Fungal Root Endophytes and Host Plant Growth

by

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Abstract: Fungal root endophytes are ubiquitous plant associates which colonize their host asymptomatically, but the plant-endophyte relationship is not well understood. The purpose of this study was to determine plant growth response to fungal root endophyte inoculation, using a meta-analysis, and to endophytic metabolites, using experimental methods. Overall, results from the meta-analysis indicate that plant response seems to be neutral to slightly positive, with a limited number of studies demonstrating very high growth responses. The identity of the plant host and endophyte species, and the use of carbon or organic nitrogen were among the most important factors explaining the variability in these data. Plant response to endophytic metabolites was similar to evidence from the meta-analysis; metabolites from most endophytes had no effect under these experimental conditions but some, particularly metabolites from *Phialocephala sphaeroides*, induced a significant growth increase.

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CHAPTER 1

INTRODUCTION

CHAPTER 1: INTRODUCTION

Plants and fungi are closely associated. Plants are not only subject to detrimental infection by fungal pathogens, but also to colonization by beneficial mycorrhizal fungi, forming mutualistic symbioses (Peay et al. 2008). However, the ecological implications of all plant-fungal associations are not as well understood. For example fungal endophytes are a ubiquitous and diverse group that can be found in all plants and all plant parts (Sieber 2007). They can be defined as fungi which colonize plant tissue internally without causing any apparent harm to the host (Saikonnen et al. 1998; Schulz and Boyle 2005). Although this group is hidden from view inside the plant tissue, an increasing amount of research has been highlighting the importance of fungal endophytes. For example, some fungal endophytes have been shown to confer heat, drought and salt resistance to their host (Rodriguez et al. 2009), the grass endophyte *Epichloë* secretes secondary metabolites toxic to mammals (Miles et al. 1998; Saikonnen et al. 1998; Rodriguez et al. 2009) and leaf endophyte secretions can protect the plant host from microbial pathogens (Arnold et al. 2003; Dingle and McGee 2003; Musetti et al. 2006). In fact, many researchers recognize that endophytes secrete many novel biologically active compounds (Tan and Zou 2001; Schulz et al. 2002; Strobel and Daisy 2003; Zhang et al. 2006). Some of these, such as the anti-cancer substance taxol, have highly practical applications (Pandi et al. 2011). Some researchers have hypothesized that root endophytes, the least well studied endophyte group (Mandyam and Jumpponen 2005; Rodriguez et al. 2009), may mineralize nitrogen into a form useable by the plant host and

may act as a surrogate to mycorrhizal associations when mycorrhizal fungi are absent (Sieber 2002; Upson et al. 2009; Newsham 2011).

Root endophytes are ubiquitous plant associates (Jumpponen and Trappe 1998) They are a diverse group and a single root system can harbour many different species that collectively colonize its entire length, including mycorrhizal root tips and lignified portions (Grünig et al. 2008). Although diverse, many endophytes, including the commonly studied dark septate endophytes (DSEs) are from the order Helotiales (Kernagahan and Patriquin 2011). There has been a bias towards studying DSEs because of their ease of observation due to their melanized hyphae and because of their ability to grow in pure culture (Addy et al. 2005). Recent research however, has demonstrated that endophytes with non-melanized hyphae are in fact more common in the root system than DSEs (Kernaghan and Patriquin 2011).

Despite their ubiquity, the ecological significance of root endophytes is elusive at best and is a source of debate in the literature (Mandyam and Jumpponen 2005; Rodriguez 2009; Newsham 2011). There are several hypotheses on the role these endophytes play in nature. As previously mentioned, some researchers argue that root endophytes may act as primitive mycorrhizae by allowing plants to access otherwise unavailable sources of nitrogen (Jumpponen 2001). Indeed, several studies have demonstrated that plants inoculated with fungal root endophytes supplied with only organic nitrogen show an increase in biomass over non-inoculated controls (Usuki and Narisawa 2007; Upson et al. 2009; Newsham 2011). Conversely, many other experiments

have shown either no effect or only slightly negative effects of fungal endophyte inoculation (Fernando and Currah 1996; Hashimoto and Hyakumachi 2001; Tellenbach et al. 2011).

Much like in above ground plant tissue, researchers also argue that fungal root endophytes secrete biologically active compounds including plant hormones and anti-microbial compounds (Schulz and Boyle 2005; Schulz 2006). The production of plant hormones could significantly affect plant development and anti-fungal compounds may protect the plant from pathogens, or the presence of the endophytes may illicit systemic acquired resistance to pathogens (Muciarelli et al. 2002; Arnold et al. 2003; Mandyam and Jumpponen 2005; Schulz 2006; Sieber 2007; Tellenbach et al. 2011). Alternatively, fungal endophytes could be latent saprophytes or pathogens, ready to cause disease upon injury or decompose plant tissue upon senescence (Schulz et al. 1999). Finally, they may simply be tolerated by the host since they do not cause any apparent harm and the physical space they occupy in the root system might prevent colonization by other, potentially pathogenic fungi (Sieber 2007; Tellenbach et al. 2011).

The general focus of this thesis is on the effects of fungal root endophytes on plant growth. More specifically, Chapter 2 is a meta-analysis on the effect of fungal root endophyte inoculation on plant root, shoot and total biomass and nitrogen concentration. Meta-analysis can be used as a tool to objectively obtain a quantitative effect measurement using data existing in the literature. In addition to quantifying the effect of fungal inoculation on plant growth, over 30 factors were assessed for their importance in

modulating the plant-endophyte relationship. Chapter 3 focuses on the effects of secondary metabolite production of root fungal endophytes on the growth and root morphology of *Betula papyrifera* seedlings and the production of the plant growth hormone indole acetic acid. In these experiments, fungi were always physically separated from the growing medium and from the host using polycarbonate filters which cannot be digested by the fungus, but allow secondary metabolites to seep into the growing medium. The aim was to determine if the metabolites produced by fungal root endophytes cause changes in plant biomass or morphological changes in plant roots. Collectively, the two main chapters objectively address whether or not root fungal endophytes and the compounds they secrete affect plant growth and highlight how this interaction is affected by varying experimental conditions.

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CHAPTER 2

THE EFFECTS OF FUNGAL ROOT ENDOPHYTES ON PLANT GROWTH: A META-ANALYSIS

Abstract

Root endophytes are ubiquitous plant associates that colonize plant tissue asymptomatically. However, the effects of endophytic colonization on host plant growth are not well understood. The range of the response of plant biomass to the inoculation of a fungal root endophyte ranges from negative to positive depending on the identity of the host or endophyte and the experimental conditions. Significant increases in biomass have been attributed in particular to the use of an organic form of nitrogen or to the secretion of phytohormones by the endophyte. Meta-analysis was used to quantitatively determine the direction and significance of this response based on existing studies as well as discerning experimental conditions that may affect the plant-endophyte relationship. The response of plant growth (root, shoot and total biomass) and nitrogen concentration was recorded and the analyses were done at three taxonomic levels: Ascomycetes, Helotiales and *Phialocephala fortinii sensu lato*. One hundred and thirty-three studies derived from 30 publications were used in the analyses. Overall, plant response to the inoculation of a root endophyte seems to be neutral to slightly positive, with a limited number of studies demonstrating very high growth responses. The identity of the plant host, and endophyte species, the use of an endophyte isolated from the same plant species as the host and the use of carbon, organic nitrogen or peat moss were among the most important factors explaining the variability in plant response to endophyte inoculation. This meta-analysis highlights the importance of controlling experimental conditions to obtain truly comparable responses and shows that, except under certain conditions, the increases in

plant biomass *in vitro* are generally small and relationships between fungal root endophytes and their host may not be strictly mutualistic.

Introduction

Despite the ecological importance of certain plant-fungal interactions (e.g.: plant pathogens and mycorrhizae), the functions of others, such as fungal endophytes, remain to be clearly identified even though they can be found in the roots, stems and leaves of all plants (Sieber 2007). The term endophyte, which literally means within the plant, is commonly used to describe microorganisms living within plant tissue without causing any apparent harm or generating any negative response from the host (Saikonnen et al. 1998; Schulz and Boyle 2005). This group includes a diverse array of fungi, the host-endophyte relationship being better studied for some than others. For instance, some clavicipitaceous fungi and leaf endophytes are known to confer herbivore and pathogen defense respectively (Saikonnen et al. 1998; Arnold et al. 2003; Dingle and McGee 2003; Musetti et al. 2006) and other species are known to induce environmental resistance to heat or drought (Rodriguez et al. 2009). However, the nature of the relationship between plants and root endophytes, including dark septate endophytes (DSE), is likely the least well understood (Mandyam and Jumpponen 2005; Rodriguez et al. 2009).

Several hypotheses have arisen for the potential function of root endophytes, the most prominent being the modulation of plant growth via nutrient mineralization or transfer, which is similar to functions accomplished by mycorrhizae (Jumpponen 2001;

Mandyam and Jumpponen 2005; Upson et al. 2009; Newsham 2011), or via the production of phytohormones (Mucciarelli et al. 2002; Schulz and Boyle 2005; Schulz 2006). Note that the plant-endophyte relationship is distinguished from mycorrhizae by lacking three key features: a cellular interface where specialized structures, such as arbuscules, occur; synchronized development between the plant and the fungal associate; and significant benefits of nutrient transfer to both partners from this association (Brundrett 2006).

Regardless of specific functions, hypotheses on the overall effect of colonization by root endophytes on plant growth are controversial. The most evident discrepancy is between studies published before and after 1994. Prior to this date, most studies report DSE or *Mycelium radicis atrovirens* (MRA) – an older term coined by Melin (1922) – as affecting the host negatively or not at all. For instance, Melin (1922) viewed MRA as forming 'pseudomycorrhizas' detrimental to their host, unlike ectomycorrhizae. Richard and Fortin (1974) believed that although MRA are common in healthy roots, they could be pathogenic under the right conditions. Stoyke and Currah (1993) found that *Phialocephala fortinii* caused a ten-fold increase in *Menziesia ferruginea* seedling mortality compared to the control, but inoculated plants that survived showed no significant differences. Prior to 1994, the only report of increased plant growth upon colonization by a root endophyte was from Haselwandter and Read (1982) who observed increased biomass and phosphorus concentrations in shoots in *Carex firma* and *C. sempervirens* when inoculated with 2 strains of DSE. Since then, several researchers have

found that although root endophytes often have a variable effect on plant growth, many can induce a substantial increase in biomass depending on the strain and the experimental conditions (Newsham 1994; Jumpponen and Trappe 1998b; Newsham 1999; Usuki and Narisawa 2005; Schulz 2006; Usuki and Narisawa 2007; Wu and Guo 2008; Alberton et al. 2009; Upson et al. 2009; Wu et al. 2010).

To assess the effect of root endophyte inoculation on plant growth based on data in the literature, a meta-analysis was conducted. Meta-analysis is a quantitative review of a research question that uses statistical methods to compare results across studies and synthesize a measure of overall effect (Arnqvist and Wooster 1995; Gurevitch and Hedges 1999; Hedges 1999; Rosenberg et al. 2000). It is particularly useful in obtaining an objective answer to specific questions based on a set of experiments (Gurevitch and Hedges 1999); in this case, we asked the following three questions: (1) is the biomass or nitrogen concentration of a plant modulated by the inoculation of a root endophyte? (2) Does the identity of the host and endophyte affect this relationship? (3) Do experimental conditions affect this relationship?

Alberton et al. (2010) and Newsham (2011) have previously carried out meta-analyses. Alberton et al. (2010) include a brief paragraph in their publication simply on the general effect of a DSE inoculation on root and shoot biomass based on 11 publications. They concluded that DSE inoculation has no significant effect on shoot biomass, but can increase root mass up to 30%. Newsham (2011) conducted a much more extensive analysis using 18 publications and stricter selection criteria: only journal

articles which presented accurate values of sample size and dispersion were used. He also used six additional forms of plant response and conducted categorical analyses using nitrogen form, DSE taxa and host taxa as factors. Results show that DSE increase root, shoot and total biomass and phosphorus and nitrogen content from 26%-103%. A greater effect was observed for plant biomass when nitrogen was available mostly in organic form (52%-138%).

Here, meta-analysis was used to determine the effects of inoculating a host plant with root endophytes at three taxonomic levels: the Ascomycota, excluding the Clavicipitaceae; the Helotiales, which includes many DSE (Addy et al. 2005); and the most studied DSE, *Phialocephala fortinii* s.l. Unlike Newsham (2011) who used only publications in peer-reviewed journals, all scientific publications, including edited books and theses were used. Moreover, two separate analyses were performed using different kinds of variance: parametric variance, which requires standard deviation as well as sample size; and non-parametric variance which requires only sample size. Although precision is lost when using non-parametric variance, power is increased since a greater number of studies can be included. Variance type does not affect the estimation of the mean effect but non-parametric variance will have larger confidence intervals around this effect size and more homogeneity in the data (see methods and results sections). Finally, thirty-one factors based on host and endophyte identity and experimental conditions were used for further analyses when data were found to be heterogeneous. The analyses at different taxonomic levels and with two different kinds of variance increased the overall

power of the meta-analysis over the previous analyses by Alberton et al. (2011) and Newsham (2011), but still allows for comparisons among the studies.

Methods

The current study focuses on root endophytes within the Ascomycetes excluding endophytes from the Clavicipitaceae. This includes the ubiquitous DSEs, so called because hyphae in colonized roots are septate and melanized (Jumpponen and Trappe 1998; Mandyam and Jumpponen 2005). However, DSEs are not a taxonomic but a morphological grouping that may have been studied more commonly because of their ease of culturing and observation under light microscopy (Addy et al. 2005). It also includes root endophytes with hyaline hyphae, which have been traditionally less well studied (Addy et al. 2005) and endophytes of more common genera like *Fusarium* and *Acremonium* yet it excludes Basidiomycetes, in particular *Piriformospora indica* (Varma et al. 1999), or others such as *Umbellopsis rammaniana* of the polyphyletic Zygomycetes (Summerbell and Kuyper 2005).

A total of 30 publications in English or French including data on plant biomass or nitrogen concentration response to the inoculation of an ascomycetous root endophyte were used in the meta-analysis. These were selected from a much larger number of publications screened between February and August 2010, which were found by searching the ISI Web of Science database using the key terms 'fung* and endophyt*', 'root and endophyt*', 'dark septate endophyt*' or 'DSE'. The bibliographies of all publications included in the meta-analysis as well as many pertinent publications on

fungal endophytes, such as Jumpponen and Trappe (1998), were also consulted. Most of these publications were obtained from journals, but Schulz (2006) is a section from an edited book, Cameron (1998) and Yu (2000) are Master's theses and Perez-Naranjo (2010) is a PhD thesis.

Information on 31 different factors pertaining to the taxonomy of the host, taxonomy of the inoculated endophyte and experimental conditions were recorded for each publication (Table 1). When a publication had multiple treatments or experiments that yielded differences in these factors, each was considered an independent study in the meta-analysis. For example, if a publication used different hosts or different endophyte species or strains, each combination was considered to be an independent study and represented the individual unit analyzed in the subsequent analyses. Only studies that inoculated a single host with one endophyte strain were used. Likewise, if researchers modified experimental conditions encompassed in the observed factors, each treatment was considered an independent study. For example, 12 studies were derived from Upson et al. (2009), who looked at the effects of inoculating a single host with six different strains of endophytes when grown in a substrate supplemented either with inorganic or organic nitrogen. If a publication contained multiple treatments that were not differentiated by the selected factors then only one was selected. For example, in a time series, such as in Schulz (2002) the latest data point was taken or when different types of amino acids were used, such as in Usuki and Narisawa (2007), the treatment causing the average response was selected. Including several studies per publication increases

dependence among studies assumed to be independent in the meta-analysis and can therefore increase overall homogeneity of the variance among studies (Gurevitch and Hedges 1999). However, the largest number of studies should be used to obtain the most power (Arnqvist and Wooster 1995b; Lajeunesse and Forbes 2003) and many meta-analyses have used a similar procedure (Alberton et al. 2005; Karst et al. 2008; Hoeksema et al. 2010; Newsham 2011). A detailed list of all recorded values for factors and response ratios of each study can be found in Appendix 1.

For each study, mean plant biomass (root, shoot or total) and nitrogen concentration of the control and inoculated plants as well as sample size and standard deviations were recorded whenever possible. If a sample size was given as a range, as in Hashimoto and Hyakumachi (2001), the smallest sample size number was used. Standard error and 95% confidence intervals were converted to standard deviations. Publications that did not include a measure of dispersion were only used in analyses weighted using non-parametric variance, which is calculated based on sample size alone as opposed to parametric variance, which is calculated based on means, standard deviation and sample size (see below). Data presented graphically were digitized and included in the analyses.

