., Jones, D. L., Nebbioso, A., Mazzei, P., Piccolo, A., 2015. Humic and fulvic acids as biostimulants in horticulture. *Sci Hort*-England 196: 15-27.
- Cantliffe, D.J., Castellanos, J.Z., Paranjpe, A.V., 2007. Yield and quality of greenhouse-grown strawberries as affected by nitrogen level in coco coir and pine bark media. *Proc Fla State Hort Soc* 120: 157-161.
- Carlile, B., Coules, A., 2013. Towards sustainability in growing media. *Act Hort* 1013: 341-350.
- Carlile, W.R., 1997. The effects of the environment lobby on the selection and use of growing media. *Act Hort* 1013: 43-46.
- Carlile, W.R., 2008. The use of composted materials in growing media. *Proceedings of the International Symposium on Growing Media. Act Hort* 779: 321-328.
- Carmona, E., Abad, M., 2008. Aplicación del compost en viveros y semilleros. 397-424 pp. En: Moreno, J., y Moral, R., (Eds), *Compostaje*. Mundi-Prensa, Madrid.
- Carmona, E., Avilés, M., Domínguez, I., Moreno, M. T., Pajuelo, P., Ordovás, J., 2004. Exploitation of composted agricultural wastes as growing media. *Sustainable organic waste management for environmental protection and food safety* 1: 141-144.
- Carmona, E., Ordovás, J., Domínguez, I., Sáñez, J.A., Moreno, M.T., 2002. Sustratos alternativos a la turba para el cultivo en maceta de plantas ornamentales [Alternative growing media to peat for ornamental potted plant production]. *Actas de las I Jornadas Ibéricas de Plantas Ornamentales (SECH and APH)*. Consejería de agricultura y Pesca de la Junta de Andalucía, Sevilla, Spain. 287-291 pp.
- Carrión, C., Abad, M., Puchades, R., 2006. Desarrollo de nuevos sustratos de cultivo para la producción de planta ornamental en maceta a partir de composts de residuos de cultivos hortícolas. *Tesis Doctorales N° 5326*. Editorial de la Universidad Politécnica, Valencia.
- Carrión, C., Abad, M., Puchades, R., Fornes, F., Maquieira, A., Noguera, V., 2005. Leaching of compost from agricultural wastes to prepare nursery potting media. *Acta Hort* 697: 117-124.

- Carrión, C., García de la Fuente, R., Fornes, F., Puchades, R., Abad, M., 2008. Acidifying composts from vegetable crop wastes to prepare growing media for containerized crops. *Compost Sci Util* 16: 20-29.
- Castaño, R., Borrero, C., Trillas, M.I., Avilés, M., 2013. Selection of biological control agents against tomato Fusarium wilt and evaluation in greenhouse conditions of two selected agents in three growing media. *Biocontrol* 58: 105-116.
- Chet, I., Ordentlich, A., Kless, H., Oppenheim, A., 1987. The potential of chitinolytic microorganisms in controlling soilborne plant-pathogens. *Phytoparasitica* 15: 146-147.
- Choi, J.M., Latigui, A., Chiwon, W.L., 2013. Visual symptom and tissue nutrient contents in dry matter and petiole sap for diagnostic criteria of phosphorous nutrition for "Seolhyang" strawberry cultivation. *Hort Environ Biotechnol* 54(1): 52-57.
- Chong, C., 2005. Experiences with wastes and substrates. *Hortechonology* 15: 739-747.
- Chung, Y.R., Hoitink, H.A.J., 1990. Interactions between thermophilic fungi and *Trichoderma hamatum* in suppression of Rhizoctonia damping off in a bark compost-amended container medium. *Phytopathology* 80: 73-77.
- Cook, R.J., Baker, K.F., 1983. *The nature and practice of biological control of plant pathogens*, APS Press ed. St. Paul, Minnesota, USA.
- Cooper, J. R., Vaile, J. E., 1945. Effect of fertilizers, soil reaction and texture, and plant stand on the performance of strawberries. Arkansas Agricultural Experiment Station. Bulletin nº 454.
- Copena, D., Simón, X., 2014. A produción da enerxía eléctrica a partir da biomasa forestal primaria: Análise do caso galego. *Revista Galega de Economía*, 23 (2): 91-112.
- Costa, F., García, C., Hernández, T., Polo, A., 1991. *Residuos orgánicos urbanos. Manejo y utilización*. Ed. CSIC-CEBAS. Murcia.
- Cotxarrera, L., Trillas-Gay, M.I., Steinberg, C., Alabouvette, C., 2002. Use of sewage sludge compost and *Trichoderma asperellum* isolates to suppress Fusarium wilt of tomato. *Soil Biol Biochem* 34: 467-476.
- Cunha-Queda, A.C., Ribeiro, H.M., Ramos, A., Cabral, F., 2007. Study of biochemical and microbiological parameters during composting of pine and eucalyptus bark. *Bioresour Technol* 98: 3213-3220.
- Day, M., Shaw, K. 2001. Biological, Chemical, and Physical Processes of Composting. In: Stoffella, P.J., Kahn, B.A. (Eds) *Compost Utilization in Horticultural Cropping Systems*, chap 2. CRC Press LLC. 17-50 pp.

- De Boodt, M., Vendonck, O., Cappaert, I., 1974. Method for measuring the water release curve of organic substrates. *Act Hort* 37: 2054-2062.
- De Ceuster, T.J.J., Hoitink, H.A.J., 1999. Prospects for composts and biocontrol agents as substitutes for methyl bromide in biological control of plant diseases. *Compost Sci Util* 7: 6-15.
- De Luis, M., González-Hidalgo, J. C., Raventós, J., 2003. Effects of fire and torrential rainfall on erosion in a Mediterranean gorse community. *Land Degrad Dev* 14(2), 203-213.
- Díaz, F., Arbones, E., Iglesias, I., Gómez, J., 2008. Preliminary study of the viability of substrate manufacture using gorse (*Ulex europaeus* L.). *Agricultural and biosystems engineering for a sustainable world. International Conference on Agricultural Engineering, Hersonissos, Crete, Greece, 23-25 June. 188 p.*
- Dijksterhuis, J., Sanders, M., Gorris, L.G.M., Smid, E.J., 1999. Antibiosis plays a role in the context of direct interaction during antagonism of *Paenibacillus polymyxa* towards *Fusarium oxysporum*. *J Appl Microbiol* 86: 13-21.
- Dimitrios, P., Ioannis, S., 2009. A statistical analysis to assess the maturity and stability of six composts. *Waste Manage* 1504-1513 pp.
- Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3
- Domeño, I., Irigoyen, I., Muro, J., 2010. New wood fibre substrates characterization and evaluation in hydroponic tomato culture. *Eur J Hort* 75 (2): 89–94.
- Dwinnell, L.D., Fradrich, S.W., Adams, D., 2001. Disease of pines caused by the pitch canker fungus. in: *Fusarium* Paul E. Nelson Memorial Symposium Summerell, B.A., Leslie, J.F., Blackhouse, D., Bryden, W.L., Burgess, L.W. (Eds), The American Phytopathological Society, St. Paul, MN. 225-232 pp.
- Economakis C.D., Koleilat R., Chartzonlakis K.S., 1997. Effect of nitrogen concentration on growth, water and nutrient uptake of lettuce plants in solution culture. *Act Hort* 449: 223-228.
- Emino, E.R., Warman, P.R., 2004. Biological assay for compost quality. *Compost Sci Util* 12: 342-348.
- EN-13039, 1999. Soil Improvers and Growing Media: Determination of organic matter content and ash. European Committee for Standardization.
- EN-13040, 2007. Soil Improvers and Growing Media: Sample preparation for chemical and physical tests, determination of dry matter content, moisture content and laboratory compacted bulk density. European Committee for Standardization.