Studies are compared in a meta-analysis via an effect size; a value obtained from a study summarizing differences between experimental and control groups which is comparable across studies. Once the effect sizes for a desired set of studies have been calculated, they can be used to measure the overall effect (the mean effect size of a treatment compared to the control) and its associated variance (Arnqvist and Wooster

1995; Gurevitch and Hedges 1999; Hedges 1999). In this case, the treatment was always the inoculation of a root endophyte and the control was non-inoculated plants. Note that in a one case fungal colonization of the host roots did not occur (Ruotsalainen and Kytöviita 2004). The effect sizes are the response of the plant to this inoculation and were calculated as the natural log of the response ratio, which can be described as:

$$\ln R = \ln\left(\frac{\bar{X}^E}{\bar{X}^C}\right) = \ln(\bar{X}^E) - \ln(\bar{X}^C)$$

Where R is the response ratio and $\bar{X}^E$ and $\bar{X}^C$ are the experimental and control means. Response ratios were chosen because they have direct biological significance: values above 1 indicate an increase in biomass or nitrogen concentration (positive response) and values between 0 and 1 indicate a decrease (negative response) while 1 is neutral. When log transformed, positive values, 0 and negative values indicate a positive, neutral and negative response respectively. At least one of four different responses – root, shoot or total biomass or nitrogen concentration – was measured for each study and each was used in a separate analysis. Biomass measured as dry weight, fresh weight, length or height was used. Nitrogen concentration was measured from the leaves, shoot or the entire plant.

To assess the effects of different data collection methods for each plant response to endophyte inoculation, separate categorical analyses were conducted with the 'measurement type' as a factor. 'Measurement type' refers to the way data were collected for a certain plant response. For example, total plant weight may have been as either dry

or fresh weight. This factor has no biological significance, but can be useful in validating the combination of a set of studies.

Individual studies within meta-analyses can be weighted by standard deviations and sample sizes of the control and experimental means (parametric variance) or by sample sizes alone (non-parametric variance). Explicitly,

$$v_{\ln R} = \frac{(S^E)^2}{N^E(\bar{X}^E)^2} + \frac{(S^E)^2}{N^C(\bar{X}^C)^2}$$

for parametric variance and

$$v_{\ln R} = \frac{N^E + N^C}{N^E N^E}$$

for non-parametric variance, where $v_{\ln R}$ is the variance of the natural log of the response ratio, R, s is the standard deviation and N^E and N^C are the sample sizes of the experimental and control treatments, respectively. Because parametric variance also includes standard deviation, it allows for a more accurate meta-analysis, however, many publications only report sample size and excluding these publications would represent a loss of potential data, thereby generating an inaccurate effect size (Gurevitch and Hedges 1999). Therefore, separate analyses were conducted with each variance type.

In addition to the kind of variance used for weighting, three different analyses were conducted based on a taxonomic grouping of the endophytes. First, all studies using non-systemic ascomycetous root endophytes were considered (i.e.: all the studies

collected); second, only those using endophytes in the order Helotiales; third, *Phialocephala fortinii* s.l. The Helotiales and P. *fortinii* s.l. were the order and species that had by far the most associated studies.

Mean effect sizes were estimated using Metawin v. 2.2 (Rosenberg et al. 2002) assuming fixed effects with 4999 bootstrap iterations to generate 95% confidence intervals. Effect sizes were considered significantly positive or negative when 0 was not included in the confidence interval. Publication bias was measured by using Spearman's Rho, a rank correlation test of the effect size versus variance (Rosenberg et al. 2002). When the homogeneity statistic Q, an estimate of the among study variance, was large enough to be significant ($p<0.05$ when tested against a chi-square distribution), data were considered to be heterogeneous and further single factor categorical analyses were pursued.

In addition to 'measurement type', thirty-one other factors selected for their potential effects on plant response to root endophyte inoculation were tested on heterogeneous data. 'Publication' was added as a factor to assess the importance and bias of deriving several studies from a single publication. This factor was expected to be significant because it would encompass a large amount of among-study variation arising from the use of similar methods except in cases where a publication includes studies with contrasting results (Usuki and Narisawa 2007; Upson et al. 2009). Each of these factors has at least two categories and a minimum of two studies per category. The categorical analyses were conducted assuming fixed-effects and 95% confidence intervals were

bootstrapped around the mean effect size with 4,999 iterations. When conducting categorical analyses, three Q statistics are generated per factor: one for the variation within categories (Q_W), one for the variation among categories (or the variation for the model, Q_M) and the total Q (Q_T), which is the sum of the previous two ($Q_W + Q_M = Q_T$). Factors were further investigated when Q_M was significant and described at least 10% of the total variation ($Q_M/Q_T \times 100 \geq 10$). Randomization tests were also used to generate a p-value with 4,999 iterations as an additional test for significance.

Finally, the individual categories within significant factors were carefully examined. The effect size of a category was deemed to be significant when its mean effect size and 95% bootstrapped confidence interval did not include 0. To highlight particularly meaningful results, only categories with confidence intervals that did not overlap with at least one other category were discussed. In other words, even if a category had a significant effect size, if the effect size of a given category within a factor was not significantly different from the others, it was generally omitted from the results section of this chapter.

Results

Detailed results for the summary analyses are presented in Table 2. Heterogeneity of the results (Q statistic) differed depending on the variance type, the number of studies, the response ratio and the endophyte group. An analysis conducted with parametric variance always had a much higher Q than the equivalent analysis using non-parametric

variance. For any endophyte group, the root biomass response always had a great deal more heterogeneity than the other response ratios, whereas the nitrogen concentration always had the least. In general, Q increased with the number of studies (degrees of freedom + 1). Consequently, the overall heterogeneity is highest in the Ascomycetes analyses and lowest for the *P. fortinii s.l.* analyses.

All analyses for the Ascomycetes had a significant Q except for the shoot biomass and nitrogen concentration response ratios when using non-parametric variance. Helotiales analyses using non-parametric variance were not significant except for the root biomass response ratio, but all were significant for parametric variance. For the *P. fortinii* s.l. analyses, the root biomass response ratio was significant for both variance types; analyses on shoot and total biomass were significant when using parametric variance; nitrogen concentration was not significant. All significant analyses mentioned here were further investigated with categorical analyses.

Significant negative mean effect sizes were not observed. For the Ascomycetes analyses, significant positive responses were observed for the shoot response ratio with parametric and non-parametric variance and nitrogen concentration when using parametric variance. For the Helotiales analyses, positive effect sizes were observed for the shoot biomass, total biomass and nitrogen concentration only when using parametric variance. For *P. fortinii s.l.* analyses, positive effect sizes were observed for the parametric and non-parametric root biomass response and for shoot biomass and nitrogen

concentration with parametric variance. Publication bias was detected for 7 out of 32 summary analyses (Table 3).

A total of 459 categorical analyses were conducted of which 208 were significant. Of these, the following factors did not have significant among category heterogeneity (Q_M): 'measurement type', 'system aeration', 'initial sterilization', 'agar', 'nitrogen'. 'Carbon (detailed)' is the only factor significant for all response ratios and variance types and described up to 80.0% of the total variation, Q_T, the highest of all analyses. For the Ascomycetes, 93 of 192 analyses were significant (Table 4). The Q_M of 'publication', 'host genus' and 'host species' equal over 50% of Q_T when significant except for the total biomass response ratio with parametric variance. The Q_M of 'carbon (detailed)' accounts for 33.8% to 80.0% of Q_T. The 'fungal genus', 'fungal species', 'fungal strain', 'growth habit', 'pH stabilizer (detailed)', 'protein and amino acids' and 'other organic nitrogen' also described over 10% for many of the response ratios. Parametric and non-parametric analyses for the root response ratio were similar but differed with respect to a few factors, notably: 'endophyte isolation from host' and 'phosphorus' when using non-parametric variance and 'organic nitrogen' when using parametric variance, all of which described over 20% of Q_T.

For the shoot biomass response ratio, the factors 'fungal order' and 'colonization of host' were significant in addition to all significant factors for the root response ratio. For the parametric total biomass response ratio, only 6 factors were significant. Of these, 3 described less than 18% of Q_T, but 'carbon (detailed)', 'protein and amino acids' and

'inorganic nitrogen' described 80.0%, 74.4% and 28.9% respectively. When using non-parametric variance, the total biomass response ratio was much more similar to shoot biomass with many factors significant and the most obvious differences being with 'fungal family', 'pH stabilizer (detailed)', 'growth conditions', 'peat moss' and 'nitrate'. Finally, for nitrogen concentration the factors describing the most variation were 'fungal strain', 'inorganic nitrogen' and 'ammonium'; the latter two are identical however, using the same studies and describing 34.4% of Q_T.

For the Helotiales, 69 out of 155 analyses were significant and described up to 66.9% of Q_T (Table 5). As with the analyses of the Ascomycetes, 'publication', 'host genus', 'host species' and 'carbon (detailed)' are the factors describing most of Q_T. 'Fungal strain', 'growth habit', 'host family', 'pH stabilizer (detailed)', 'simple sugars' and 'organic nitrogen' also account for much of Q_T for most of the response ratios. The analyses for the root and shoot biomass response ratios are nearly the same as that for the Ascomycetes analyses. However, there were many more factors describing a larger percentage of Q_T for the total biomass response ratio. All significant factors except for 'peat moss' described at least 14.6% with the highest percentage being 40.2% for 'fungal strain'. The nitrogen concentration response ratio was similar to that of the Ascomycetes analyses, except that there were less significant factors and they described less of the variation overall with the exception of 'fungal family', 'carbon (detailed)' and 'carbon (binomial)'.

For *Phialocephala fortinii* s.l., 46 out of 112 analyses were significant and described up to 60.7% of the variation (Table 6). Two analyses accounted for more than

50% of the variation: 'carbon (detailed)' and 'simple sugars' for the non-parametric root biomass response ratio. 'Growth habit', 'host group', 'host family', 'host genus', 'carbon (detailed)', 'simple sugars', 'peat moss' and 'other organic nitrogen' were the most descriptive factors. For all response ratios, significant factors were the same as the Helotiales analyses except for 'nitrate' and 'peat moss' for the parametric root biomass response ratio and 'nitrate' for shoot biomass.

One hundred and forty-two of the 208 analyses describing a significant model had at least one category with a significant effect size that had a confidence interval that did not overlap with at least one other category (hereafter referred to as a significant category) (Table 7). In other words, for a category to be considered significant, its effect size had to be significantly different from another category and the neutral response. Readers can consult Appendices 2-4 for a full listing of effect sizes and homogeneity statistics for the categorical analyses. The factors 'publication', 'fungal strain', 'growth habit', 'host family', 'host genus', 'carbon (detailed)' and the two binomial factors 'protein and amino acids' and 'other organic nitrogen' most often had significant categories. Of these, 'fungal strain', 'carbon (detailed)' and 'protein and amino acids' were significant for the nitrogen concentration response ratio. It was also the only response ratio for which the factors 'colonization of host' and 'ammonium' had significant categories.

The display of meaningful data on 'publication' or on factors relating to fungal or host taxonomy, which have significant categories for at least one analysis, can quickly become overwhelming because of the large number of categories in each factor

(multiplied by the analyses on different levels of endophytes, response ratios and variance types). To facilitate the interpretation of these factors, I used a subset of data for 'fungal genus', 'host genus' and 'publication' for the parametric root biomass response ratio (Figures 1, 2, 3). The subset was chosen for two additional reasons: (1) overall patterns among response ratios are similar except for the non-parametric total biomass response, which has more significant negative effect sizes and (2) researchers used a large diversity of host species and fungal strains, resulting in higher level taxonomic factors with single species or strain representatives. In simpler words, there is little difference among factors such as host species and host family. Often, when different species are grouped under the same family, effect sizes were not significantly different from the neutral response and many families with significant effect sizes, such as the Cyperaceae, are derived from a single genus or species. This does not hold true for 'growth habit' and 'host group', therefore these factors will be discussed separately. Effect sizes and their associated confidence intervals for the categories of 'fungal genus', 'host genus' and 'publication' displayed a similar pattern. For each of the factors, only about half of the categories were significant. Most significant categories had a biomass response between +8 and +31% compared to the control, but at least one per factor had a response over +100%. Negative biomass responses were between -5% and -16%. Note that some effect sizes are identical between 'publication' and the other two factors: Haselwandter and Read (1982) and *Carex* (+30%); Maciá-Vicente et al. (2008) and *Hordeum* (-7%); *Phialophora* and Newsham (1999) (+104%); and Schulz (2006) and *Larix* (+426%). The host or endophyte species is

frequently only used in one publication creating homologous categories in the analyses of two different factors. Less obvious are *Vulpia* and *Phialophora* which are linked because *Vulpia* has only one other study using a different endophyte species, *Phoma fimeti*. *Acremonium* and *Fusarium* are also associated because the studies for these two genera originate from Maciá-Vicente et al. (2008). Another issue with these factors is the low number of studies associated with each category. Significant categories often reflect the findings of a single publication, possibly due to publication bias, which was detected in the summary analyses for parametric root biomass. The low number of studies also caused bias in the bootstrapping of 95% confidence intervals around the effect size, most notable for the host genus *Saussurea*. However, bias corrected bootstrap intervals generated by Metawin 2.2 (Rosenberg et al. 2002) were not different from the regular bootstrap intervals. Although the results of these analyses reflect the findings in the literature, most are too biased to be of interest for detecting potential factors that may modulate plant response to endophyte inoculation.

'Growth habit' of the host had an influence on its response to endophyte inoculation for the biomass response ratios, particularly for the Ascomycetes analyses (Figures 4 and 5). Trees had a growth response of +53% and +46% for root and shoot biomass with parametric variance respectively, but a response of -34% for non-parametric total biomass. Shrubs had a growth response of -20% and -15% for root and total biomass with non-parametric variance. Graminoids showed a response of +95% for non-parametric total biomass. Forbs and herbs also showed a positive response of +25% to

+43% for root and shoot biomass response ratios. Results were very similar for the Helotiales analyses. For *P. fortinii s.l.* analyses, only graminoids had a significantly positive growth response for root and total biomass response ratios, but this was based on only 2 studies.

'Host group' only influenced the non-parametric total biomass response for the Ascomycetes analyses. Gymnosperms showed a response of -35% compared to non-inoculated controls (23 studies). Monocotyledonous plants had a positive response of +31% (19 studies).

When hosts were inoculated with an endophyte isolated from the same plant species, a significant growth increase was observed for the non-parametric root biomass response within the Ascomycetes and Helotiales analyses. This response is estimated at +84% using 28 studies and +88% using 17 studies respectively. Using an endophyte that was not isolated from the same host caused a neutral response.

'Colonization of host' was significant only for the nitrogen concentration response. For the Ascomycetes analyses, nitrogen concentration response of inoculated plants compared to the control was -14% when host was not colonized and +15% when host was only slightly colonized (5 and 2 studies, respectively); colonized plants were not significantly different from non-inoculated plants. For the Helotiales analyses, colonized plants had a positive response of +12% and non-colonized plants of -11% (19 and 3 studies respectively).

Somewhat contrasting results between the total biomass and the root or shoot biomass were observed for the factor 'growth conditions' when it was significant. For the root and shoot biomass response ratios, inoculated plants grown in growth chambers have a positive response, showing an increase of +40% to +82% compared to non-inoculated plants; the number of studies varied between 17 and 22. When plants were grown under sterile conditions, the effects were neutral. When inoculated plants were grown in a greenhouse root biomass response was estimated at -23% of the control (15 studies) when using non-parametric variance. Conversely, nearly opposite results were observed for non-parametric total biomass analysis of the Ascomycetes; a negative response of -23% (29 studies), a positive response of +33% (28 studies) and a positive response of +37% (2 studies) were estimated when plants were grown in a growth chamber, under sterile conditions or in a greenhouse, respectively.

All remaining significant factors are related to the substrate in which hosts were grown. Two have more than 2 categories, 'pH stabilizer (detailed)' and 'carbon (detailed)', and the other 10 are specific to the addition or exclusion of a particular element of the growing medium, such as peat moss or organic nitrogen. The factor 'pH stabilizer (detailed)' only had one significant category, expanded clay medium, for which the response of shoot and root biomass of inoculated plants was about +87% and +425% of the control, respectively. However, only two studies from a single publication (Schulz 2006) were included in all analyses.

Parametric root biomass of plants inoculated with ascomycetous root endophytes had a negative response compared to the control when carbon was excluded but non-parametric total biomass was positive (Figures 6, 7). When peat moss was the sole source of carbon, non-parametric root biomass had a negative response. The categories simple sugars, plant material and protein and amino acids had a positive response of +94% to +326% for the root and shoot response ratios. For parametric and non-parametric total biomass, the addition of peat and simple sugars induced a negative response of -47% and -18% respectively but the addition of simple sugars, proteins and amino acids had a positive response of +511% and +592%, although only two studies were included in this category. Results for the Helotiales analyses were similar to the Ascomycetes analyses, except that fewer categories were significant. For the *P. fortinii s.l.* analyses, plant material had a negative response of -26% to -17% for all biomass response ratios, but only two studies were used in the category. Similarly, simple sugars for the root biomass response had a positive response of +86% to +270%, but only had 2 associated studies. The exclusion of carbon had a positive response of +30% on parametric root biomass and had 5 associated studies.