- EN-13041, 1999. Soil Improvers and Growing Media: Determination of physical properties. Dry bulk density, air volume, water volume, shrinkage value and total pore space. European Committee for Standardization.
- EN-13652, 2001. Soil Improvers and Growing Media: Extraction of water soluble nutrients and elements. European Committee for Standardization.
- Environmental Protective Agency (EPA), 2011. The phase out of methyl bromide. (<http://www.epagov/ozone/mbr>; last accessed 01/02/2011).
- EPPO, 2012. A2 List of pests recommended for regulation as quarantine pests. (<http://www.eppo.int/QUARANTINE/listA2.htm>, last accessed 30/05/13).
- Escudero, J., 1993. Cultivo hidropónico del tomate. In: Curso Superior de Especialización sobre cultivos sin suelo. Cánovas, F. and Díaz, J.R. (Eds). I.E.A./F.I.A.P.A. Almería, Spain. 261-297 pp.
- Estévez-Schwarz, I., Seoane-Labandeira, S., Núñez-Delgado, A., López-Mosquera, M. E., 2012. Production and characterization of compost made from garden and other waste. *Pol J Environ Stud* 21(4): 855-864.
- EU Commission, 2001. Commission Decision of 28 Aug. 2001 establishing ecological criteria for the award of the Community eco-label to soil improvers and growing media (2001/688/EC). *Official Journal of the European Communities*, L 242/17–L 242/22.
- EU Commission, 2006. Commission Decision of 3 Nov. 2006 establishing revised ecological criteria and the related assessment and verification requirements for the award of the Community eco-label to growing media (2006/799/EC). *Official Journal of the European Communities*, L 325/28-L 325/34.
- EU Commission, 2012. Anexes to the final report of the: Study on options to fully harmonise the EU legislation on fertilizing materials including technical feasibility, environmental, economic and social impacts. Spay, D., Traon, Arcadia International; Joas R., BIPRO (Eds) Brussels (Belgium).
- EU Commission, 2015a. Commission Decision of 15 Dec. 2015 establishing the ecological criteria for the award of the EU Ecolabel for growing media, soil improvers and mulch (2015/ 7891/EC). *Official Journal of the European Communities*, L 303/75-L 303/100.
- EU Commission, 2015b. Ecolabel Catalogue. (<http://ec.europa.eu/ecat>; last accessed 20/10/2015).
- EU Commission, 2017. Ecolabel Catalogue. (<http://ec.europa.eu/ecat> last accessed 27/01/2017)
- Evans, M.R., Konduru, S., 1996. Source variation in physical and chemical properties of coconut coir dust. *Hort Science* 31 (6): 965-967.

- FCQAO, 1994. Methods Book for the Analysis of Compost. Federal Compost Quality Assurance Organization, Essen, Germany.
- Fiasconaro, M.L., Antolín, M.C., Lovato, M.E., Gervasio, S., Martín, C.A. 2015. Study of fat compost from dairy industry wastewater as a new substrate for pepper (*Capsicum annuum* L.) crop. *Sci Hortic-Amsterdam* 193: 359-366.
- Fisher, R.F., Garbett, W. S., Underhill, E. M., 1981. Effects of fertilization on healthy and pitch-canker infected pines. *South J Appl For* 5: 77-79.
- Fonteno, D.C., 1999. Sustratos: tipos y propiedades físicas/químicas. En: Agua, sustratos y nutrición en los cultivos de flores bajo invernadero. David Wm. (Reed Ed.). Ball Publishing. Panamericana Formas e Impresos. Santafé Bogotá. Colombia.
- Food and Agriculture Organization of the United Nations (FAO), 2003. International standards for phytosanitary measures. Manual on Pesticides. (<http://www.fao.org/ag/AGP/.../qualitycontrol05.pdf>; last accessed 21/01/2011).
- Fornes, F., Mendoza-Hernandez, D., Belda, R.M., 2013. Compost versus vermicompost as substrate constituents for rooting shrub cuttings. *Span J Agri Res* 11(2): 518-528.
- Fuchs, J. G., 2002. Practical use of quality compost for plant health and vitality improvement. In *Microbiology of composting*. 435-444 pp. Springer Berlin Heidelberg.
- Fuchs, J.G., Moëgne-Loccoz, Y., Défago, G., 1999. Ability of non-pathogenic *Fusarium oxysporum* Fo47 to protect tomato against *Fusarium* Wilt. *Biol Control* 14: 105-110.
- Gantzer, C., Gaspard, P., Galvez, L., Huyard, A., Dumouthier, N., Schwartzbrod, J., 2001. Monitoring of bacterial and parasitological contamination during various treatment of sludge. *Water Res* 35 (16): 3763-3770.
- García de la Fuente, R., Carrión, C., Botella, S., Fornes, F., Noguera, V., Abad, M., 2007. Biological oxidation of elemental sulphur added to three composts from different feedstocks to reduce their pH for horticultural purposes. *Bioresour Technol* 98: 3561-3569.
- Gaynor, D.L., McCarter, L.E., 1981. Biology, ecology, and control of gorse: a bibliography. *NZ J Agri Res*, 24: 123-127.
- Golueke, C.G., 1981. Principles of biological resource recovery. *BioCycle* 22: 36-40.
- Gómez, J., Minhorst, R., Piñeiro-Iglesias, I., 2009. Evaluación de diferentes sistemas de elaboración de sustratos de cultivo obtenidos a partir de tojo (*Ulex euroapeus* L.). *Spanish J Rural Dev* 1: 188-204

- Gordon, T.R., Kirkpatrick, S.C., Aegerter, B.J., Wood, D.L., Storer, A.J., 2006. Susceptibility of Douglas fir (*Pseudotsuga menziesii*) to pitch canker caused by *Gibberella circinata* (anamorph = *Fusarium circinatum*). *Plant Path* 55: 231-237.
- Gordon, T.R., Storer, A.J., Wood, D.L., 2001. The pitch canker epidemic in California. *Plant Dis* 85: 1128-1139.
- Gruda, N., Schnitzler, W.H., 2004. Suitability of wood fiber substrate for production of vegetable transplants: I: Physical properties of wood fiber substrates. *Sci Horti-Amsterdam* 100:309-322.
- Grundy, A.C., Green, J.M., Lennartsson, M., 1998. The effect of temperature on the viability of weed seeds in compost. *Compost Sci Util* 6(3): 26-33.
- Guerra-Santos, J.J., 1999. Pitch canker on Monterrey pines in Mexico, in: *Forestry and forest products. Current and Potential Impacts of Pitch Canker in radiate Pine*. Devey, M.E., Matheson, A.C., Gordon, T.R. (Eds), Tech. Rep. CSIRO, Canberra, Australia, 112.
- Guerrero, F., Gascó, J.M., Hernández-Apaolaza, L., 2002. Use of pine bark and sewage sludge compost as components of substrates for *Pinus pinea* and *Cupressus arizonica* production. *J Plant Nutr* 25: 129-141.
- Handreck, K.A., 2011. Container media: the Australian experience. *Acta Hort* 891: 287–295.
- Hargreaves, J.C., Adl, M.S., Warman, P.R., 2008. A review of the use of composted municipal solid waste in agriculture. *Agr Ecosyst Environ* 123: 1-14.
- Harman, G.E., Chet, I., Baker, R., 1981. Factors affecting *Trichoderma hamatum* applied to seeds as a biocontrol agent. *Phytopathology* 71: 569-572.
- Hartz, T.K., Costa, F.J., Schrader, W.L., 1996. Suitability of composted green waste for horticultural uses. *HortScience* 31 (6): 961–964.
- Hassen, A., Belguith, K., Jedidi, N., Cherif, A., Cherif, M., Boubabous, A., 2001. Microbial characterization during composting of municipal solid waste. *Bioresour Technol* 80: 215-225.
- Heisnaken, J., 2013. Effects of compost additive in sphagnum peat growing medium on Norway spruce container seedlings. *New For* 44: 101-118.
- Hepting, G.H., Roth, E.R., 1946. Pitch canker, a new disease of some southern pines. *J For* 44: 742-744.
- Hernández-Apaolaza, L., Gascó, A.M., Gascó, J.M., Guerrero, F., 2015. Reuse of waste materials as growing media for ornamental plants. *Bioresour Technol* 96 (1): 125–131.