Generally, the addition of a substance to the growing medium more frequently caused a significant response in inoculated plants than its exclusion (Table 8, 9). These responses were often greater in magnitude. The most interesting factors are 'carbon (binomial)', 'organic nitrogen' and 'peat moss', which had significant contrasting effect sizes for both the addition to and exclusion from the growing medium. Supplementing

carbon or organic nitrogen and excluding peat moss generally caused positive response when significant. There were contrasting data for 'simple sugars'. Only 2 to 3 studies were included in the analyses of root biomass response of inoculated plants when simple sugars were added in the media. However, for the non-parametric total biomass response in which 16 studies were included, the response was negative when simple carbohydrates were added in and positive when excluded. 'Protein and amino acids' and 'inorganic nitrogen' were the only significant factors for the nitrogen concentration response ratio. Response to the addition and exclusion of proteins and amino acids caused a negative and positive response respectively, the reverse of the biomass responses.

Discussion

The meta-analysis conducted here has shown that plant growth and nutrient response *in vitro* to ascomycetous root endophyte inoculation is mainly neutral to slightly positive. The recorded magnitude of plant response is in agreement with the analyses of response to DSE colonization by Alberton et al. (2010), but is lower than results published for DSEs by Newsham (2011). Alberton et al. (2010) recorded growth increases strictly for root biomass, whereas the current analysis found increases in shoot, root and total biomass similar to findings by Newsham (2011). Slight increases in the nitrogen concentration of inoculated plants compared to controls were also observed, unlike Newsham (2011), who noted increases in nitrogen and phosphorus content, but not concentration.

A number of biotic and abiotic factors account for this variability, particularly the identity of the host or endophyte, the source of carbon or organic nitrogen added to (or excluded from) the growing medium and, to a lesser extent, the inoculation of a host with an endophyte isolated from the same plant species. It is logical to expect dissimilar responses from various combinations of host-endophyte species, which is reflected in the results. However, most families, genera and species do not induce a response in inoculated plants that is significantly different from the control and those that do are often representative of a single publication. It is difficult to discern if the significant effect is in fact due to the identity of the host or endophyte species or to other experimental conditions when all studies within a category are from the same publication. There is a notable exception for the factors relating to the host plant, that is growth habit of the host, and another for the endophyte species, that is *P. fortinii* s.l., each of which engender distinct discussion that require further elaboration.

First, the growth habit of the host was a significant factor in determining response to endophyte inoculation. Shoot and root biomass response was positive for trees, forbs and herbs. Conversely, very different results were observed for total biomass (when using non-parametric variance). Inoculated trees weighed less than the control, the response of forbs and herbs were neutral and the response of graminoids positive. These apparently conflicting results are the product of different studies being used in the analyses of each of the response ratios and, particularly for the total biomass, parametric and non-parametric variance. Many of the older publications such as Richard and Fortin (1974)

and Currah et al. (1993) that assessed plant response to endophyte inoculation measured total biomass only and did not report standard deviations. Despite the statement by Newsham (2011) that standard deviations are 'necessary for weighted analyses', it is quite common for measures of dispersion to be omitted from publications, particularly in ecology, thereby making weights based solely on sample size (non-parametric variance) very practical. As stated above, the largest number of studies should be used to obtain the greatest power (Arnqvist and Wooster 1995b; Lajeunesse and Forbes 2003). Without the inclusion of these studies, one could have invalidly assumed that trees have a positive response to endophyte inoculation. A similar argument can be made for the factor 'growth conditions' where effect sizes between non-parametric total biomass and parametric shoot and root biomass contrasted between plants grown in growth chambers and greenhouses. There is no doubt that the identity of the host and endophyte are important in determining the response of the host to endophyte inoculation, but these conflicting results highlight the importance of experimental conditions in modulating the outcome of this relationship.

Second, more studies used *P. fortinii* s.l. as a study organism than any other root endophyte included in this meta-analysis. Unlike factors relating to host identity in which the results conflict, plant response to *P. fortinii* s.l. inoculation is neutral to slightly positive. There is also some evidence from these analyses that the addition of organic nitrogen or simple sugars enhances this response, but more study is required to obtain more power for these analyses. These results are of particular interest because of the ubiquity of *P. fortinii* s.l. There is evidence that every single Norway Spruce (*Picea*

abies) in Europe might be colonized by this root endophyte (Grünig et al. 2004; Grünig et al. 2008b). *P. fortinii* s.l. has also been isolated from the roots of a wide variety of plant hosts such as ericaceous shrubs (Stoyke and Currah 1991; Currah et al. 1993; Jumpponen and Trappe 1998a; Grünig et al. 2008b; Zhang et al. 2009), many herbaceous alpine plants (Currah et al. 1993), coniferous trees (Wang and Wilcox 1985; Ahlich and Sieber 1996; Jumpponen and Trappe 1998a; Grünig et al. 2008b), deciduous trees (Ahlich and Sieber 1996) and even members of the Cyperaceae (Addy et al. 2000), the Juncaceae (Jumpponen 1999) and the grass *Deschampsia* (Zijlstra et al. 2005) and can be successfully inoculated onto cultivated plants like *Asparagus officinalis* (Yu et al. 2001).

Elucidating the ecological role of *P. fortinii* s.l. has been challenging however. Richard and Fortin (1974) believed that under certain conditions MRA, likely *P. fortinii* s.l., is a mild pathogen, although it could be commonly isolated from healthy roots. This pathenogenicity may due to a drastic decrease in pH caused by secretions of acid from the fungus. The pH of an unbuffered *P. fortinii* liquid culture can fall as low as 2.5 (personal observation). Acid secretion by endophytes and the pH of the growing medium at the end of an experiment are factors that seem to be largely ignored and pH stabilizing buffers such as 2-(N-morpholino)ethanesulfonic acid (MES) (Good et al. 1966; Child, Knapp and Eveleigh 1973) are not often used. The acidity of peat moss (Marx and Zak 1965; Richard and Fortin 1974) may very well be the reason for the exclusion of peat generating a more positive response than including it in the growing medium; even the formation of mycorrhizae, and therefore the biotrophic relationship between host and fungus, is

affected by pH (Marx and Zak 1965). The opposite can be argued for the use of certain proteins, like casein, and amino acids if the carbon to nitrogen ratio is not properly adjusted. The hydrolysis of the protein releases more nitrogen than can be assimilated by the fungus, releasing ammonium and raising the pH of the media (Davet and Rouxel 2000).

Recent studies have determined that *P. fortinii* s.l. is in fact a complex of at least 14 species (Grünig et al. 2004; Queloz et al. 2005; Brenn et al. 2008; Grünig et al. 2008a; Grünig et al. 2008b) and it is likely that many more will be identified in the years to come. Several questions come to mind: do species within the complex moderate plant growth differently? Do they exhibit host specificity? Do they inhabit different ecological niches? The current study indicates that fungal strain is a significant factor for the *P. fortinii* s.l. analyses. Significant positive effects were only detected for the strain SE24 however, which had 5 and 6 associated studies for total and shoot biomass respectively and for strain C2, which only had 2 associated studies. Since the completion of the meta-analysis, Tellenbach et al. (2011) conducted an experiment on the effects of the inoculation of a number of isolates from the *Phialocephala fortinii* s.l.- *Acephala applanata* complex on the growth of Norway Spruce. Host response ranged from neutral to negative. These results may have decreased the slightly positive response of *P. fortinii* seen in these meta-analyses. Interestingly, the growing medium used by Tellenbach et al. (2011) was a mixture of peat and vermiculite at a ratio of 1:1, lending further support to

the results seen in this meta-analysis that peat may indeed be a cause of a negative plant response when inoculated by a root fungal endophyte.

Inoculation of a host with an endophyte isolated from the same plant species caused a significant increase in root biomass compared to control and hosts inoculated with endophytes isolated from a different plant species, but only for the Ascomycetes and Helotiales analyses. These results show that benefits from root endophytes may be host specific, but as several researchers have already discussed, experiments using well-defined strains under controlled conditions comparable to those already published will be required to determine this conclusively (Sieber and Grünig 2006). Kernaghan and Patriquin (2011) argue that at least certain endophyte species exhibit host preference, whereas others are generalists. The diversity of endophytes colonizing an individual host also adds to the complexity. Many species can be isolated from the roots of a single plant (Kernaghan and Patriquin 2011; Walker et al. 2011), some specific to different locations along the root system (Sieber and Grünig 2006; Grünig et al. 2008b).

Categorical analyses on the addition of organic nitrogen to the media are in accordance with the meta-analysis of Newsham (2011): all forms of organic nitrogen increased the relative biomass of inoculated plants for at least one analysis, except for peat moss. Categorical analyses on the addition of carbon generated similar results. Except for the addition of simple carbohydrates such as glucose or polysaccharides such as cellulose, the addition of organic nitrogen sources like casein hydrolysate necessarily

means the addition of carbon to the media (Davet and Rouxeau 2000), an important aspect not accounted for by most researchers.

Several researchers argue that dark septate endophytes may replace the nutrient transferring capability of mycorrhizae by mineralizing organic nitrogen into a form useable by plants– particularly in cold-stressed habitats where nitrogen is available predominantly in organic form (Caldwell et al. 2000; Upson et al. 2009; Newsham 2011). Mycorrhizal fungi do not generally thrive in a wide variety of habitats (Brundrett 2006), whereas some root endophytes such as *P. fortinii* s.l., for example, can be found growing in soil, decaying wood and in lignified parts of the roots (Menkis et al. 2004; Grünig et al. 2008b) and possess the necessary enzymes to hydrolyze polysaccharides, proteins and nucleic acids (Caldewell et al. 2000). Research also suggests that dark-septate endophytes are especially common in alpine and arctic habitats where endomycorrhizae are uncommon (Jumpponen and Trappe 1998; Mandyam and Jumpponen 2005; Upson et al. 2009). Data from Upson et al. (2009), from which many of the studies for the 'protein and amino acids' factor were derived, clearly demonstrate that the use of casein hydrolysate greatly increases the biomass of inoculated plants compared to the controls and to inoculated plants grown on ammonium sulfate. However, no additional carbon was added to the ammonium sulfate treatment to adjust for the carbon in the casein hydrolysate, which would likely affect the growth of the endophyte and consequently the host-endophyte relationship. Indeed, Usuki et al. (2002) state that colonization of Chinese cabbage (*Brassica rapa*) by the dark septate endophyte *Heteroconium chaetospira* is

greatly influenced by glucose concentration. Moreover, because the carbon to nitrogen ratio was not adjusted in the casein hydrolysate treatment, it is possible that the endophytes could not uptake all the ammonium released in the hydrolysis of the organic compound resulting in an increase substrate pH (Davet and Rouxeau 2000), which was acidified at the begin of the experiment. Finally, some endophytes have been shown to produce the plant growth hormone indole-3-acetic acid (IAA) (Gogala 1991; Schulz 2006) and microbial IAA production is substantially increased when the media is supplemented with tryptophan or tryptophan precursors (Gogala 1991), which can be found in casein (Gordon et al. 1953). Therefore, the increased plant biomass upon inoculation with fungal root endophytes seen in both Upson et al. (2009), and other studies used in the current meta-analysis, may also be due to phytohormone production. Nevertheless, experiments supplementing media with single amino acids as the only organic nitrogen source and controlling for the carbon to nitrogen ratio by Usuki and Narisawa (2007) have shown a similar positive growth response as Upson et al. (2009) for the DSE *Heteroconium chaetospira*.

Conclusion

The meta-analysis conducted here demonstrates that plant biomass and nitrogen concentration response to root endophyte inoculation is neutral to slightly positive. There are few cases where endophyte inoculation caused a negative response, and these can be attributed to experimental conditions, particularly the addition of peat and exclusion of

organic compounds from the growing media. There are a number of possible reasons which may explain the increase or decrease in biomass of inoculated plants compared to controls: (1) the identity of the host and endophyte species; (2) the breakdown of organic compounds into forms usable by the host plant; (3) the secretion of phytohormones that modulate plant growth and (4) the pH of the substrate. More studies are needed to confirm which endophyte species can improve plant growth under controlled conditions. Researchers should ensure factors such as the carbon to nitrogen ratio, the use of organic compounds, inorganic versus organic nitrogen and the pH are properly taken into account to allow appropriate comparisons among experiments. Moreover, more studies should focus on root endophytes with hyaline hyphae (non-DSEs) since measures of root endophyte species composition and diversity differ markedly between studies employing culture based techniques (which are biased towards fast growing fungi such as DSEs) and those using direct polymerase chain reaction techniques (Kernaghan and Patriquin 2011; Walker et al. 2011). Finally, this meta-analysis shows that except in certain cases, the increases in plant biomass are generally not very high and their associations with plants may not be strictly mutualistic.

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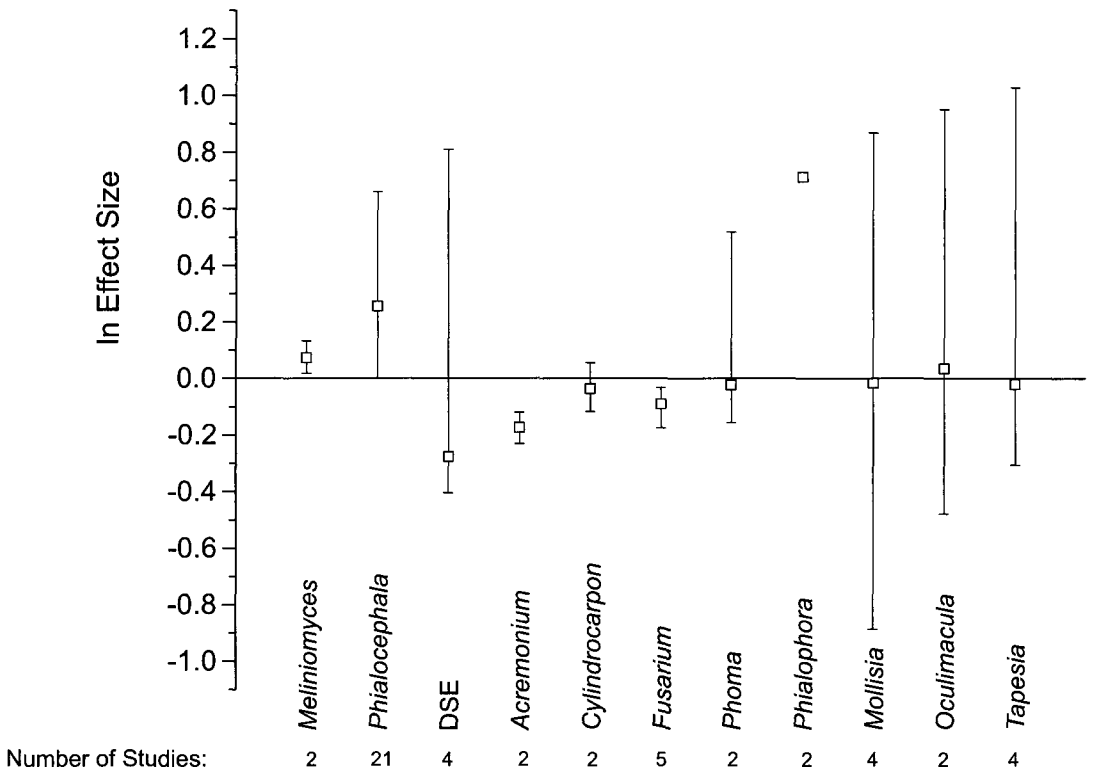

Figure 1. Natural log of mean effect sizes of the categories for different fungal genera for parametric root biomass analyses of ascomycetous root endophytes. Bars represent 95% bootstrapped confidence intervals. The number of studies included in the analysis of each category is included below. The category 'DSE' includes all dark-septate endophytes that were not identified to genus. A category was considered significant if the intervals do not include 0, the neutral response, and do not overlap with at least one other category.

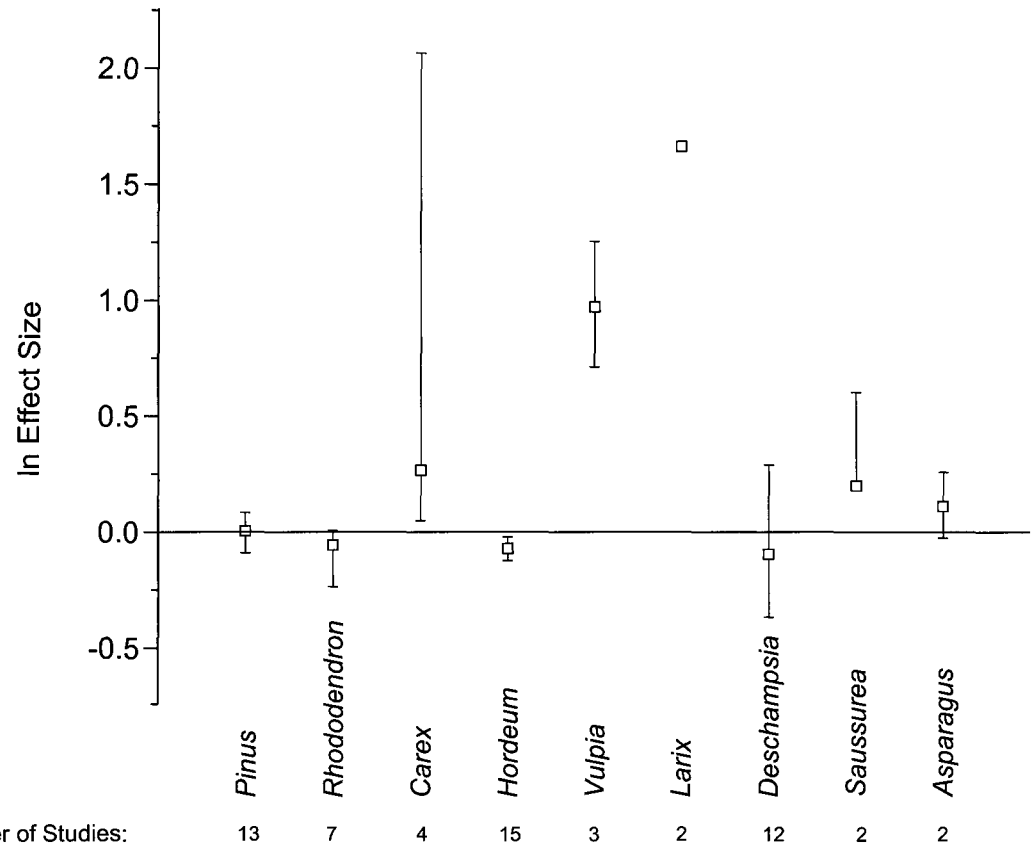

Figure 2. Natural log of mean effect sizes of the categories for different host genera for parametric root biomass analyses of ascomycetous root endophytes. Refer to figure 1 for more details.

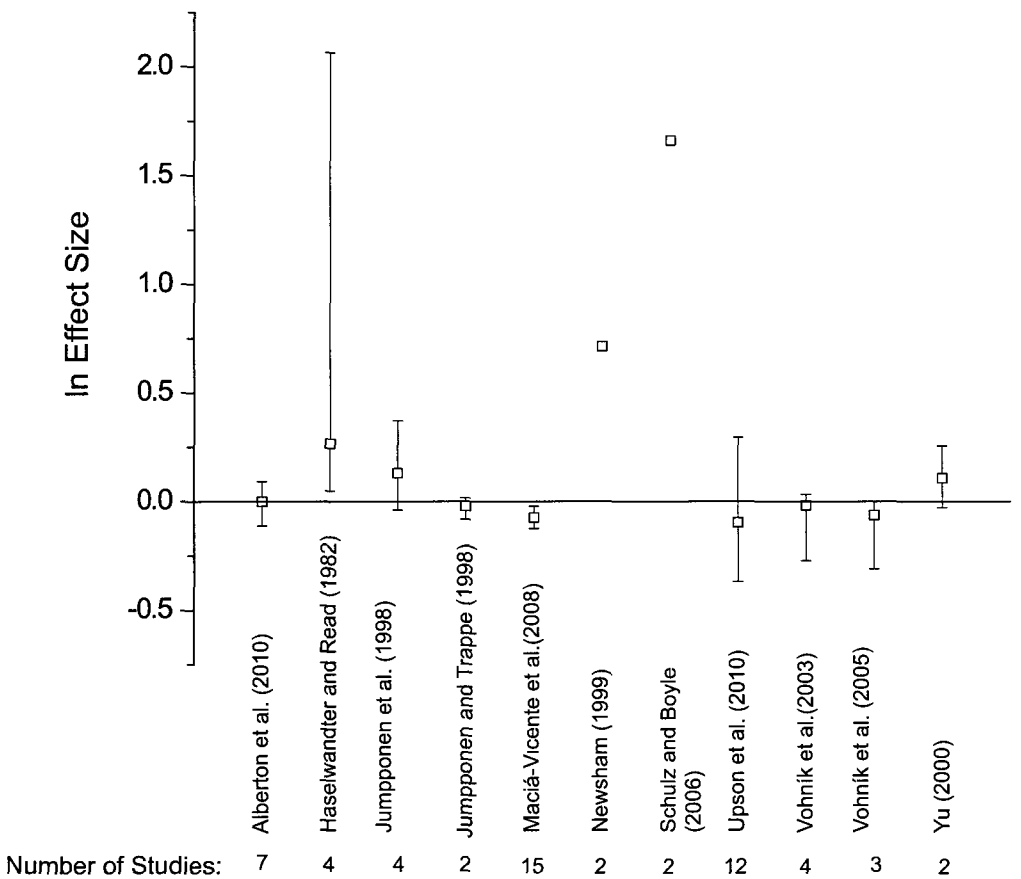

Figure 3. Natural log of mean effect sizes of the categories for different publications for parametric biomass analyses of ascomycetous root endophytes. The number of studies included in the analysis of each category is included below. Refer to figure 1 for more details.

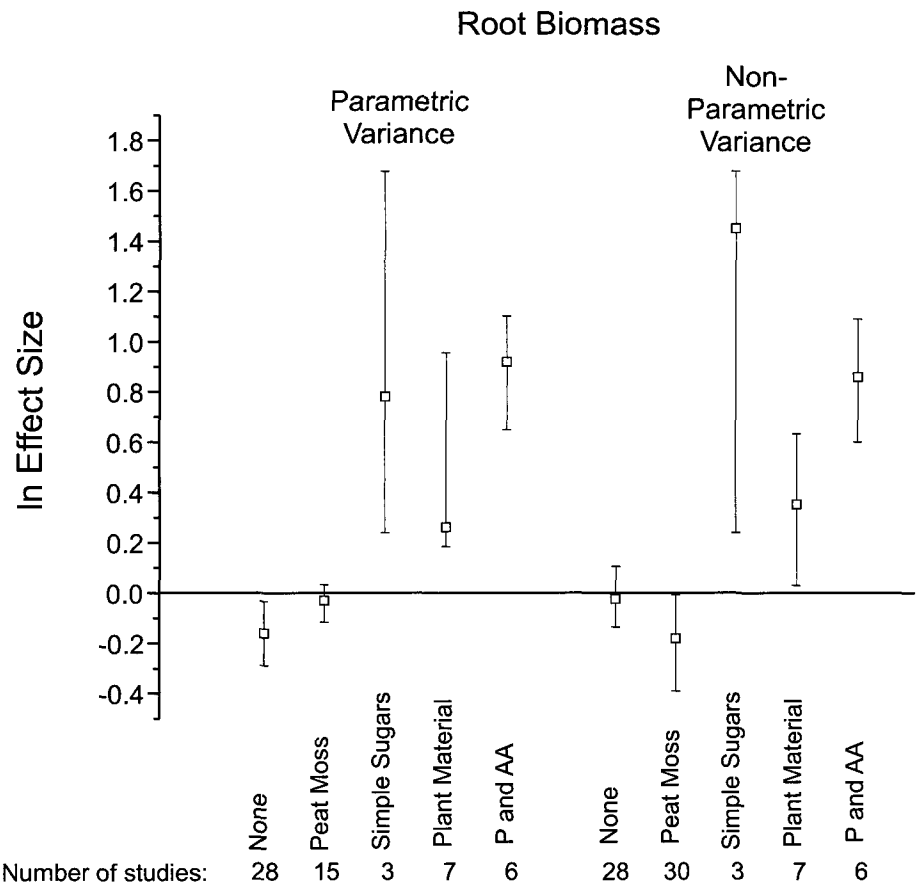

Figure 4. Natural log of mean effect sizes of the categories for the factor 'growth habit' for parametric and non-parametric root biomass analyses of ascomycetous root endophytes. Refer to figure 1 for more details.

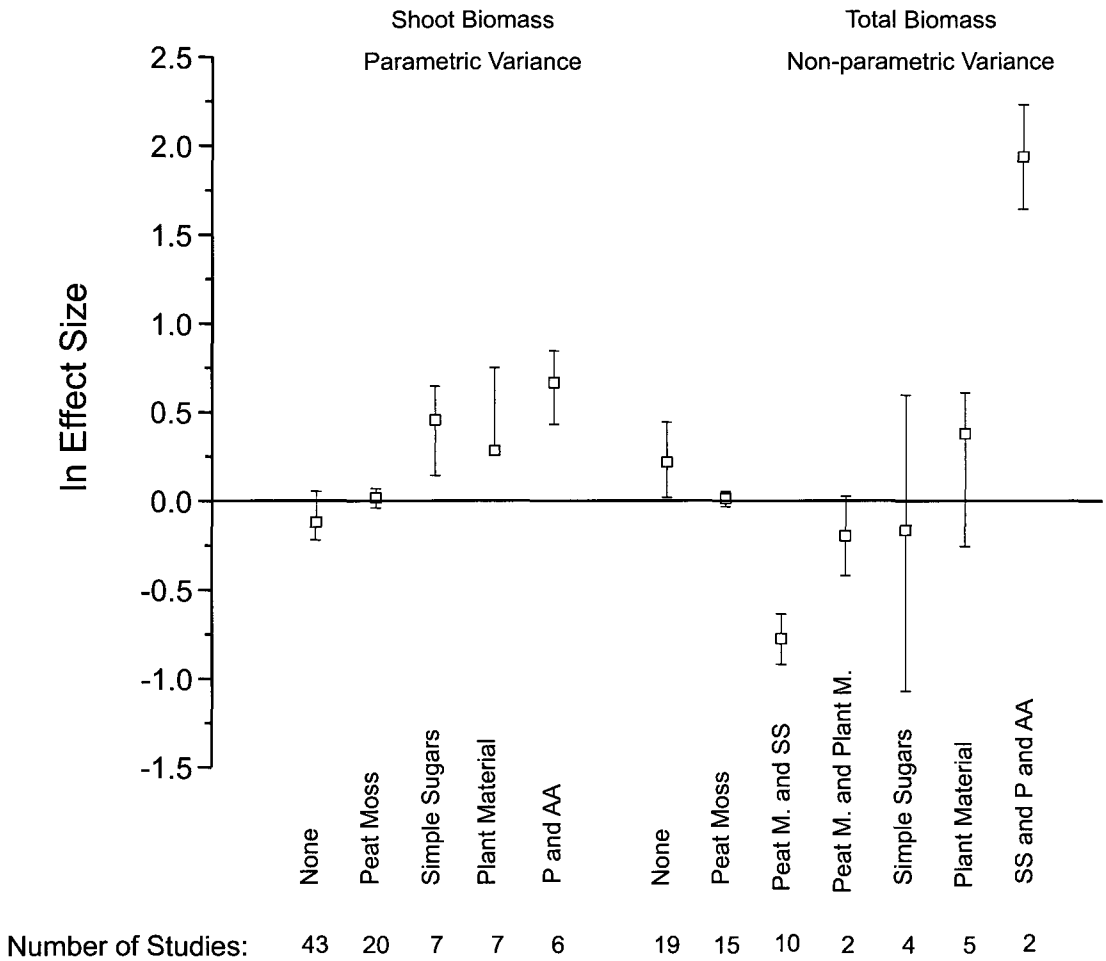

Figure 5. Natural log of mean effect sizes of the categories for the factor 'growth habit' for parametric shoot biomass and non-parametric total biomass analyses of ascomycetous root endophytes. Refer to figure 1 for more details.

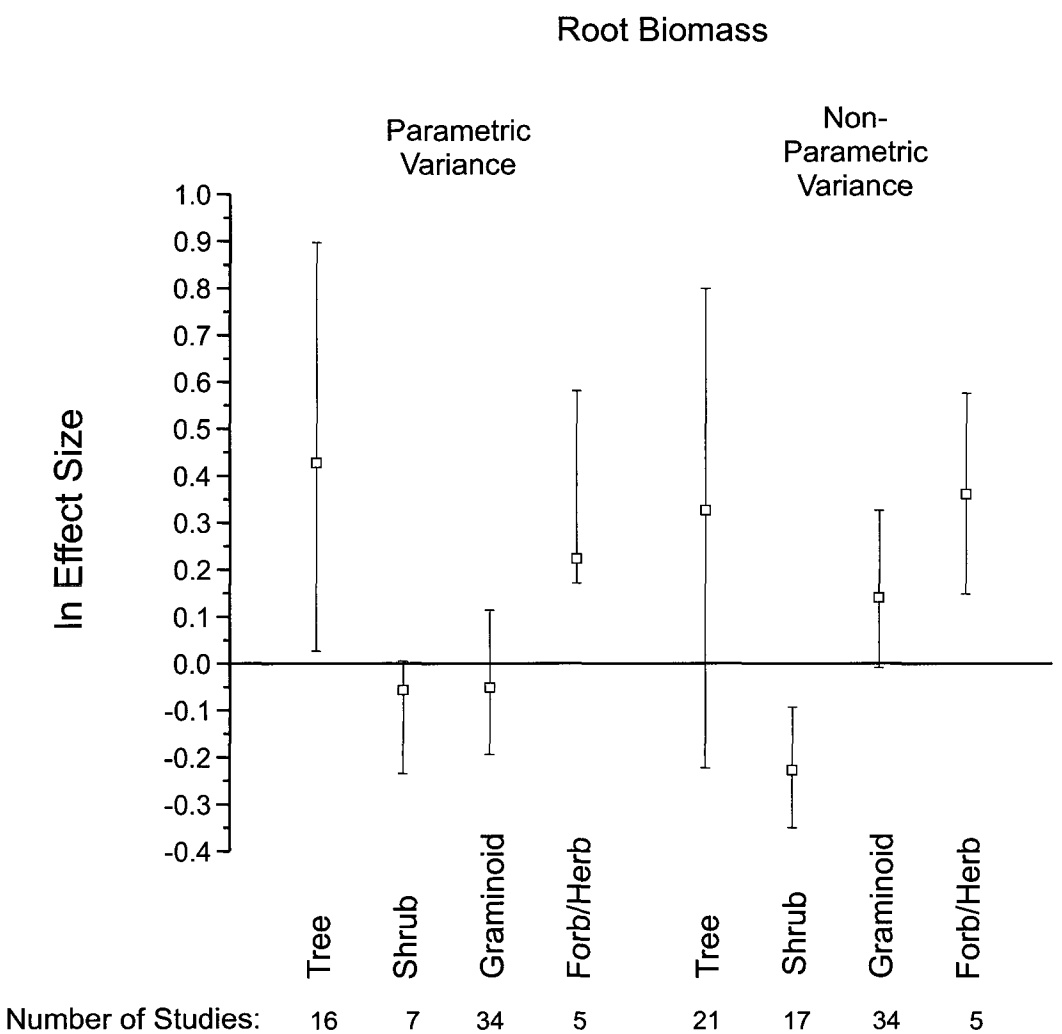

Figure 6. Natural log of mean effect sizes of the categories for the factor 'carbon (detailed)' for parametric and non-parametric root biomass analyses of ascomycetous root endophytes. Refer to figure 1 for more details.