- Hervas, A., Landa, B., Datnoff, L.E., Jimenez-Diaz, R.M., 1998. Effects of commercial and indigenous microorganisms on *Fusarium* Wilt development in chickpea. *Biol Control* 13: 166-176.
- Hohmann, P., Jones, E.E., Hill, R.A., Stewart, A., 2012. Ecological studies of the bio-inoculant *Trichoderma hamatum* LU592 in the root system of *Pinus radiata*. *Microbiol Ecol* 80: 719-721.
- Hoitink, H.A.J., Boehm, M.J., Hadar, Y., 1993. Mechanism of suppression of soilborne plant pathogens in compost-amended substrates. In: Hoitink, H.A.J., Keener, H.M. (Eds), *Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects*. Renaissance Publications, Worthington, Ohio. 601-621 pp.
- Hoitink, H.A.J., Fahy, P.C., 1986. Basis for the control of soilborne plant pathogens with composts. *Annu Rev Phytopathol* 24: 93-114.
- Hoitink, H.A.J., Schmitthener, A.F., Herr, L.J., 1975. Composted bark for control of root rot in ornamentals. *Ohio Rep* 60: 25-26.
- Holm, L.G., Plucknett, J.V., Herberger, J.P, 1977. *The world's worts weeds-distribution and biology*. The Univ. of Hawaii Press, Honolulu, HI.
- Hoshovsky, M., 1986. Element stewardship abstract for *Ulex europaeus*. The Nature Conservancy, California Field Office, San Francisco, CA.
- Howell, C.R., 2003. Mechanisms employed by *Trichoderma* species in the biological control of plant disease: The history and evolution of current concepts. *Plant Dis* 87: 4-10.
- Iannotti, D.A., Grebus, M.E. Toth, B.L., Elwell, D.L., Keener, H.M. y Hoitink, H.A.J. 1993. A quantitative respirometric method for monitoring compost stability. *Compost Sci Util* 1: 52-65.
- IFOAM, 2009. *Definition of Organic Agriculture*. The International Federation of Organic Agriculture Movements (IFOAM), Bonn, Germany.
- IFOAM, 2016. *The world of organic agriculture. Statistics and Emerging Trends*, ed. By Willer H and Yussefi M. International Federation of Organic Agriculture (IFOAM), Bonn, Germany, and Research Institute of Organic Agriculture FiBL, Frick, Switzerland.
- Iglesias, I., Rodil, C., Bessa, P., Lamosa, S., 2008. Gorse compost as a peat-substitute in growing media for the production of *Thuja plicata* "Zebrina". *Proc. IS on Growing Media. Act Hort* 779: 615-622.
- Iglesias-Díaz, I., Rodil, C., Lamosa, S., Díaz, F., 2004b. Utilización de compost de tojo (*Ulex europaeus* L.) en la producción de planta leñosa ornamental. *Actas da Associação Portuguesa de Horticultura* 4: 319-324.

- Iglesias-Díaz, I., Rodil, C., Lamosa, S., Arbones, E., 2004b. Crecimiento de *Cotoneaster dammeri* en medios de cultivo basados en compost de tojo (*Ulex europaeus*). Actas da Associação Portuguesa de Horticultura 4: 307-311.
- Iglesias-Díaz, I., Rodil, C., Lamosa, S., Díaz, F., 2004a. Utilización de compost de tojo (*Ulex europaeus* L.) en la producción de planta leñosa ornamental. Actas da Associação Portuguesa de Horticultura 4: 319-324.
- Iglesias-Díaz, M.I., Lamosa, S., Rodil, C., Díaz-Rodríguez, F., 2009. Root development of *Thuja plicata* in peat-substitute rooting media. Sci Hortic-England 122: 102-108.
- Iglesias-Jimenez, E., Pérez-García, V., 1989. Evaluation of city refuse compost maturity. A review. Biol Wastes 27: 112-115.
- IGME, 2015. Panorama minero 2015. Instituto Geológico y Minero de España. Ministerio de Economía y Competitividad. Gobierno de España.
- Ingelmo, F., Canet, R., Ibáñez, A., Pomares, F., García, J., 1998. Use of MSW compost, dried sewage sludge and other wastes as partial substitutes for peat and soil. Bioresour Technol 63: 123-129.
- IPS, 2007. International Peat Society. Annual Report. (http://www.peatsociety.org/user_files/files/Peatlands%20International%201-2008.pdf; last accessed 01/11/2009).
- IPCS, 2006. The WHO recommended classification of pesticides by hazard. (http://www.who.int/entity/ipcs//pesticides_hazard/en/index.html)
- ISO 14021, 1999. Environmental labeling declarations - Self- declared environmental claims (Type II Labels).
- ISO 14024, 1999. Labeling and Environmental Declarations - Type 1 Environmental Labeling, International Organization for Standardization.
- ISO 14025, 2000. Environmental Labels and Declarations, Type III Environmental Declarations, International Organization for Standardization.
- Jarecki, M.K., Chong, C., Voroney, R.P., 2005. Evaluation of compost leachates for plant growth in hydroponic culture. J Plant Nutrition 28(4): 651-667.
- Jhorar, B., Phogat, V., Malik, R., 1991. Kinetics of composting rice straw with glue waste at different carbon: nitrogen ratios in a semiarid environment. Arid Land Res Manag 5:297-306.
- John, R.P., Tyagi, R.D., Prevost, D., Brar, S.K., Pouleur, S., Surampalli, R.Y., 2010. Mycoparasitic *Trichoderma viride* as a biocontrol agent against *Fusarium oxysporum* f. Sp adzuki and *Pythium arrhenomanes* and as a growth promoter of soybean. Crop Prot 29 (12): 1452-1459.

- Kim, H.S., Park, J., Choi, S.W., Choi, K.H., Lee, G.P., Ban, S.J., Lee, C.H., Kim, C.S., 2003. Isolation and characterization of Bacillus strains for biological control. *J Microbiol* 41: 196-201.
- Knight, A., 2012. Towards sustainable growing media. Sustainable growing media task force. Chairman's report and roadmap. UK Department for Environment, Food & Rural Affairs. 29 pp.
- Komada, H. 1975. Development of a selective medium for quantitative isolation of *Fusarium oxysporum* from natural soil. *Rev Plant Protect Res* 8:114-125
- Krucker, M., Hummel, R.L., Cogger, C., 2010. Chrysanthemum production in composted and non composted organic waste substrates fertilized with nitrogen at two rates using surface and subirrigation. *HortScience* 45 (11): 1695–1701.
- Lambert, M. G., Jung, G. A., Harpster, H. W., Lee, J., 1989. Forage shrubs in North Island hill country. 4. Chemical composition and conclusions. *New Zeal J of Agri Res* 32(4): 499-506.
- Landeras, E., García, P., Fernández, Y., Brana, M., Fernando-Alonso, O., Méndez-Lodos, S., Pérez-Sierra, A., León, M., Abad-Campos, P., Berbegal, M., Beltran, R., García-Jiménez, J., Armengol, J., 2005. Outbreak of pitch canker caused by *Fusarium circinatum* on Pinus spp. in Northern Spain. *Plant Dis* 89: 1015.
- Landis, T.D., Morgan, N., 2009. Growing media alternatives for forest and native plant nurseries, in: Dumroese R.K., Riley L.E. (Tech. cords), National Proceedings: forest and conservation nursery associations 2008. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, 26-31 pp.
- Landis, T.D., Tinus, R.W., McDonald, S.E., Barnett, J.P., 1990. Containers and growing media, in: USDA, Forest Service (Eds). The container tree nursery manual. *Agric Handbook*, Washington. 2: 674.
- Larcher, F., Scariot, V., 2009. Assessment of partial peat substitutes for the production of *Camellia japonica*. *HortScience* 44:312-316.
- Larney, F.J., Olson, A.F., Carcamo, A.A., Chang, C., 2000. Physical changes during active and passive composting of beef feedlot manure in winter and summer. *Bioresour Technol* 75: 139-148.
- Lasaradi, K.E. y Stentiford, E.I. 1998. A simple respirometric technique for assessing compost stability. *Water Research*. 32, 3717-3723.
- Lemaire, F., Dartigues, A., Riviere, L.M., Charpentier, S., Morel, P., 2003. Cultures en pots et conteneurs. Principes agronomiques et applications. INRA Editions, 2^a Ed. Paris. France. 210 pp
- Lemaire, F., Rivière, L.M., Stievenard, S., Marfà, O., Gschwander, S., Giuffrida, F., 1998. Consequences of organic matter biodegradability on the physical, chemical parameters of substrates. *Act Hort* 469: 129-138.

- Litterick, A.M., Harrier, L., Wallace, P., Watson, C.A., Wood, M., 2004. The role of uncomposted materials, compost, manures and compost extracts in reducing pest and diseases incidence and severity in sustainable temperature agricultural and horticultural crop production -A review. *Crit Rev Plant Sci* 23: 453-479.
- López-Fabal, A. López-López, N., Sainz-Osés, M.J., López-Mosquera, M.E., 2009. Modificación de las propiedades físicas y químicas de la corteza de pino mediante la adición de cenizas y modificación granulométrica. *Actas de Horticultura* 53: 68-72.
- López-Fabal, A., López-López, N., López-Mosquera, M.E., Sainz-Osés, M.J., 2011. Producción de albahaca en maceta sobre un compost de matorral. *Actas de Horticultura* 59: 131-136.
- López-Fabal, A., López-López, N., López-Mosquera, M.E., 2011. Modificación de las propiedades de retención de agua de sustratos mediante el uso de superabsorbentes. *Actas de Horticultura* 59: 42-47.
- López-Fabal, A., López-López, N., Sainz-Osés, M.J., López-Mosquera, M.E., 2008. Modificación de las propiedades físicas y químicas de la corteza de pino mediante la adición de cenizas y modificación granulométrica. *Actas de Horticultura* 53: 68-72.
- López-López, N., López-Fabal, A., 2012. Uso de un sustrato alternativo a la turba para la producción viverística de plantas hortícolas y aromáticas. *Recursos Rurais* 8: 31-38.
- López-López, N., López-Fabal, A., 2013. Evaluation of urban solid waste and sewage sludge composts as components of growing media. *Act Horticult* 1013: 231-238.
- López-López, N., López-Fabal, A., López-Mosquera, M.E., Sainz-Osés, M.J., 2011. Sustrato a base de compost de tojo para un cultivo de lechuga ecológica. *Actas de Horticultura* 59: 102-107.
- López-López, N., López-Fabal, A., Amboaje, J.L., 2008. Evaluación preliminar de mezclas de gallinaza y tojo para su uso como sustrato en agricultura ecológica. *Actas de Horticultura* 53: 135-139.
- López-López, N., Segarra, G., Vergara, O., López-Fabal, A., Trillas, M.I., 2016. Compost from forest cleaning green waste and *Trichoderma asperellum* strain T34 reduced incidence of *Fusarium circinatum* in *Pinus radiata* seedlings. *Biol Control* 95: 31-39.
- Lu, W., Sibley, J.L., Gilliam, C.H., Bannon, J.S., Zhang, Y., 2006. Estimation of U.S. bark generation and implications for horticultural industries. *J Environ Horticult* 24(1): 29-34.
- Luginbuhl, J. M., Castagni, S. P., 2007. Use of goats to control undesirable vegetation. *Arch Latinoam Prod Anim* 15 (1): 294-309.
- Lumis, G.P., Johnson, A.G., 1982. Boron toxicity and growth suppression of Forsythia and Thuja grown in mixes amended with municipal waste compost. *HortScience* 17 (5): 821-822.

- MacCarter, L. E., Gaynor, D. L., 1980. Gorse: a subject for biological control in New Zealand. *New Zeal J Exp Agr* 8 (3-4): 321-330.
- Madejón, E., Díaz, M. J., López, R. y Cabrera, F., 2002. New approaches to establish optimum moisture content for compostable materials. *Bioresour Technol* 85: 73-78.
- MAGRAMA., 2013. Anuario de estadística. Ministerio de Agricultura, Alimentación y Medio Ambiente. Madrid, 2014.
- Maher, M., Prasad, M., Raviv, M., 2008. Organic soilless media components. In: Raviv M. and J.H. Lieth. (Eds). *Soilless substrates theory and practice*. Elsevier BV. 459-504 pp.
- Maher, M.J., Prasad, M., 2004. The effect of peat type and lime on growing medium pH and structure and growth of *Hebe pinguifolia* 'Sutherlandii'. *Acta Hort* 644: 131-137.
- Mäkiranta, P., Riutta, T., Penttilä, P., Minkkinen, K., 2010. Dynamics of net ecosystem CO₂ exchange and heterotrophic soil respiration following clearfelling in a drained peatland forest. *Agr Forest Meteorol* 150: 1585- 1596.
- Maltby, E., Proctor, M.C.F., 1996. Peatlands: their nature and role in the biosphere. In: E. Lappalainen (ed.). *Global peat resources* published by International Peat Society, Saarijärvi, Finland. 359 pp.
- MAPA., 2010. Anuario de estadística. Ministerio de Medio Ambiente y Medio Rural y Marino. Madrid, 2011.
- MAPAMA, 2015. Agricultura Ecológica. Estadísticas 2014. Ministerio de Agricultura, Alimentación y Medio Ambiente (Eds). Madrid. Spain.
- Martínez-Álvarez, P., Alves-Santos, F.M., Diez, J.J., 2012. *In vitro* and *in vivo* interactions between *Trichoderma viride* and *Fusarium circinatum*. *Silva Fen.* 46 (3): 303-316.
- Masaguer, A., López-Fabal, A., Carmona, E., Fornés, F., Ordovás, J., Gómez, M.A., Moreno, M.A., Marfá, O., Cáceres, R., López, R., Belda, R., 2015. De residuo a recurso. El camino hacia la sostenibilidad. Ediciones Mundi-Prensa, Madrid.
- Michel, J. C., Pecchia, J. A., Rigot, J., Keener, H. M., 2004. Mass and nutrient losses during the composting of dairy manure amended with sawdust or straw. *Compost Sci Util* 12(4): 323-334.
- Michel, J.C., 2010. The physical properties of peat: a key factor for modern growing media. *Mires and Peat* 6, (2).
- Michel, J.C., Rivière, L.M., Bellon-Fontaine, M.N., 2001. Measurement of the wettability of organic materials in relation to water content by the capillary rise method. *Eur J Soil Sci* 52: 459-467.