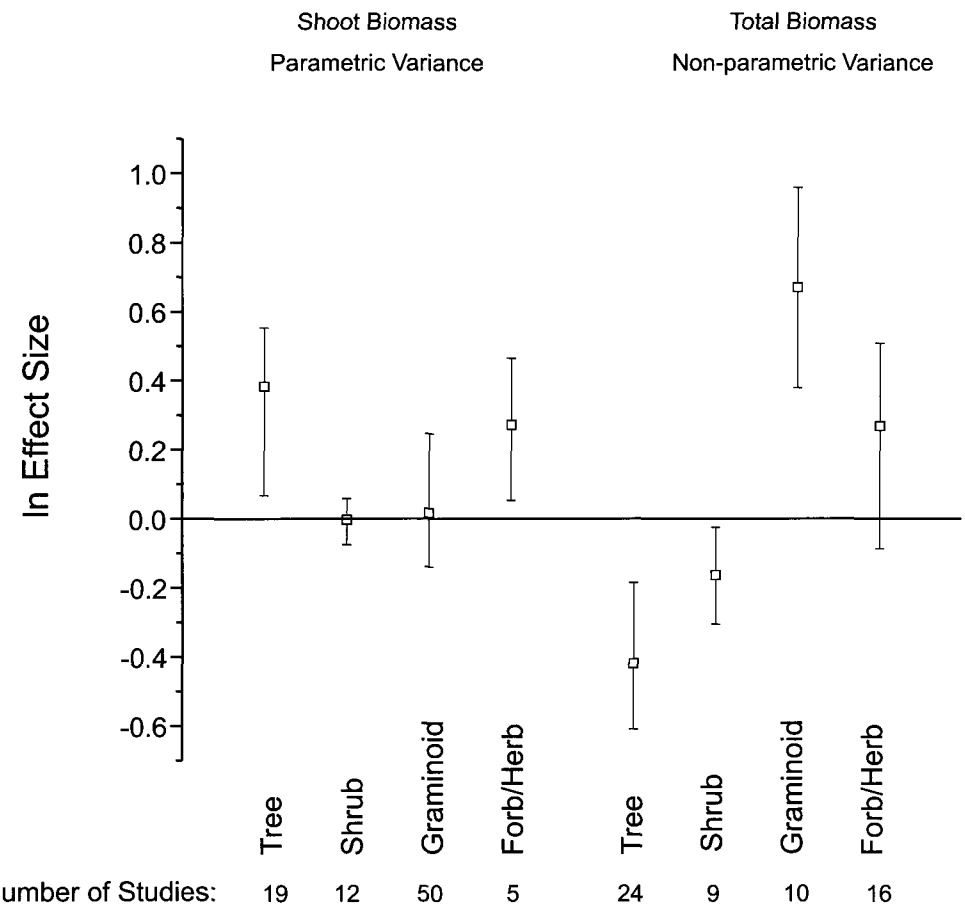

Figure 7. Natural log of mean effect sizes of the categories for the factor 'carbon (detailed)' for parametric shoot biomass and non-parametric total biomass analyses of ascomycetous root endophytes. Refer to figure 1 for more details.

Table 1. List of factors used for categorical analyses in the meta-analysis.

Factor	Comments	Categories
Measurement type	Indicates how data were collected for a specific study within a response ratio	4 categories for biomass response ratios: dry weight, fresh weight, length, height. 3 categories for nitrogen concentration response ratio: plant, shoot or foliar nitrogen concentration.
Publication	Publication from which a study was derived. Several studies are frequently obtained from a single publication.	Individual publications.
Fungal order	When unknown, given as *incertae sedis*	Order of inoculated endophyte.
Fungal family	When unknown, given as *incertae sedis*	Family of inoculated endophyte.
Fungal genus	Unknown dark septate endophytes were grouped together	Genus of inoculated endophyte.
Fungal species	If the endophyte was not identified to species, only genus was used. Unknown dark septate endophytes were grouped together and other unknown species were left as 'unknown'.	Species of inoculated endophyte.
Fungal strain	If no specific strain was given, the species or genus was used as the strain. Unknown dark septate endophytes were grouped together and other unknowns were left as 'unknown'.	Strain of inoculated endophyte.
Growth habit		4 categories: tree, shrub, forb/herb, graminoid.
Host group		3 categories: gymnosperm, monocotyledonous, dicotyledonous.
Host family		Family of host plant.
Host genus		Genus of host plant.
Host species		Species of host plant.

Table 1 (continued from previous page).

Factor	Comments	Categories
Endophyte isolation from host	Indicates whether or not the inoculated endophyte was isolated from the same host species.	3 categories: yes, no, unknown.
Colonization of host	Indicates if hyphal penetration and colonization occurred in the roots.	4 categories: yes, slightly, no, unknown.
System aeration	Indicates if there was significant air exchange. For example, plants grown in Petri dishes were considered to be in a closed system (unless researchers regularly opened them up for air exchange).	2 categories: open or closed system.
Growth conditions	Describes if the plants were grown under sterile conditions or the location of plants when grown under semi-sterile or non-sterile conditions.	3 categories: sterile, growth chamber, greenhouse.
Initial sterilization	Indicates if media was sterilized before experiment.	3 categories: yes, no, unknown.
Agar	Indicates if plants were grown in agar media.	3 categories: yes, no, unknown.
pH stabilizer (detailed)	Indicates if (and which) substances were added to the growth medium that may have acted to stabilize the pH.	5 categories: Vermiculite, expanded clay medium, buffer, cellulose and none. Note: only 2 studies used a buffer and 1 used cellulose and these 2 categories are therefore excluded from the analyses using this factor.
pH stabilizer (binomial)		2 categories: addition and exclusion from growth medium.

Table 1 (continued from previous page).

Factor	Comments	Categories
Carbon (detailed)	Indicates if (and which) carbon source were added to the growth medium, including sugars (glucose or sucrose), plant material (sawdust, wood debris or leaf litter), peat moss, bone meal, urea, proteins and amino acids. Peat moss was used as a separate category from plant material since it was used in many studies, sometimes with additional plant material.	6 categories: sugars, plant material, peat moss, bone meal, urea and proteins and amino acids.
Carbon (binomial)		2 categories: addition and exclusion from growth medium.
Simple sugars	Indicates the addition of glucose, sucrose or fructose to the growth medium.	2 categories: addition and exclusion from growth medium.
Nitrogen	Indicates if a nitrogen source, organic or inorganic, was added to the growth medium.	2 categories: addition and exclusion from growth medium.
Organic nitrogen	Indicates if any form of organic nitrogen was added to the growth medium, including peat moss, proteins, amino acids, other plant material (e.g.: sawdust) and bone meal.	2 categories: addition and exclusion from growth medium.
Peat moss		2 categories: addition and exclusion from growth medium.
Protein and amino acids	Indicates if single amino acids or a protein (such as casein) was added to the growth medium.	2 categories: addition and exclusion from growth medium.
Other organic nitrogen	Indicates if any form of organic nitrogen, other than peat moss or proteins and amino acids, was added to the growth medium.	2 categories: addition and exclusion from growth medium.
Inorganic nitrogen		2 categories: addition and exclusion from growth medium.

Table 1 (continued from previous page).

Factor	Comments	Categories
Ammonium		2 categories: addition and exclusion from growth medium.
Nitrate		2 categories: addition and exclusion from growth medium.
Phosphorus		2 categories: addition and exclusion from growth medium.

Table 2. Data from the summary analyses on the response of plant root, shoot and total biomass and nitrogen concentration (N%) to the inoculation of root endophytes within the Ascomycetes, root endophytes within the Helotiales and *Phialocephala fortinii sensu lato*. Analyses were performed using parametric (Para) variance (v) and non-parametric (Non-P) variance. The Q statistic represents the variation among studies; a significant p-value when tested against a Chi-square distribution indicates heterogeneity in the data with degrees of freedom = number of studies - 1. The mean natural log (ln) of the effect size for each meta-analysis with 95% bootstrapped confidence intervals (BS CI) is included. Significant p-values and effect size intervals that do not include 0, the neutral response, are in bold.

Group	Response	v	Q	df	p	ln Effect size	-95% BS CI	+95% BS CI
Ascomycetes	Root	Para	1117.92	61	**0.0000**	0.0881	-0.0554	0.2493
	Root	Non-P	181.86	76	**0.0000**	0.1323	-0.0481	0.3189
	Shoot	Para	1750.50	85	**0.0000**	**0.1595**	**0.0092**	**0.2684**
	Shoot	Non-P	89.79	97	0.6853	**0.1295**	**0.0033**	**0.2367**
	Total	Para	1113.19	36	**0.0000**	0.0940	-0.0431	0.3472
	Total	Non-P	122.74	58	**0.0000**	-0.0538	-0.2398	0.1410
	N%	Para	137.16	29	**0.0000**	**0.0695**	**0.0055**	**0.1352**
	N%	Non-P	2.43	29	1.0000	0.0201	-0.0356	0.0832
Helotiales	Root	Para	859.13	35	**0.0000**	0.1785	-0.0245	0.4267
	Root	Non-P	154.26	50	**0.0000**	0.1041	-0.1294	0.3431
	Shoot	Para	627.21	39	**0.0000**	**0.2428**	**0.0897**	**0.3377**
	Shoot	Non-P	51.12	50	0.4295	0.0105	-0.1245	0.141
	Total	Para	58.83	21	**0.0002**	**0.042**	**0.0038**	**0.0974**
	Total	Non-P	11.63	23	0.9758	0.0092	-0.1077	0.1339
	N%	Para	71.64	22	**0.0000**	**0.0934**	**0.0484**	**0.1467**
	N%	Non-P	1.71	22	1.0000	0.0454	-0.0148	0.1155

Table 2 (continued from previous page).

Group	Response	v	Q	df	p	ln Effect size	-95% BS CI	+95% BS CI
	Root	Para	333.86	20	**0.0000**	**0.2546**	**0.0033**	**0.6615**
	Root	Non-P	48.98	23	**0.0013**	**0.2604**	**0.0016**	**0.6043**
	Shoot	Para	264.46	21	**0.0000**	**0.1846**	**0.0147**	**0.4219**
Phialocephala	Shoot	Non-P	16.78	24	0.8577	0.0709	-0.0668	0.2368
fortinii s.l.	Total	Para	56.03	17	**0.0000**	0.0248	-0.0229	0.0957
	Total	Non-P	11.53	19	0.9048	0.0003	-0.1287	0.1434
	N%	Para	13.18	10	0.2140	**0.0645**	**0.0149**	**0.0974**
	N%	Non-P	0.39	10	1.0000	0.0150	-0.0476	0.0871

Table 3. Spearman's rank correlation test of effect size versus variance. A significant Spearman's Rho ($p<0.05$) indicates publication bias. See Table 2 for more details.

Group	Response	v	Spearman's Rho	p
Ascomycetes	Root	Para	0.423	**0.00061**
	Root	Non-P	0.198	0.08464
	Shoot	Para	0.200	0.06510
	Shoot	Non-P	0.136	0.18312
	Total	Para	0.371	**0.02379**
	Total	Non-P	0.419	**0.00096**
	N%	Para	-0.365	**0.04716**
	N%	Non-P	-0.030	0.87628
Helotiales	Root	Para	0.249	0.14317
	Root	Non-P	0.125	0.38045
	Shoot	Para	0.114	0.48324
	Shoot	Non-P	0.264	**0.06140**
	Total	Para	0.136	0.54740
	Total	Non-P	0.461	**0.02343**
	N%	Para	-0.347	0.10528
	N%	Non-P	0.085	0.70044
Phialocephala fortinii s.l.	Root	Para	0.340	0.13124
	Root	Non-P	0.029	0.89480
	Shoot	Para	0.446	**0.03739**
	Shoot	Non-P	0.322	0.11620
	Total	Para	0.261	0.29507
	Total	Non-P	0.378	0.10018
	N%	Para	-0.123	0.71861
	N%	Non-P	0.351	0.28921

Table 4. Percent of total variation (Q_T) described by the among category variation (Q_M= Q for the model) for categorical analyses on ascomycetous root endophytes of different factors and the response ratios root biomass, shoot biomass, total biomass or nitrogen concentration (N%) with parametric (Para) or non-parametric variance (Non-P). Only factors which generated a significant model for at least one categorical analysis are included. Values were obtained with the equation Q_M/Q_T x 100. Analyses with a significant Q_M ($p<0.05$ when tested against chi-square distribution) and which describe more than 10% of the total variation are in bold (see text for further discussion).

Factor	Root Para	Root Non-P	Shoot[1] Para	Total Para	Total Non-P	N%[1] Para
Publication	**57.9***	**59.6***	**53.9***	**10.7**	**56.3***	1.1
Fungal order	6.0	4.9	**42.4***	8.3	**42.5***	1.5
Fungal family	5.5	**13.6**	**26.6**	5.6	8.9	5.7
Fungal genus	**13.3**	**16.0**	**48.0**	6.0	**38.8***	6.9
Fungal species	**13.7**	**20.8**	**30.3**	5.6	**38.5***	5.8
Fungal strain	**35.3**	**42.2**	**52.3**	7.7	**38.0**	**45.2**
Growth habit	**16.5**	**13.8**	**26.9**	7.9	**38.3***	**13.6**
Host group	**15.5***	4.4	**24.4**	1.8	**26.9***	**12.2**
Host family	**18.3**	**17.9**	**35.1**	8.3	**38.9***	**13.6**
Host genus	**58.9***	**60.3***	**69.6***	**10.7**	**61.3***	0.7
Host species	**61.9***	**64.9***	**74.6***	**17.2**	**67.0***	0.8
Endophyte isolation from host	1.6	**28.6***	3.0	0.6	**14.0**	1.4
Colonization of host	2.2	2.3	**29.4***	6.0	**19.7***	**19.8**
Growth conditions	**24.7***	**22.6***	0.3	0.3	**23.3***	0.8
pH Stabilizer (detailed)	**50.5***	**40.8***	**36.9***	0.9	4.0	0.9
pH Stabilizer (binomial)	3.8	7.9	**24.3***	0.8	3.8	0.9
Carbon (detailed)	**50.7***	**51.5***	**56.8***	**80.0***	**64.7***	**33.8***
Carbon (binomial)	**22.6***	2.1	**26.6***	0.4	7.2	9.3
Simple sugars	**27.1***	**35.0***	**18.4***	3.4	**29.5***	N/A
Organic nitrogen	**22.5***	1.8	**29.1***	3.3	7.3	**11.7**
Peat moss	1.2	**15.4***	7.3	7.3	**31.5***	7.6
Protein and amino acids	**12.6***	4.5	**11.6**	**74.4***	**16.4***	**16.6**
Other organic nitrogen	**26.1***	**27.2***	**35.1***	0.2	**13.4***	**13.0**

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).

* Randomization tests generated $p<0.05$.

N/A: Not applicable. Categorical analyses could not be conducted when less than 2 studies were included in one or more categories.

Table 4 (continued from previous page).

Factor	Root Para	Root Non-P	Shoot[1] Para	Total Para	Total Non-P	N%[1] Para
Inorganic nitrogen	0.1	**15.9***	0.0	**28.9***	2.9	**31.4***
Ammonium	0.2	**12.5***	0.0	9.5	6.7	**31.4***
Nitrate	0.1	3.4	5.2	6.3	**21.4***	6.1
Phosphorus	1.6	**20.8***	1.9	0.1	0.2	**15.6**

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
* Randomization tests generated $p<0.05$.
N/A: Not applicable. Categorical analyses could not be conducted when less than 2 studies were included in one or more categories.

Table 5. Percent of total variation (Q_T) described by the among category variation (Q_M= Q for the model) for categorical analyses on root endophytes of the Helotiales. See Table 4 for more details.

Factor	Root Para	Root Non-P	Shoot Para[1]	Total Para[1]	N% Para[1]
Publication	**65.7**	**61.5***	**51.0**	**36.4**	6.7
Fungal family	1.8	**20.5**	4.5	3.9	**12.6**
Fungal genus	**18.6**	**15.5**	**10.5**	3.6	9.5
Fungal species	**18.6**	**20.1**	**10.5**	N/A	8.8
Fungal strain	**27.9**	**38.5**	**24.7**	**40.2**	**32.8**
Growth habit	**16.6**	**13.8**	**16.6**	**34.2**	5.7
Host group	**17.6**	9.1	**11.1**	**18.4***	7.0
Host family	**20.7**	**16.7**	**23.5**	**34.2**	5.7
Host genus	**65.6***	**61.3***	**51.0**	**34.2**	5.7
Host species	**66.9***	**61.8***	**53.2**	11.8	6.2
Endophyte isolation from host	0.4	**24.4***	**10.5**	0.0	0.1
Colonization of host	0.0	1.6	0.0	N/A	**18.6**
Growth conditions	**23.1***	**24.7***	**10.6**	1.6	1.0
pH stabilizer (detailed)	**61.4***	**51.5***	**41.8***	0.2	0.8
pH stabilizer (binomial)	**12.1**	**18.0***	**14.2**	0.2	0.8
Carbon (detailed)	**51.4***	**54.2***	**54.3***	**18.2**	**40.4***
Carbon (binomial)	**21.7***	0.2	**15.0**	**14.6***	**20.8***
Simple sugars	**29.6***	**44.4***	**17.0**	N/A	N/A
Organic nitrogen	**21.4***	0.1	**18.5***	**16.8**	**21.9***
Peat moss	3.6	**19.6***	**17.2***	**10.3***	5.5
Protein and amino acids	8.2	3.5	**11.7**	N/A	**18.8***
other organic nitrogen	**22.5***	**24.0***	**23.1***	0.0	0.1
Inorganic nitrogen	2.0	**17.2***	2.8	0.6	9.4
Ammonium	2.4	**14.4***	3.1	1.6	9.4
Phosphorus	0.1	**21.2***	0.1	0.0	1.0

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
* Randomization tests generated $p<0.05$.
N/A: Not applicable. Categorical analyses could not be conducted when less than 2 studies were included in one or more categories.

Table 6. Percent of total variation (Q_T) described by the among category variation (Q_M= Q for the model) for categorical analyses on root endophytes of *Phialocephala fortinii* s.l. See Table 4 for more details.