- Miller, J.H., Jones, N., 1995. Organic and compost-based growing media for tree seedling nurseries. The International Bank for Reconstruction and Development. The World Bank (Ed.). Washington, D.C.
- Miramontes, A., 2001. Adaptación de un paisaje agrícola tradicional a nuevos usos que lleven a la sostenibilidad. El ejemplo del municipio de A Estrada (Pontevedra). Actas IV Coloquio hispano-portugués de estudios rurales.
- Molina, E., Salas, R., Castro, A., 1993. Curva de crecimiento y absorción de nutrientes en fresa (*Fragaria x Ananasa* cv. Chandler) en Alajuela. *Agronomía Costarricense* 17(1): 67-73.
- Molina, J., Clapp, C., Larson, W., 1980. Potentially mineralizable nitrogen in soil: the simple exponential model does not apply for the first 12 weeks of incubation. *Soil Sci Soc Am J* 44:442-443.
- Moore, K.K., 2005. Uses of compost in potting mixes. *Hort Technol* 15 (1): 58-60.
- Moraga-Suazo, P., Opazo, A., Zaldúa, S., González, G., Sanfuentes, E., 2011. Evaluation of *Trichoderma* spp. and *Clonostachys* spp. strains to control *Fusarium circinatum* in *Pinus radiata* seedlings. *Chil J Agr Res* 71 (3): 412-416.
- Morales-Corts, M.R., Gómez-Sánchez, M.A., Pérez-Sánchez, R., 2014. Evaluation of green/pruning wastes compost and vermicompost, slungum compost and their mixes as growing media for horticultural production. *Sci Hortic-Amsterdam* 172: 155-160.
- Morell, I., Sánchez, J.M., 1998. Evaluación de tomamuestras de cápsula porosa bajo condiciones de laboratorio: comparación entre cápsulas de cerámica y pete. *Progresos en la investigación en zona no saturada*. Publicaciones Universidad de Huelva. 90-91 pp.
- Moreno, J., Moral, R. 2008. *Compostaje*. Ed.: Mundi-Prensa. Madrid.
- Muramoto, M., Dwinell, L.D., 1990. Pitch canker of *Pinus Luchuensis* in Japan. *Plant Dis* 74: 530.
- Naasz, R., Michel, J.C., Charpentier, S., 2008. Water repellency of organic growing media related to hysteretic water retention properties. *Eur J Soil Sci* 59: 156-165.
- NiChualain, D., Carlile, W., Hynes, C., Phelan, G., O'Haire, R., Doyle, O.P.E., 2011. Nutrient status of co-composted indigenous Irish wastes, and their use in growing media. *Acta Hort* 891: 85-92.
- Noble, R., Coventry, E., 2005. Suppression of soil-borne plant disease with composts: A review. *Biocontrol Sci Technol* 15: 3-20.
- Noble, R., Roberts, S.J., 2004. Eradication of plant pathogens and nematodes during composting: A review. *Plant Pathol* 5: 548-568.

- Noguera, P., Abad, M., Puchades, R., Maquieira, A. y Noguera, V. 2003. Influence of particle size on physical and chemical properties of coconut coir dust as container medium. *Commun Soil Sci Plant Anal* 34: 593-605.
- Nogués, S., Munné-Bosch, S., Casadesús, J., López-Carbonell, M., Alegre, L., 2001. Daily time course of whole-shoot gas-exchange rates in two drought-exposed Mediterranean shrubs. *Tree Physiol* 21: 53-60.
- Olsen, S.R., Sommers, L.E., 1982. Phosphorus. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds). *Methods of Soil Analysis*. American Society of Agronomy, Madison, WI, USA.. 403-427 pp.
- Olson, H.A., Benson, D.M., 2007. Induced systemic resistance and the role of binucleate *Rhizoctonia* and *Trichoderma hamatum* 382 in biocontrol of Botrytis blight in geranium. *Biol Control* 42: 233-241.
- Ortega, M.C., Ordovás, J., Carmona, E., Aguado, M.T., Moreno, M.T., 1999. El nitrógeno en la obtención y manejo de un sustrato de origen vegetal. *Actas de Horticultura* 23: 65-78.
- Ostos, J.C., López-Garrido, R., Murillo, J.M., López, R., 2007. Substitution of peat for municipal solid waste- and sewage sludge-based composts in nursery growing media: effects on growth and nutrition of the native shrub *Pistacia lentistus* L. *Bioresour Technol* 99(6): 1973-1800.
- Papafotiou, M., Kargas, G., Lytra, I., 2005. Olive-mill waste compost as a growth medium component for foliage potted plants. *HortScience* 40(6): 1746-1750.
- Papafotiou, M., Phsyhalou, M., Kargas, G., Chatzipavlidis, I., Chronopoulos, J., 2004. Olive-mill wastes compost as growing medium component for the production of poinsettia. *Scia Hortic-Amsterdam* 102(2): 167-175.
- Paredes, C., Roig A., Bernal M.P., Sánchez-Monedero M.A., Cegarra J., 2000. Evolution of organic matter and nitrogen during co-composting of olive mill wastewater with solid organic wastes. *Biol Fertil Soils* 32: 222-227.
- Pearce, D.W., Moran, D., 1994. The economic value of biodiversity. The World Conservation Union (Ed.). Earthscan Publications Ltd, London, England.
- Pérez, J., Delgado, J.L., 1995. Análisis del riesgo de incendio forestal en Galicia. *Agricultura y Sociedad*, 77: 109-124.
- Pérez-Cruzado, C., Fehrmann, L., Magdon, P., Cañellas, I., Sixto, H., Kleinn, C., 2015. On the site-level suitability of biomass models. *Environl Modell Software* 73: 14-26.
- Pérez-Murcia, M.D., Moral, R., Moreno-Caselles, J., Pérez-Espinosa, A., Paredes, C., 2006. Use of composted sewage sludge in growth media for broccoli. *Bioresour Technol* 97: 123- 130.

- Pérez-Sierra, A., Landeras, E., León, M., Berbegal, M., García-Jiménez, J., Armengol, J., 2007. Characterization of *Fusarium circinatum* from *Pinus* spp. in Northern Spain. *Mycol Res* 111: 832-839.
- Pitman, R. M., Webber, J., 2013. The character of composted bracken (*Pteridium aquilinum* L. Kuhn) and its potential as a peat replacement medium. *Europ J of Hort Sci* 78(4): 145-152.
- Plana, R., 2009. Una introducción general al compostaje. In: *Compostaje: la salud de la Tierra. Utilización en agricultura ecológica*. SEAE, Villaframil-Ribadeo, Spain, 26 pp.
- Poole, R.T., 1970. Rooting response of four ornamental species propagated in various media. *Proc. Florida State Hort Soc* 82: 393-396.
- Poulter, R., 2014. Quantifying differences between treated and untreated coir substrate. *Acta Horti* 1018: 557-564.
- Prado-Giménez, A.P., Zamora, M.A.P., Núñez, J.P., 2008. Utilización de fibra de kenaf (*Hibiscus cannabinus* L.) en la elaboración de sustratos específicos para cultivo de *Pleurotus ostreatus* (Jacq. ex Fr.) Kummer. *Revista Iberoamericana de Micología* 5(1): 57-61.
- Prasad, M., Maher, M., 2001. The use of composted green waste (CGW) as growing medium component. *Acta Horti* 549: 107-113.
- Preusch, P.L., Takeda, F., Tworowski, T.J., 2004. N and P uptake by strawberry plants grown with composted poultry litter. *Sci Horti- Amsterdam* 102: 91-103.
- Puustjärvi, V., 1994. La turba y su manejo en horticultura. Ediciones de Horticultura S.L., Reus. Tarragona. España. 123 pp.
- Quesada, T.V., Gopal, P., Cumbie, A., Eckert, J., Wegrzyn, D., Neale, D.B., Goldfarb, B., Huber, D.A., Casella, G., Davis, J.M., 2010. Association mapping of quantitative disease resistance in a natural population of loblolly pine (*Pinus taeda* L.). *Genetics* 186:677-686.
- Quispe, G.A., 2007. Cultivos sin suelo: aplicación de tecnología para una agricultura de precisión. Proyecto INNOVA-PRODUCCIÓN 07PCS-1413.
- Rainbow, A., 2009. The use of green compost in the production of container nursery stock in the UK: challenges and opportunities. *Acta Horti* 819: 27-32.
- Rainbow, A., Wilson, N., 1998. The transformation of composted organic residues into effective growing media. *Act Horti* 469: 79-88.
- Raviv, M., 2005. Production of high-quality composts for horticultural purposes: a mini-review. *Hort Technol* 15: 52-57.

- Raviv, M., 2011. SWOT analysis of the use of composts as growing media components. *Act Hort* 1013: 191-202.
- Raviv, M., 2013. Composts in growing media: what's new and what's next? *Acta Hort* 982: 39-47.
- Raviv, M., Chen, Y., Inbar, Y., 1986. Peat and peat substitutes as growth media for container-grown plants. En: Chen, Y., Avnimelech, Y. (Eds). *The role of organic matter in modern agriculture*. Martinus Nijhoff Publishers. Dordrecht. Holanda. 257-287 pp.
- Raviv, M., Oka, Y., Katan, J., Hadar, Y., Yogev, A., Medina, S., Krasnovsky, A., Ziadna, H., 2005. High-nitrogen compost as a medium for organic container-grown crops. *Bioresour Technol* 96: 419-427.
- Raviv, M., Wallach, R., Blom, T.J., 2004. The effect of physical properties of soilless media on plant performance- A review. *Act Hort* 644: 251-259.
- Raviv, M., Wallach, R., Silber, A., Bar-Tal, A., 2002. Substrates and their analysis (2): Pp: 25-101. In: Souvas, D. (Ed). *Hydroponic production of vegetables and ornamentals*. Embryo publications. 463 pp.
- Reinikainen, O., Herranen, M., 2001. Different methods for measuring compost stability and maturity. *Acta Hort* 549: 99-104.
- Ribeiro, H.M., Romero, A.M., Pereira, H., Borges, P., Cabral, F., Vasconcelos, E., 2007. Evaluation of a compost obtained from forestry wastes and solid phase of pig slurry as a substrate for seedlings production. *Bioresour Technol* 98: 3294-3297.
- Robertson, R.A., 1993. Peat, horticulture and environment. *Biodivers Conserv* 2(5): 541-547.
- Sabuquillo, P., De Cal, A., Melgarejo, P., 2006. Biocontrol of tomato wilt by *Penicillium oxalicum* formulations in different crop conditions. *Biol Control* 37: 256-265.
- Saña, J., Giró, F., Soliva, M., Florensa, P., 1989. Methodology used for evaluating the quality of compost produced in Catalonia. *Llibre d'Actes del Simposio Internazionale 'Produzione e impiego del compost'*, S. Michele, All'Adige, Italy.
- Sánchez-Monedero, M.A., Roig, A., Cegarra, J., Bernal, M.P., Noguera, P., Abad, M., Anton, A., 2004. Composts as media constituents for vegetable transplant production. *Compost Sci Util* 12: 161-168.
- Sánchez-Monedero, M.A., Roig, A., Paredes, C., Bernal, M.B. 2001. Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. *Bioresour Technol* 78: 301-308.

- Sanderson, K.C., 1980. Use of sewage-refuse compost in the production of ornamental plants. Hort Science 15: 173-178.
- Sant, D., Casanova, E., Segarra, G., Avilés, M., Reis, M., Trillas, M.I., 2010. Effect of *Trichoderma asperellum* strain T34 on Fusarium wilt and water usage in carnation grown on compost-based growth medium. Biol Control 53: 291-296.
- Sarooshi, R.A., Creswell, G.C., 1994. Effects of hydroponic solution composition, electrical conductivity and plant spacing on yield and quality of strawberry. Austral J Exp Agr 34: 529-535.
- Schaller, L., Kantelhardt, J., 2009. Prospects for climate friendly peatland management – Results of a socioeconomic case study in Germany. Paper presented at the 83rd annual conference of the Agricultural Economics Society. March 30-April 1, 2009, Dublin, p. 23. Schmilewski, G., 2005. The eco-label for growing media attempting objectivity on the peat issue. Example Manuscript layout. Saterland-Sedelsberg (Germany).
- Schmilewski, G., 2008. The role of peat in assuring the quality of growing media. Mires Peat 3: 8 (article 02).
- Schmilewski, G., 2009. Growing medium constituents used in the EU. Act Hort 819: 33-46.
- Segarra, G., Casanova, E., Borrero, C., Aviles, M., Trillas, M.I., 2007. The suppressive effects of composts used as growth media against *Botrytis cinerea* in cucumber plants. Eur J Plant Pathol 117: 393-402.
- Segarra, G., Avilés, M., Casanova, E., Borrero, C., Trillas, M.I., 2013. Effectiveness of biological control of *Phytophthora capsici* in pepper by *Trichoderma asperellum* strain T34. Phytopathol Medit 52: 77-83
- Segarra, G., Casanova, E., Avilés, M., Trillas, M.I., 2010. *Trichoderma asperellum* strain T34 controls Fusarium wilt disease in tomato plants in soilless culture through competition for iron. Microb Ecol 59: 141-149.
- Segarra, G., Van der Ent, S., Trillas, M.I., Pieterse, C.M.J., 2009. MYB72, a node of convergence in induced systemic resistance triggered by a fungal and a bacterial beneficial microbe. Plant Biol 11:90-96.
- Seijas, E., Balboa Murias, M.A., Merino, A., Ruíz González, A.D., Álvarez González, J.G., 2009. Ecuaciones de estimación de biomasa en formaciones de tojo de alta densidad de matorral. En: S.E.C.F y Junta de Castilla y León (Editores). 5º Congreso Forestal Español. Montes y Sociedad: Saber qué hacer. Sociedad Española de Ciencias Forestales.