Factor	Root Para	Root Non-P	Shoot Para[1]	Total Para[1]
Publication	29.4	42.5	30.1	**41.4**
Fungal strain	19.9	40.4	**35.8**	**40.2**
Growth habit	**16.0**	**24.1**	**28.8**	**36.1**
Host group	**17.5**	**13.7**	**48.1**	**19.6**
Host Family	**23.4**	**25.8**	**51.8**	**36.1**
Host genus	**25.2**	42.9*	**24.4**	**36.1**
Endophyte isolation from host	6.5	**40.3***	**14.5**	0.8
Growth conditions	**22.2**	8.0	**38.8**	3.6
pH stabilizer (binomial)	**11.4**	**11.0**	**33.5**	1.3
Carbon (detailed)	**34.6**	**60.7***	**40.9**	**21.2**
Carbon (binomial)	0.0	0.0	0.1	**17.5***
Simple sugars	**29.8**	**50.8***	**36.0**	N/A
Organic nitrogen	0.0	0.0	2.5	**20.1***
Peat moss	**27.0**	**12.2**	**34.8**	**12.8***
Other organic nitrogen	**31.8**	**20.0**	**56.1***	0.0
Inorganic nitrogen	1.3	**30.4***	2.1	0.1
Ammonium	0.6	**22.3**	0.9	3.6
Nitrate	**11.6**	0.4	**19.5**	2.7
Phosphorus	0.5	**18.1**	0.0	0.1

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
* Randomization tests generated $p<0.05$.
N/A: Not applicable. Categorical analyses could not be conducted when less than 2 studies were included in one or more categories.

Table 7. Significance of factors tested for effects on the response of plant root, shoot and total biomass and nitrogen concentration (N%) to the inoculation of root endophytes within the Ascomycetes, endophytes within the Helotiales and *Phialocephala fortinii sensu lato* using parametric (Para) variance and non-parametric (Non-P) variance. An 'X' indicates a factor with at least one significant category which was based on the absence of overlapping of 95% bootstrapped confidence intervals among categories (see text for more details).

	Ascomycetes						Helotiales					*P. fortinii* s.l.			
	Para Root	Non-P Root	Para Shoot[1]	Para Total	Non-P Total	Para N%[1]	Para Root	Non-P Root	Para Shoot[1]	Para Total[1]	Para N%[1]	Para Root	Non-P Root	Para Shoot[1]	Para Total[1]
Publication	X	X	X	X	X		X	X	X	X					X
Fungal order			X		X		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fungal family		X	X									N/A	N/A	N/A	N/A
Fungal genus	X	X	X		X							N/A	N/A	N/A	N/A
Fungal species	X	X	X		X			X				N/A	N/A	N/A	N/A
Fungal strain	X	X	X		X	X	X	X	X	X	X			X	X
Growth habit	X	X	X		X		X	X	X	X		X	X		X
Host group					X										
Host family	X	X	X		X		X	X	X	X		X	X		X

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
N/A: Not applicable. Categorical analyses could not be conducted.

Table 7 (continued from previous page).

	Ascomycetes						Helotiales					*P. fortinii* s.l.				
	Para Root	Non-P Root	Para Shoot[1]	Para Total	Non-P Total	Para N%[1]	Para Root	Non-P Root	Para Shoot[1]	Para Total[1]	Para N%[1]	Para Root	Non-P Root	Para Shoot[1]	Para Total[1]
Host genus	X	X	X	X	X		X	X	X	X		X			X
Host species	X	X	X	X	X		X	X	X	X					
Isolation from host		X						X							
Colonization of host						X					X				
Growth conditions	X	X			X		X	X				X		X	
pH stabilizer (detailed)		X	X				X	X	X						
Carbon (detailed)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
N/A: Not applicable. Categorical analyses could not be conducted.

Table 7 (continued from previous page).

	Ascomycetes						Helotiales					*P. fortinii* s.l.			
	Para Root	Non-P Root	Para Shoot[1]	Para Total	Non-P Total	Para N%[1]	Para Root	Non-P Root	Para Shoot[1]	Para Total[1]	Para N%[1]	Para Root	Non-P Root	Para Shoot[1]	Para Total[1]
pH stabilizer			X												
Carbon (binomial)	X		X				X		X						
Simple sugars	X		X		X		X					X	X		
Organic nitrogen	X		X				X		X						
Peat moss		X			X			X	X						
Protein and am. ac.[2]	X		X	X	X	X			X		X				
Other organic nitrogen	X	X	X				X	X	X			X			
Inorganic nitrogen		X				X									
Nitrate					X										
Phosphorus		X						X							

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
[2] Protein and amino acids
N/A: Not applicable. Categorical analyses could not be conducted.

Table 8. Mean effect sizes of the response of endophyte-inoculated plants to the addition of a media supplement. Values are displayed only if the effect size of the addition is significantly different from the exclusion of the same supplement as well as the neutral response. There were no significant factors for the total biomass response of the Helotiales and the shoot biomass, total biomass and nitrogen concentration responses of *P. fortinii* s.l. Effect sizes are expressed as percentage growth of inoculated plants compared to the control where 0% is the neutral response.

	Ascomycetes						Helotiales				Pf	
	Root Para	Root Non-P	Shoot[1] Para	Total Para	Total Non-P	N%[1] Para	Root Para	Root Non-P	Shoot[1] Para	N%[1] Para	Root Para	Root Non-P
pH stabilizer			+35%									
Carbon (binomial)	+30%		+25%				+38%		+31%			
Simple sugars	+118%	+326%			-43%		+118%				+86%	+270%
Organic nitrogen	+37%		+30%				+38%		+32%			
Peat moss					+58%				+6%			
Prot. and am. ac.[2]	+150%		+94%	+511%	+592%	-17%			+82%	-14%		
Other org. nit.[3]	+71%	+91%	+45%				+68%	+90%	+40%		+82%	
Inorganic nitrogen		+64%				+13%						
Nitrate					+40%							
Phosphorus		+62%						+63%				

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
[2] Proteins and amino acids
[3] Other organic nitrogen

Table 9. Mean effect sizes of the response of endophyte-inoculated plants to the exclusion of a media supplement. Values are displayed only if the effect size of the exclusion is significantly different from the addition of the same supplement in the media and the neutral response. Effect sizes are expressed as percentage growth of inoculated plants compared to the control where 0% is the neutral response.

	Ascomycetes						Helotiales				Pf	
	Root Para	Root Non-P	Shoot[1] Para	Total Para	Total Non-P	N%[1] Para	Root Para	Root Non-P	Shoot[1] Para	N%[1] Para	Root Para	Root Non-P
pH stabilizer												
Carbon (binomial)	-7%						-27%					
Simple sugars					+18%							
Organic nitrogen	-15%											
Peat moss		+43%			+36%			+62%	+35%			
Prot. and am. ac.[2]						+9%			+25%	+11%		
Other org. nit.[3]												
Inorganic nitrogen												
Nitrate					-23%							
Phosphorus												

[1] Categorical analyses could not be pursued using non-parametric variance because data was homogenous (see Table 2).
[2] Proteins and amino acids
[3] Other organic nitrogen

CHAPTER 3

EFFECTS OF FUNGAL ROOT ENDOPHYTE METABOLITES ON PLANT GROWTH

Abstract

Fungal root endophytes are ubiquitous plant associates that colonize the root tissue of their host internally without causing any apparent harm. They secrete a number of biologically active compounds including plant growth promoters and regulators, such as the auxin indole-3-acetic acid (IAA). The effects of the metabolites of nine different endophytes, one known ectomycorrhizal fungus and one root pathogen on the growth of *Betula papyrifera* seedlings were assessed. The media was supplemented with with L-tryptophan, an IAA precursor, to determine if the endophytes could produce IAA and consequently affect plant growth. A subset of the 11 fungi was further tested for their production of IAA in liquid culture using Salkowski's reagent, a colorometric test for indole compounds. *Cryptosporiopsis ericae* metabolites reduced plant growth, but unlike all the other fungi, *C. ericae* was not isolated from *B. papyrifera*,. Species of *Cryptosporiopsis* are known to produce potent herbicidal and anti-fungal substances. *Phialocephala sphaeroides* metabolites increased plant weight, root width and root length, but did not produce IAA on the basis of the Salkowski's test. Hyaloscyphaceae sp. I and Helotiaceae sp. III metabolites contained indole compounds and affected plant and root morphology, but indole compound production and plant responses were variable. These results are in accordance with the findings of the meta-analysis in chapter 2.

CHAPTER 3: FUNGAL METABOLITES

Introduction

Fungal root endophytes are ubiquitous plant associates that colonize the root tissue of their host internally without causing any apparent harm (Saikonnen et al. 1998; Schulz and Boyle 2005). They are a diverse group and many species (and isolates) can be found on a single host (Sieber and Grünig 2006; Grünig et al. 2008; Kernaghan and Patriquin 2011). Due to their ubiquitous nature, some researchers have hypothesized that they may be responsible for important ecological functions, elusive to this date (Mandyam and Jumpponen 2005; Sieber and Grünig 2006; Rodriguez 2009). Potential functions include root endophytes potentially acting as latent pathogens (Schulz et al. 1999), defense mutualists protecting the plant from pathogens (Narisawa et al. 2004) and mineralization of organic nitrogen in a form available to the host (Mandyam and Jumpponen 2005; Upson et al. 2009; Newsham 2011). The hypothesis regarding nutrient mineralization has been of particular interest in the root endophyte literature, yet studies on plant biomass and nutrient content of plants inoculated with a single root endophyte isolate *in vitro* show an overall neutral, albeit highly variable, response (see chapter 2). Effects of fungal root endophytes on their host seem to depend on the fungal isolate and on experimental conditions (Tellenbach et al. 2011), particularly with respect to the nitrogen source (Usuki and Narisawa 2007; Upson et al. 2009; Newsham 2011).

CHAPTER 3: FUNGAL METABOLITES

Biologically active compounds naturally secreted in the secondary metabolites of endophytes further complicate plant response to endophyte inoculation. For example, root endophytes have been shown to produce anti-fungal and herbicidal compounds (Schulz et al. 1999), plant growth promoting substances (Kim et al. 2006), as well as plant growth hormones such as auxins (Gogala 1991; Schulz 2006) and gibberellins (Hwang et al. 2011). It is difficult to discern the ecological role of root endophytes based on the compounds they produce, especially considering the difference in biomass (and consequently the concentration of metabolites produced) between an isolate in culture and hyphae colonizing a root in a natural setting. Nevertheless, these compounds may very well play an important role in the plant-endophyte relationship and may be one of the underlying causes of the variation in plant response seen in studies assessing the effects of root endophyte colonization.

The purpose of the present study was to further understand the relationship between fungal root endophytes and their hosts by developing a system to test the effects of fungal metabolites on plant growth and root morphology in agar media. The endophytes were physically separated from the solid media, and consequently the host, using an indigestible polycarbonate filter. This was done to prevent any active nutrient transfer (as in mycorrhizal symbioses) between the endophyte and the host. Agar media was selected because there is evidence that fungal metabolite production is higher on solid media than in liquid culture (B. Schulz pers. comm.). Furthermore, it is easier to observe root morphology in clear agar media than in soil or peat. These experiments were

oriented towards assessing the production of the growth hormone indole-3-acetic acid (IAA). IAA is a plant growth regulator produced naturally in leaf primordia and seeds that diffuses passively from leaves to root tips and causes cell elongation in roots as well as the formation of adventitious and lateral roots (Raven et al. 2003; Tanimoto 2005; Woodward and Bartel 2005). Many fungi and bacteria secrete IAA naturally, including mycorrhizal fungi and fungal pathogens (Schulz 2006). The secretion of IAA by fungi is often associated with hyphal colonization and may cause changes root morphology. In fact, the typical bifurcation and swelling seen in ectomycorrhizal root tips of *Pinus* sp. can be induced by exposure to IAA (Gogala 1991). Understanding the effects of fungal endophyte metabolites on plant growth and determining their plant hormone content is therefore an important step in advancing our understanding of the plant-endophyte relationship.

Methods

Fungal isolates and host

Eleven fungal isolates (nine root endophytes, one ectomycorrhizal fungus and one root pathogen), were used in the following experiments (Table 1). Cultures were maintained on malt media (15g Bacto® malt extract, 15g agar and 1g BBL™ yeast extract per liter of distilled H_20) and regularly subcultured. Experiments were carried out with particular attention of the growth rate of each isolate.

Betula papyrifera was selected as the host species for its high germination rate, fast growth and low contamination rate after surface sterilization. Also, many of the root endophytes in the culture collection of the Atlantic Root Symbiosis Laboratory at Mount Saint Vincent University were isolated from *B. papyrifera*. Seeds were obtained from the Natural Tree Seed Centre of Natural Resources Canada, Fredericton, New-Brunswick and originated from Cape Breton, NS (46.20°N 60.18°W, elevation 50m), seedlot number 9810025.3.

Effects of fungal metabolites on plant growth (Experiment I)

The effects of fungal metabolites on plant growth were tested by growing *B. papyrifera* seedlings on agar medium on which an endophyte was previously grown (Figure 1). *B. papyrifera* seeds were surface sterilized in 15% hydrogen peroxide for 30 minutes, rinsed in sterile distilled water at least 5 times and placed in Petri dishes with water agar (15g agar per liter of dH_2O) to germinate under sterile conditions.

Meanwhile, an autoclaved 47mm 0.2µm Whatman® nuclepore polycarbonate filter was placed near the edge of a Petri dish filled with 24mL of buffered media supplemented with L-tryptophan. A 1.1 cm disk of the same media as in the Petri dish was then placed in the center of the filter and a 5mm mycelial plug was placed on top. The agar disk was half the thickness of the media in the Petri dish. The desired thickness was obtained by pouring 12mL into a Petri dish using an automatic pipettor, which is half the amount poured into the Petri dishes used for inoculation. The agar medium consisted of

15g agar, 10g dextrose, 0.5g $MgSO_4 \cdot 7H_2O$, 1g KH_2PO_4, 0.2g $CaCl_2$, 0.8g $(NH_4)_2SO_4$ and 0.2g of L-tryptophan per liter of dH_2O, buffered with 50mM 2-(N-morpholino)ethanesulfonic acid (MES) titrated at pH 6.0. The initial pH was 5.7.

Six replicates, each of *Cenococcum geophilum*, *Phialocephala fortinii*, *P. sphaeroides*, *Cryptosporiopsis ericae*, Dermataceae I, *Chaetosphaeria* sp., *Meliniomyces* sp., *Meliniomyces variabilis*, Hyaloscyphaceae sp. I and Helotiaceae sp. III were used. Fungi were grouped on the basis of growth rate and a control treatment was added for each group. From fastest to slowest, the groups were: (1) *P. fortinii* and *C. ericae*; (2) *Chaetosphaeria* sp. and Helotiales VI; (3) Helotiaceae sp. III; (4) *P. sphaeroides*; (5) Heliotiales II; and (6) *M. variabilis*, *C. geophilum* and Dermateaceae I.

Once the fungi neared the edge of the filter or had grown for 37 days, the filters and the mycelia they supported were removed and half of the underlying agar was removed (under sterile conditions). A groove was then made on the newly exposed agar surface in the center of the plate and a 7 to 14 day old seedling was placed in the groove. Seedling age varied only between the previously defined fungal groups. The Petri dishes were closed, sealed with parafilm and placed in a growth chamber with a 16 hour light ($200\mu M \cdot m^{-2} \cdot s^{-1}$) -8 hour dark cycle at a constant 20°C. Humidity in the growth chambers was set at 80%, but varied between 30% and 65%. After 46 days, the plants were processed for root scanning.

Desiccation was a problem for this first experiment and several plants died or showed stunted growth. All living plants were carefully removed from the agar, using 90°C dH_20 for melting excess agar stuck to the roots when necessary. Plants were then scanned on an HP Scanjet 4370 scanner at 1200 dots per inch. These images were analyzed for root length, shoot length, root width and number of root tips using WinRHIZO (2009). After scanning, plants were dried at 75°C for 6 hours and dry weight was measured (plants were too small to measure shoot or root weight separately).

This method involved growing seedlings within the Petri dishes after the fungal mycelia had been removed. This helped reduce contamination as well as the vulnerability of the seedlings to desiccation. By growing the fungi before the plant, any potential influence of fungal respiration (carbon dioxide emitted by the fungi) on plant growth was also eliminated. This proved to be a much more effective and replicable experimental setup than simultaneous plant and fungus inoculation. Appendix 5 contains the methodology and results of an experiment where *B. papyrifera* seedlings were grown simultaneously with an endophyte separated by a polycarbonate filter.