- Shoresh, M., Yedidia, I., Chet, I., 2005. Involvement of jasmonic acid/ethylene signalling pathway in the systemic resistance induced in cucumber by *Trichoderma asperellum* T203. *Phytopathology* 95: 76-84.
- Singh, R., Kim, J., Shepherd, M.W., Luo, F., Jiang, X., 2011. Determining thermal inactivation of *Escherichia coli* O157:H7 in fresh compost by simulating early phases of the composting process. *Appl Environ Microbiol* 77 (12): 4126-4135
- Smith, B., 2008. The growing media market in New Zealand. *Acta Hort* 779: 179–184.
- Sofiadou, E., Tzortzakis, N.G., 2012. Olive mill waste as a substitute growing medium component in tomato seedling and crop production. *Int J Veg Sci* 18(3): 272–283.
- Soliño, M., 2003. Programas forestales en las comunidades de montes vecinales en mano común en la Red Natura 2000: Un análisis DELPHI. *Revista Galega de Economía* 12 (1): 1-22.
- Stoffella, P.J., Kahn, B.A., 2005. Utilización de compost en los sistemas de cultivo hortícola. Mundi-Prensa. Madrid.
- Storer, A.J., Gordon, T.R., Clark, S.L., 1998. Association of the pitch canker fungus, *Fusarium circinatum* f. sp. *pini* with Monterrey pine seeds, and seedlings in California. *Plant Pathol* 47: 649-656.
- Storer, A.J., Wood, D.L., Gordon, T.R., 2002. The epidemiology of pitch canker of Monterrey pine in California. *Forest Sci* 48: 694-700.
- Styer R.C., Koranski D.S., 1997. Plug & transplant production. Ball publishing
- Sullivan, D.M., Miller, R.O., 2001. Compost quality attributes measurements and variability. In: Stoffella P.J. and Brian, A. (Eds) *Compost utilization in horticultural cropping systems*. Lewis Publishers.
- Tagliavini, M., Baldi, E., Lucchi, P., Antonelli, M., Sorrenti, G., Baruzzi, G., Faedi, W., 2005. Dynamics of nutrients uptake by strawberry plants (*Fragaria x Ananassa* Duch.) grown in soil and soilless culture. *European J Agron* 23: 15-25.
- Tagliavini, M., Scuderalli, D., Marangoni, B., Toselli, M., 1996. Nitrogen fertilization uptake in orchards to reconcile productivity and environment aspects. *Fertil Res* 43: 93-102.
- Tiquia, S.M., Tam, N.F.Y., Hodgkiss, I.J., 1996. Microbial activities during composting of spent pig-manure sawdust litter at different moisture content. *Bioresour Technol* 55: 201-206.
- Tognetti, C., Mazzarino, M.J., Laos, F., 2007. Improving the quality of municipal organic waste compost. *Bioresour Technol* 98 (5): 1067–1076.

- Topcuoğlu, B., 2011. The usability of sewage sludge municipal solid waste compost and spent mushroom compost as growing media on the growth of *Euphorbia pulcherrima*. IPCBEE 24: 386–392.
- Trejo-Téllez, L.I., Gómez-Merino, F.C., 2014. Nutrient management in strawberry: Effects on yield, quality and plant health. In: Malone, N. (ed) Strawberries, Nova Sciences Publishers, Inc.
- Trillas, M.I., Casanova, E., Cotxarrera, L., Ordovás, J., Borrero, C., Avilés, M., 2006. Composts from agricultural waste and the *Trichoderma asperellum* strain T-34 suppress *Rhizoctonia solani* in cucumber seedlings. Biol Control 39: 32-38.
- Trillas, M.I., Segarra, G., 2009. Chapter 8. Interactions between nonpathogenic fungi and plants. Adv Bot Res 51: 321-359.
- Tuitert, G., Szczech, M., Bollen, G. J., 1998. Suppression of *Rhizoctonia solani* in potting mixtures amended with compost made from organic household waste. Phytopathology 88: 764-773.
- Urrestarazu, M., Mazuela, P.C., Alarcón, A.L., 2006. Cultivo en sustratos alternativos. p. 147-173. In: Alarcón, A.L. (coord.), Cultivos sin suelo. Compendios de Horticultura Vol. 17. Ediciones de Horticultura S.L., Reus, Tarragona.
- Urrestarazu, M., Salas, M.C., Padilla, M.I., Moreno, J., Elorrieta, M.A., Carrasco, G.A., 2001. Evaluation of different compost from horticultural crop residues and their uses in greenhouse soilless cropping. Act Hort 549: 147-152.
- USEPA (United States Environmental Protection Agency, USA), 1995. Test methods for evaluating solid wastes. Method 3051: Microwave assisted acid digestion of sediments, sludges, soils, and oils. Third edition. U.S. Environmental Protection Agency, Washington, DC.
- USEPA (United States Environmental Protection Agency, USA), 2003. Environmental regulations and technology. Control of pathogens and vector attraction in sewage sludge. EPA625-/R-92/-103.
- USGS, 2013. Minerals yearbook Vol. I: Metals and Minerals. United States Geological Survey. U.S. Department of Interior. Washington DC, USA
- USGS, 2015. Mineral Commodity Summaries – Clays. United States Geological Survey. U.S. Department of Interior. Washington DC, USA.
- Valat, B., Jovany, C., Rivière, L.M., 1991, Characterization of the wetting properties of air-dried peats and compost. Soil Sci 152: 100-107.
- Van den Bosch, F., Paveley, N., Shaw, M., Hobbelen, P., Oliver, R., 2011. The dose rate debate: Does the risk of fungicide resistance increase with dose? Plant Pathol 60: 597-606.

- Veeken, A., de Wilde, V., Hamelers, B., 2002. Passively aerated composting of straw-rich pig manure; effect of compost bed porosity. *Compost Sci Util* 10: 114-128.
- Vega-Hidalgo, J.A., Pérez-Garastiaga, P., Cuññas, P., Fonturbel, M.T., Fernández Figueira, M.C., 2001. Manual de queimas prescritas para matogueiras de Galicia. Consellería de Medio Ambiente. Xunta de Galicia.
- Veijalainen, A. M., Juntunen, M. L., Lilja, A. R. J. A., Tervo, L. ,2007. Composting of forest nursery waste and nutrient leaching. *Baltic Forestry* 13(1): 74-82.
- Verma, M., Brar, S.K., Tyage, R.D., Surampalli, R.Y., Valero, J.R., 2007. Antagonistic fungi, *Trichoderma spp.*: panoply of biological control. *Biochem Eng J* 37: 1-20.
- Viljoen, A., Winfield, M.J., Marasas, W.F.O., 1994. First report of *Fusarium subglutinans* f.sp. *pini* on pine seedlings in South Africa. *Plant Dis* 78: 309-312.
- Villanueva, G., Riesco, G., 2015. Ordenación forestal de masas mixtas de *Pinus pinaster* y *Pinus radiata* en Galicia. (<https://minerva.usc.es/xmlui/handle/10347/12493>; last accessed 27/01/2017).
- Waksman, S.A., 1927. Principles of soil microbiology. The Williams & Wilkins, Baltimore, M.D.
- Walker, L.P., Nock, T.D., Gosset, J.M., VanderGheynst, J.S., 1999. The role of periodic agitation and water addition in managing moisture limitations during high-solids aerobic decomposition. *Process Biochem* 34: 601-612.
- Wallach, R., 2008. Physical characteristics of soilless media, In: Raviv, M., Hienrich, J. (Eds), *Soilless Culture. Theory and Practice*. Elsevier, London. 41-408 pp.
- Webb, N. R., 1998. The traditional management of European heathlands. *J Appl Ecol* 35(6): 987-990.
- Wever, G., Scholman, R., 2011. RHP requirements for the safe use of green waste compost in professional horticulture. *Acta Hort* 891: 281–286.
- Williams, P., 1997. Ecology and management of invasive weeds. *Science and Research Series* 75- 67 pp.
- Wilson, S.B., Mecca, L.K., Danielson, H.E., Graetz, D.A., Stoffella, P.J., 2006. Container and field evaluation of three shrubs grown in compost-based media. *Compost Sci Util* 14: 179-183
- Wingfield, M.J., Hammerbacher, A., Ganley, R.J., Steenkamp, E.T., Gordon, T.R., Wingfield, B.D., Coutinho, T.A., 2008. Pitch canker caused by *Fusarium circinatum* – a growing threat to the pine plantations and forests worldwide. *Austral Plant Pathol* 37: 319-334.

- Wingfield, M.J., Jacobs, A., Coutinho, T.A., Ahumada, R., Wingfield, B.D., 2002. First report of the pitch canker fungus, *Fusarium circinatum*, on pines in Chile. *Plant Pathol* 51: 397
- WRAP, 2010. Project OAV031-002: An Investigation of Clopyralid and Aminopyralid in Commercial Composting Systems. Waste and Resources Action Program (WRAP), Banbury, UK. (www.wrap.org.uk/compost; last accessed 27-01-17).
- Yavari, S., Eshgui, S., Tafazoli, E., Yavari, S., 2008. Effects of various organic substrates and nutrient solution on productivity and fruit quality of strawberry "Selva" (*Fragaria x Ananassa* DUCH.). *J Fruit Orn Plant Research* 16: 167-178.
- Yue, B., Chen, T.B., Gao, D., Zheng, G.D., Liu, B., Lee, D.J., 2008. Pile settlement and volume reduction measurement during force-aeration static composting. *Bioresour Technol* 99: 7450-7457.
- Zamora-Nahum, S., Hadar, Y., Chen, Y., 2007. Physico-chemical properties of commercial composts varying in their source materials and country of origin. *Soil Biol Biochem* 39(6): 1263-1276.
- Zhang, R., Zeng-Qiang, D., Zhi-Guo, L., 2012. Use of spent mushroom substrate as growing media for tomato and cucumber seedlings. *Pedosphere* 22(3): 333-342.
- Zimand, G., Elad, Y., Chet, I., 1996. Effect of *Trichoderma harzianum* on *Botrytis cinerea* pathogenicity. *Phytopathology* 86: 1255-1260.
- Zucconi, F., Monaco, A., Forte, M., De Bertoli, M., 1985. Phytotoxins during the stabilization of organic matter. In: Gasser, J.K.R. (Ed) *Composting of Agricultural and Other Wastes*. Elsevier. London. U.K. 73-80 pp.
- Zucconi, F., Pera, A., Forte, M.E., Bertoldi, M., 1981. Evaluating toxicity of immature compost. *Biocycle* 22 (2): 54-57.



Akcnowledgements



ACKNOWLEDGEMENTS

Philosophiæ doctor o abreviado Ph.D significa literalmente “Doctor en Filosofía” refiriéndose en su significado al estudio general de los conocimientos y al amor por los mismos. Quizás pueda resumir así cómo es que hoy me siento y expresar mi agradecimiento por ello.

GRACIAS.

A LA VIDA por darme la oportunidad de crecer y evolucionar a través de esta experiencia.

A TODAS LAS PERSONAS que me han acompañado en este viaje, ofreciéndome el regalo de verme reflejada en ellas.

A LA TIERRA Y A TODOS LOS SERES QUE LA HABITAN por acogernos y permitirnos hacer este trabajo.

A LAS PLANTAS por permitirme conocerme y amarme a través de ellas.

A LAS IDEAS y a quienes se permiten soñarlas; pero sobre todo GRACIAS a aquellos que se permiten hacerlas realidad.

AGRADEZCO DE CORAZÓN.

A MIS PADRES por su apoyo y su amor incondicional.

A ADOLFO por estar siempre, por Ser. No existen palabras que puedan expresar la inmensa gratitud que siento.

A ALEJANDRO por acompañarme de vuelta a casa. Casa también es el corazón.

A DAVID por venir, por nacer, por Ser amor.

A MI TÍO, por poner en palabras sus sentimientos ayudándome a escucharme a mí misma a través de él.

A MARTA, ISABEL, PEDRO, JAVI, ELENA, RAFA, MIRIAM, NATALIA, CRIS, JOSÉ, JAIME, JOAQUÍN, ÓSCAR, SUSANA por vuestra amistad, por acompañarme durante este proceso.

A COMPAÑEROS Y A PROFESORES que me han apoyado durante este tiempo; ANXO, AITOR, CÉSAR, PILAR, TERESA, JUÁN, CARLOS, SUSANA, ELVIRA, SOCORRO.

A MARÍA ISABEL, GUILLÉM, OMAR por acogerme y darme la oportunidad de hacer parte de la tesis en Barcelona.

A JOSÉ LUIS AMBOAGE por ser el promotor del proyecto.

A TRANSFORMACIÓNS AGRÍCOLAS DE VILARTÓ S.L. y la XUNTA DE GALICIA por la financiación del proyecto.

A JOSÉ ANTONIO NEIRA y a RAMÓN LOURIDO por compartir su experiencia en el compostaje de tojo para uso como sustrato y por la cesión de material para alguno de los ensayos.

A PEDRO MANSILLA y a su EQUIPO de TRABAJO de la ESTACIÓN FITOPATOLÓGICA DE AREEIRO por la cesión de los inóculos patogénicos para los ensayos de supresividad.

A VIFORGA por la cesión de semillas certificadas de Pinus radiata para uno de los ensayos.

A ANTONIO LOSADA por su ayuda eficiente en la traducción y revisión del texto.

A ISABEL RIVAS por su ayuda y dedicación en las tareas de laboratorio.

GRACIAS A TODOS QUE ME HABÉIS PERMITIDO EXPERIMENTAR A VUESTRO LADO PARA CONOCERME Y AMARME UN POCO MÁS.

Noelia López López.

Gorse compost is presented as an interesting peat-substitutive substrate to be used in organic agriculture. It contributes to advance in sustainability of growing media and fulfills the requirements for award of the European Union eco-label. All the compost obtained had acceptable physical properties, although their water holding capacity was low; and they exhibited high contents in major nutrients. They are adequate for strawberry organic crop, but they'll require supplementary fertilization during the growth period. They showed natural suppressiveness against *Fusarium circinatum* disease in *P. radiata* seedlings and combined with *Trichoderma asperellum* Strain T34 reduces pre- and post-emergence incidence of the disease, even in the least suppressive gorse composts.