Effects of fungal metabolites on plant growth (experiment II)

This above experiment was repeated with several differences. Firstly the same media was used, but only the water and the agar were autoclaved, while the remainder of the ingredients was filter sterilized into the media. Secondly, only *P. fortinii*, *P. sphaeroides*, Hyaloscyphaceae sp. I , Helotiaceae sp. III , *C. geophilum* and *Armillaria*

ostoyae were used. The root pathogen, *A. ostoyae* was included to compare metabolite production of root endophytic and ectomycorrhizal fungi (*C. geophilum*) to that of a root pathogen. From fastest to slowest, the fungal groups were processed as: (1) *P. sphaeroides*; (2) *P. fortinii* and Hyaloscyphaceae sp. I (*P. fortinii* was actually the fastest growing fungus, but grew beyond the filter too quickly; Petri dishes were inoculated with *P. fortinii* a second time and the fungus approached the edge of the filter at the same time as Hyaloscyphaceae sp. I); (3) Helotiaceae sp. III , *C. geophilum* and *A. ostoyae*. Other differences in experimental setup included the fact that the fungi were grown for up to 7 weeks, trays of water were added to the growth chambers to keep the humidity between 50% and 60%, plants were grown on the media for 5 weeks instead of 47 days and finally eight replicates per treatment were used in order to have three to five replicates for root scanning and up to three replicates for microscopic analyses. The final number of seedlings used for root scanning and weighing or microscopy depended on the losses due to contamination. Replicates were randomly assigned for microscopy or root scanning and plant weighing.

Microscopy

A single root tip was removed from each seedling for root microscopy analysis. Roots were serially washed in 25%, 50% and 70% ethanol for 20 minutes, 99% ethanol for 1hour and then citrisolv© overnight. Roots were then placed in a tray of molten wax and left in overnight with a single wax change. Roots were then placed up right within the

tray with the root tip touching the bottom, attached to a plastic mould and frozen for sectioning. Sections were collected beginning at 200μm from the root tip and were 6μm thick. Sections were then placed on slides, which were serially washed in two citrisolv containers for 5 minutes and followed by 100%, 100%, 90%, 80%, 70%, 50% ethanol baths for 1 minute each and then into distilled H_2O to remove the wax and prepare for staining. Once in dH_2O, slides were stained with Toluidene blue for 1 min, the excess stain was removed and a cover slip was added for observation under the microscope. An image of the clearest root section was taken to measure the area of the root section and the average area of the cortical cells (Figure 2). The ten first cells to cross the vertical and horizontal axes were measured. If less than ten cells crossed the axes, the image was rotated 45 degrees clockwise and the process was repeated.

Assessment of IAA production

Fungi were tested for the production of indole acetic acid (IAA) and IAA-like compounds in liquid media using Salkowski's reagent (Glickmann and Desseaux 1995) three different times (Salkowski experiments I, II and III). Single mycelial plugs (5mm) of six different fungi (*P. fortinii*, *P. sphaeroides*, Hyaloscyphaceae sp. I , Helotiaceae sp. III , *C. geophilum* and *A. ostoyae*), were inoculated into 40mL of media in a 125mL polycarbonate Erlenmeyer flask with a 0.2μm filter for gas exchange. Media was prepared by adding 10g dextrose, 0.5g $MgSO_4 \cdot 7H_2O$, 1g KH_2PO_4, 0.2g $CaCl_2$, 0.8g $(NH_4)_2SO_4$ and 0.2g of L-tryptophan per liter of dH_2O, buffered with 50mM of MES

titrated at pH 6.0; initial pH of the media was 5.9. Media was sterilized by filter sterilizing 25% of the dH_2O containing dextrose, L-tryptophan and MES into autoclaved dH_2O with the remainder of the ingredients. After inoculation, flasks were placed on a shaker in the dark at 23°C and 80rpm for 2-4 weeks. The liquid media was filtered through a 0.2μm syringe filter and tested with Salkowski's reagent. Fungal mass was determined every week for three weeks (after the first two weeks of growth). There were three replicates for each treatment and each sampling time. Controls were liquid media inoculated with a 5mm malt agar plug.

Two different preparations of Salkowski reagents were made based on recommendations by Glickman and Desseaux (1995). The first, PC, was prepared by dissolving 12g $FeCl_3$ per L of 7.9 M H_2SO_4. The second, S2/1, was prepared by dissolving 4.5g $FeCl_3$ per L of 10.8 M H_2SO_4. PC can be used to reliably detect differences in small amounts of indole compounds between 0 and 200μg/mL, but is ineffective at distinguishing differences in higher concentration. On the other hand, S2/1 is most effective at determining the concentration of IAA or IAA- like compounds above 200μg/mL. Absorbance was measured at 530nm using a BioTek® Synergy HT microplate reader. Samples were loaded on a clear LINBRO conical bottom 96-well microplate in triplicate. A twelve-well dilution series using the control media and IAA dissolved in 1M NaOH was made between the concentrations of 160μg/mL and 0.078μg/mL of IAA where the concentration was diminished by half in each adjacent well. For the PC reagent,

100µL of a sample (or standard) and 100µL of PC was loaded in each well. For the S2/1 reagent, 50µL of a sample or standard and 100µL of S2/1 was loaded in each well.

Micrograms of indole compounds produced per mg of fungal dry weight was also calculated. To do so, all triplicate wells were averaged. However, the wells A5, A12, C2, C8, E1, F7, H3 and H5 were not used in the analyses since they were consistently and considerably higher or lower than the adjacent wells for each analysis. The mean value of the control was then subtracted from all other values and the dilution series was plotted to obtain a calibration curve and the equation of the logarithmic curve (for the PC reagent) or straight line (for the S2 reagent) was used to estimate the amount of indole compound produced by each sample. This value was then divided by the dry weight of the same sample to compare the potential amount of IAA produced per milligram of endophyte biomass. These data were used in a correlation analysis with the average cortical cell size from the microscopy portion of the previously described experiment. These analyses were only conducted at the 14-day collection time where the most significant differences were observed.

Several replicates were lost to contamination and the experiment was therefore repeated twice (Salkowski experiments II and III). It was first repeated (Salkowski experiment II) with *Phialocephala sphaeroides*, Hyaloscyphaceae sp. I and Helotiaceae sp. III , using with five replicates at each collection time in order to increase the statistical power. These fungi were selected because they are the three most likely endophytes to

make IAA or IAA-like compounds based on the results of the growth experiments. Collection times were at five, 11 and 14 days. It was then repeated again (Salkowski experiment III) with Hyaloscyphaceae sp. I and Helotiaceae sp. III with a single collection time at 14 days, and with 5 replicates. For this last experiment, liquid cultures were static rather than shaken.

Statistical analysis

For birch seedling weight and length measurements, differences between the means were assessed via a one-way ANOVA using SPSS using Tukey's post-hoc test when significant. Root length data were log transformed to obtain an approximately normal distribution. Differences in root cortical cell measurements between control and experimental treatments were also assessed via one-way ANOVA in SPSS. Cortical cell area and root section area were log transformed.

Results

In Experiment I, plants grown in the metabolites of *Cryptosporiopsis ericae* and Helotiaceae sp. III had significantly lower total biomass and root length than the control (Table 2). Plants grown in *C. ericae* metabolites also had a smaller number of tips. Plants grown in *Phialocephala sphaeroides* metabolites had larger roots than the control. Plants grown in Hyaloscyphaceae sp. I metabolites had significantly shorter roots than the

control, but had a larger total biomass and larger roots. All other treatments showed no significant differences.

In Experiment II, only plants grown in *P. sphaeroides* metabolites had significantly higher total biomass, root length and root width (Table 3). Plants grown in *P. fortinii* metabolites had thinner roots (nearly significantly; p=0.056). Differences in cortical cell area or root section area were not significant between treatments because of the large variation in response and low sample sizes (Table 4). However, some trends were observed; roots of plants grown in *P. sphaeroides* metabolites had on average a much larger section area, plants grown in Hyaloscyphaceae sp. I and especially Helotiaceae sp. III metabolites had larger cortical cell area as well as a larger root section area, whereas plants grown in *A. ostoyae*, *C. geophilum* and *P. fortinii* metabolites had smaller cortical sizes and root section area.

Trends in the optical density (OD) of the liquid cultures of the fungi were similar between the PC and S2 Salkowski reagents for all three Salkowski experiments (Figures 3-5). For Salkowski experiment I, Helotiaceae sp. III had the highest mean OD. It was significantly different from the other fungi at two weeks with the PC reagent, but not from Hyaloscyphaceae sp. I or *P. sphaeroides* with the S2 reagent. For weeks three and four, as well as overall, there were few significant differences between treatments. Only *P. sphaeroides* had a lower OD than some or all of the treatments depending on the week and Salkowski reagent used. For Salkowski experiment II, Hyaloscyphaceae sp. I had a

significantly higher OD at 14 days with the PC reagent and at 8 days and overall with the S2 reagent. No significant differences were observed between the treatments for Salkowski experiment III. The estimated amount of indole compound produced per milligram mycelium is found on Table 5. A significant positive correlation was noted between the amount of produced indole compound per milligram mycelium and cortical cell size for the first two Salkowski Experiments (Salkowski Experiment I: $r= 0.793$, $n=14$, $p=0.0007$; Salkowski Experiment II: $r=0.564$, $n=18$, $p=0.0147$). No correlation was calculated for the third attempt as only two species were used.

Discussion

As seen from the results of the meta-analysis in chapter 1, the effect of root endophyte colonization on plant growth is generally neutral, but variable and dependent on the experimental conditions. This pattern is reflected in the present experiments conducted on the effects of root fungal metabolites on plant growth. The metabolites of most species had no effect on plant biomass or root or shoot length. The metabolites of *Phialocephala sphaeroides* most consistently caused an increase in plant biomass and root length; plants grown in *P. sphaeroides* metabolites were considerably larger than the control in Experiment II. Similar results were also seen for *B. papyrifera* seedlings grown in Hyaloscyphaceae sp. I metabolites in Experiment I, although in this case control plants had much longer roots. Only the metabolites from Helotiaceae sp. III and

Cryptosporiopsis ericae resulted in plants significantly smaller than controls. These results were observed only for Experiment I, in which many replicates were subjected to water stress due to low humidity levels within the growth chamber. The genus *Cryptosporiopsis* is known to produce a number of biologically active compounds including herbicides (Schulz et al. 1995) and *C. ericae* produces anti-fungal compounds in solid culture (Mayerhofer and Kernaghan, unpublished data). Also, unlike the other endophytes used here, the *C. ericae* isolate was not isolated from *B. papyrifera.* It is also a possibility that the conditions in Experiment I were more favorable for IAA production. Adequate levels of IAA can stop root elongation and promote cell expansion but high levels of IAA will inhibit root growth (Tanimoto 2005), as was possibly observed for seedlings grown in Hyaloscyphaceae sp. I and Helotiaceae sp. III metabolites respectively. In Experiment I, plants grown in Hyaloscyphaceae sp. I showed increased biomass and root diameter compared to the control whereas plants grown in Helotiaceae sp. III metabolites had a smaller biomass.

The variability in plant response to fungal root endophyte metabolites was most apparent in root sections observed under the microscope. The average cortical cell size and total area the of root cross sections were larger in *P. sphaeroides* and Helotiaceae sp. III treatments than in control plants, but this was not statistically significant due to the very large standard deviation. Similar variability was seen with Helotiaceae sp. III in the experiments assessing the production of indole compounds using the Salkowski reagent. Only during certain experiments or collection times was Helotiaceae sp. III seen to

produce indole compounds at significantly greater levels than controls based on optical density. Although the optical density was not always significantly different from the control, it was consistently higher despite the small size of Helotiaceae sp. III colonies in liquid culture. Although variable, the potential of Helotiaceae sp. III to produce indole compounds was therefore very high, and second only to that of Hyaloscyphaceae sp. I overall. Indole production by Hyaloscyphaceae sp. I was also variable, likely explaining the inconsistency in seedling response to the metabolites from this fungus as well.

The interaction between plants and endophytes and even the diversity of compounds produced by fungal endophytes is isolate-dependent (Schulz et al. 1995; Sieber 2002; Tellenbach et al. 2011). Results for some of the species presented here show variability within the same isolates, particularly Hyaloscyphaceae sp. I and Helotiaceae sp. III. This may be an indication that production of secondary metabolites affecting root morphology may be dependent on factors that were not considered in these experiments. For instance, IAA is an unstable molecule (Barker and Tagu 2000) and it is possible that an uneven breakdown of IAA molecules occurred throughout these experiments. Furthermore, plant response to IAA is also variable. For example, ectomycorrhizal-like structures can be induced in *Pinus* sp. roots (Gogala 1991; Barker and Tagu 2000), but they can also occur spontaneously. These structures cannot be reproduced with as much consistency in angiosperms such as *Eucalyptus* sp. (Barker and Tagu 2000). IAA also interacts with many other phytohormones to modulate plant growth such as cytokinins and ethylene (Gogala 1991; Barker and Tagu 2000; Woodward and Bartel 2005); the

complexity of these interactions combined with the variability in production of and response to phytohormones may be the underlying cause of the variation seen in here.

Conversely, variation in *P. sphaeroides* treatments was comparable to and often lower than the control in most experiments, with the notable exception of the average root section size in the microscopy observations. Evidence here suggests that *P. sphaeroides* did not produce IAA or similar compounds, despite significantly increasing overall plant biomass, root length and root width. Microscopic observations of root sections grown in *P. sphaeroides* metabolites indicate that increased cell production, rather than an increase in the size of individual cells, underlies the overall increase in root size. Increased cortical cell size, or cortical hypertrophy, would indicate an influence of IAA on root growth (Barker and Tagu 2000). Interestingly, the indole content of *P. sphaeroides* metabolites seemed to decrease relative to the control over time (after 2 weeks). This may be due to the heavily melanized secondary metabolites of *P. sphaeroides*; dark-coloured compounds may have interfered with the absorbance readings at later stages of fungal growth. It is also possible that IAA was present in the metabolites, but in concentrations lower than the detectable limit of the Salkowski reagent. The lowest detectable limit was about 2ug/ml (3.5μM) whereas the optimal concentration of IAA for root growth is considerably lower; applied exteriorly it is 1 nM and typical endogenous concentration range from 30-130pg/mg fresh weight of *Arabidopsis thaliana* (Tanimoto 2005). Nevertheless, evidence here indicates that plant growth by *P. sphaeroides* metabolites is not due to IAA, but likely an unknown plant growth-promoting substance or regulator.

Many questions remain to be answered with respect to the production of secondary metabolites by fungal root endophytes in order to understand how these ubiquitous organisms interact with their hosts and their environments. The experiments conducted here indicate that plant response to the metabolites of root fungal endophytes is generally neutral under these experimental conditions but variable for certain species, notably Hyaloscyphaceae sp. I and Helotiaceae sp. III. Similar conclusions can be made about IAA production. *P. sphaeroides* metabolites likely promote plant growth via mechanism other than IAA production. These results are consistent with chapter 1 as well as data from the primary literature.

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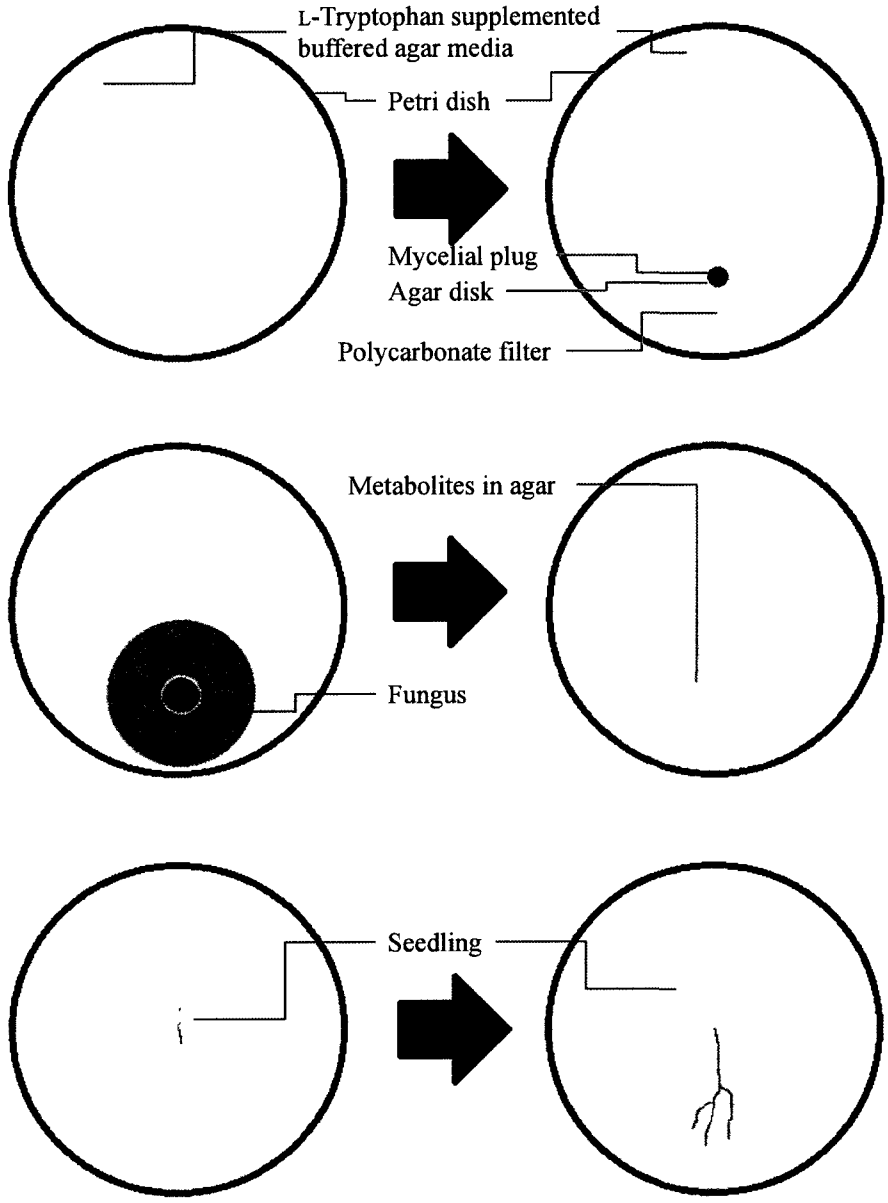

Figure 1. Diagram indicating the different steps into testing the effects of fungal metabolites when fungi are grown on buffered agar media supplemented with L-tryptophan. In this case, *B. papyrifera* seedlings and the fungi were grown separately to keep the seedlings contained in the Petri dish. Simultaneous growth in a closed environment may cause a biomass increase in the seedling due to the carbon dioxide produced by the fungus. Notice that the fungus was removed at the fourth step, revealing the metabolites beneath the filter.

Figure 2. Root cross section of a *Betula papyrifera* seedling grown in the metabolites of Hyaloscyphaceae sp. I. *Cortical cell.

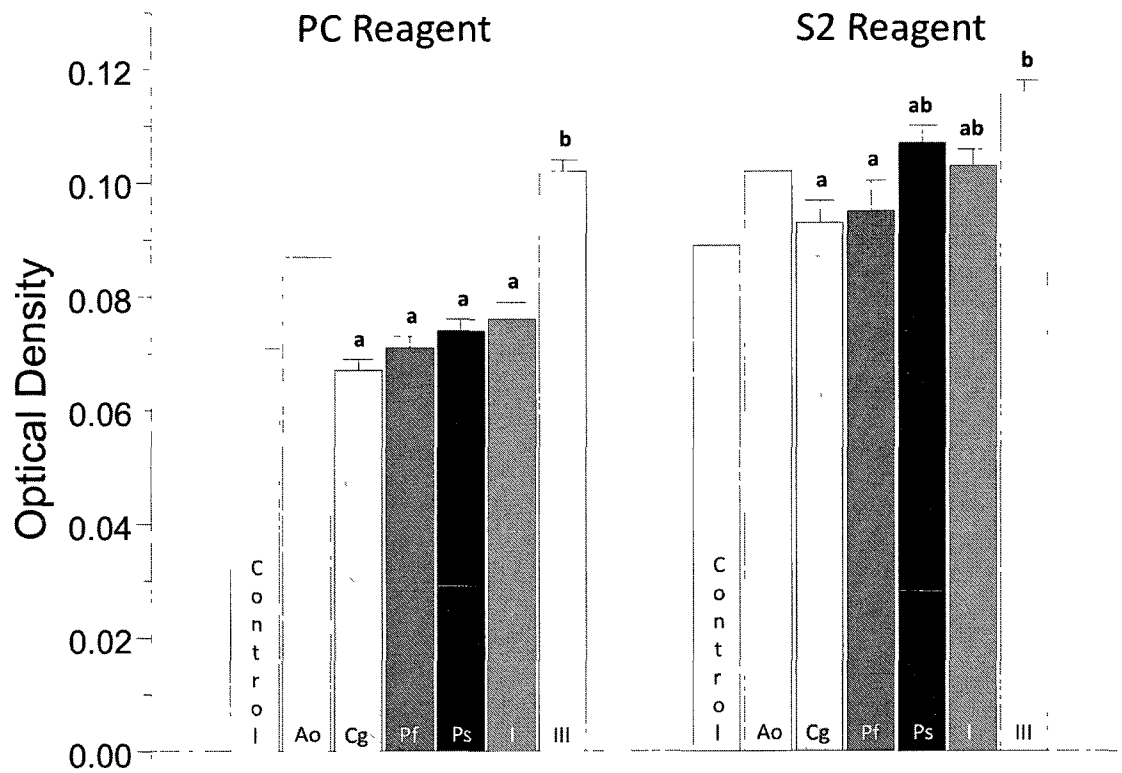

Figure 3. Salkowski experiment I. Optical density at 530nm of the liquid media combined with the PC or S2 Salkowski reagent in which control media, *Armillaria ostoyae* (Ao), *Cenoccocum geophilum* (Cg), *Phialocephala fortinii* (Pf), *Phialocephala sphaeroides* (Ps), Hyaloscyphaceae sp. I (I) and Helotiaceae sp. III (III) were grown. Letters indicate Tukey test groups. Data are for the repetition of the Salkowski experiments at the 2-week collection time. Sample size for the treatments are: Control 1, Ao 1, Cg 2, Pf 2, Ps 3, I 3, III 3.

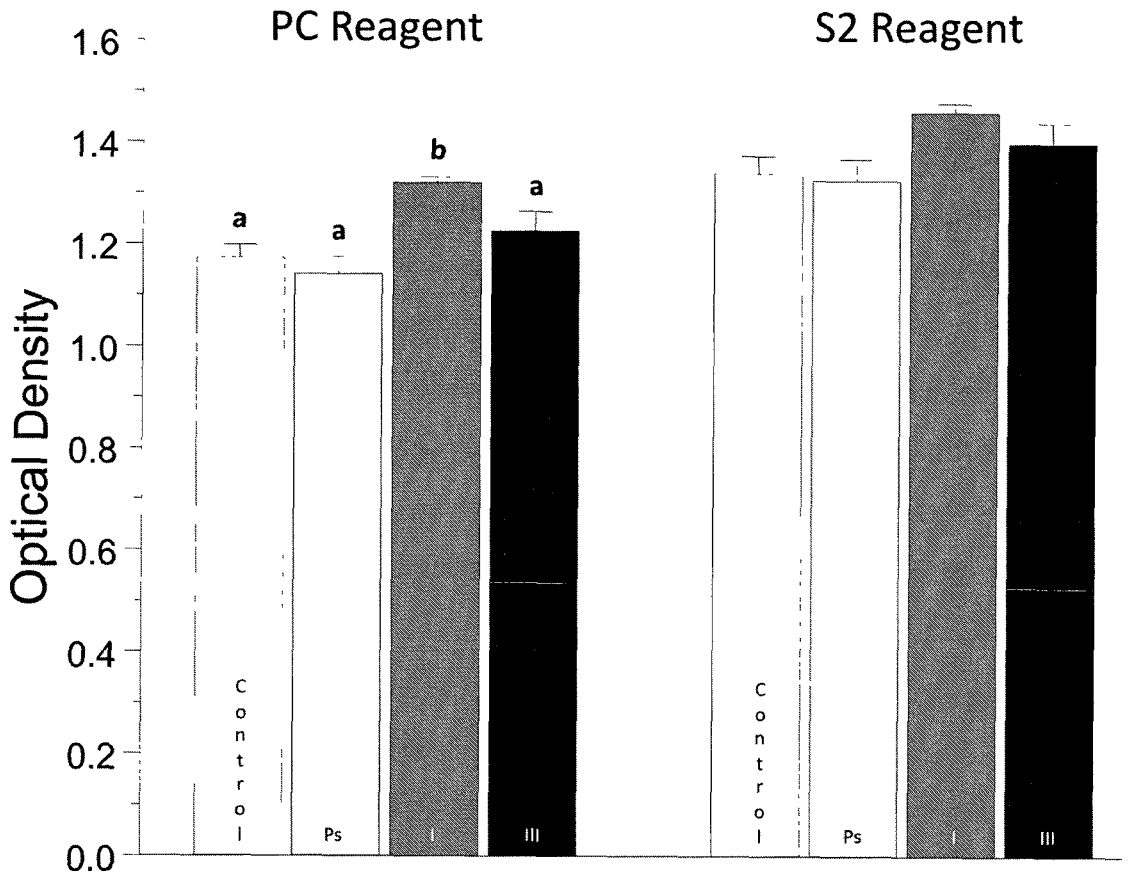

Figure 4. Salkowski experiment II. Optical density at 530nm of the liquid media combined with the PC or S2 Salkowski reagent in which control media, *Phialocephala sphaeroides* (Ps), Hyaloscyphaceae sp. I (I) and Helotiaceae sp. III (III) were grown. Letters indicate Tukey test groups. Data are for the 2-week collection time. Sample sizes for the treatments are as follows: Control 5, Ps 6, I 6, III 6.

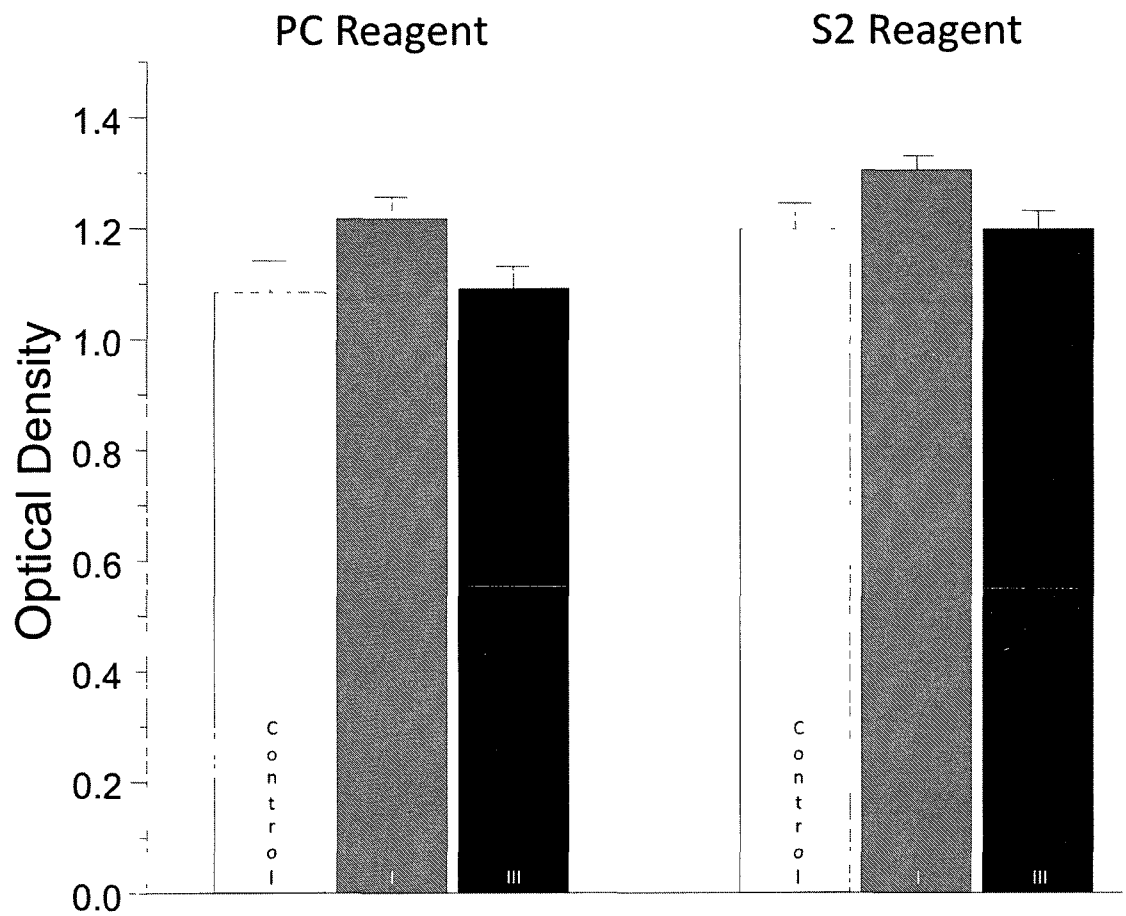

Figure 5. Salkowski experiment III. Optical density at 530nm of the liquid media combined with the PC or S2 Salkowski reagent in which control media, Hyaloscyphaceae sp. I (I) and Helotiaceae sp. III (III) were grown. Letters indicate Tukey test groups. Sample size = 5 for each treatment.

Table 1. List of fungal isolates used in the simultaneous or separate growth experiments and their Atlantic root symbiosis laboratory (ARSL) and University of Alberta Microfungus Collection and Herbarium (UAMH) accession numbers.

Species	ARSL	UAMH	Isolation	Relationship
Phialocephala fortinii	250507.1		*Betula papyrifera*	Endophyte
Phialocephala sphaeroides	230507.34		*Betula papyrifera*	Endophyte
Cryptosporiopsis ericae	190907.12	11126	*Abies balsamea*	Endophyte
Dermateaceae I	060907.18I		*Betula papyrifera*	Endophyte
Chaetosphaeria sp.	060907.80	11124	*Betula papyrifera*	Endophyte
Helotiaceae sp. III	060907.20		*Betula papyrifera*	Endophyte
Hyaloscyphaceae sp. I	230507.52	11166	*Betula papyrifera*	Endophyte
Meliniomyces variabilis	230507.30I		*Betula papyrifera*	Endophyte
Meliniomyces vraolstadiae	250507.3		*Betula papyrifera*	Endophyte
Cenococcum geophilum	220507.51		*Picea marianna*	Ectomycorrhizal fungus
Armillaria ostoyae	151009.1		Fruiting Body	Root Pathogen

Table 2. Values of analyzed parameters of *B. papyrifera* seedlings grown with fungal metabolites (Experiment I). See materials and methods section for differences between repetitions. Data in bold are significant ($p<0.05$).

	n	Total weight (mg)		Shoot length (cm)		Root length (cm)		Average root diameter (mm)		Number of tips	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group 1											
Control	4	**2.6^{b}**	**0.8**	0.369	0.091	**1.929^{b}**	**0.325**	0.365	0.048	**9.0^{b}**	**0.8**
Cryptosporiopsis ericae	4	**1.3^{a}**	**0.2**	0.266	0.112	**0.788^{a}**	**0.063**	0.356	0.076	**5.5^{a}**	**1.3**
Phialocephala fortinii	5	**2.6^{b}**	**0.3**	0.362	0.051	**1.878^{b}**	**0.228**	0.367	0.055	**7.4^{a,b}**	**2.1**
Group 2											
Control	5	1.7	0.4	0.369	0.116	0.838	0.190	0.358	0.029	6.0	2.5
Chaetosphaeria sp.	3	1.7	0.6	0.340	0.058	1.042	0.235	0.416	0.049	5.7	3.1
Meliniomyces vraolstadiae	2	2.2	0.0	0.376	0.033	1.187	0.072	0.416	0.072	8.5	0.7
Group 3											
Control	4	**2.4^{b}**	**0.4**	0.378	0.139	**2.181^{b}**	**0.601**	0.291	0.020	8.0	3.8
Helotiaceae sp. III	5	**1.2^{a}**	**0.3**	0.303	0.069	**1.225^{a}**	**0.291**	0.305	0.054	4.4	1.5
Group 4											
Control	4	2.8	1.0	0.395	0.069	2.005	0.648	**0.313^{a}**	**0.039**	10.5	4.7
Phialocephala sphaeroides	5	2.6	0.7	0.421	0.095	2.357	1.252	**0.390^{b}**	**0.038**	11.8	8.6

Table 2 (continued from previous page)

	n	Total weight (mg)		Shoot length (cm)		Root length (cm)		Average root diameter (mm)		Number of tips	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group 5											
Control	5	**1.2**[a]	**0.6**	0.353	0.059	**7.481**[b]	**3.985**	**0.217**[a]	**0.019**	9.0	4.2
Hyaloscyphaceae sp. I	5	**2.0**[b]	**0.3**	0.370	0.061	**2.524**[a]	**0.667**	**0.305**[b]	**0.028**	6.8	1.1
Group 6											
Control	2	2.1	0.0	0.424	0.037	2.214	0.490	0.339	0.018	8.0	2.8
Cenococcum geophilum	3	1.6	0.6	0.379	0.147	1.640	0.614	0.328	0.012	11.7	8.1
Meliniomyces variabilis	2	1.8	0.5	0.338	0.101	2.160	0.169	0.337	0.079	10.0	2.8
Dermataceae I	4	2.0	0.4	0.300	0.127	1.570	0.325	0.365	0.044	9.0	1.8

Table 3. Values of analyzed parameters of *B. papyrifera* seedlings grown with fungal metabolites (Experiment II). See materials and methods section for differences between repetitions. Data in bold are significant ($p<0.05$).

	n	Total weight (mg)		Shoot length (cm)		Root length (cm)		Average root diameter (mm)		Number of tips	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group 1											
Control	3	**1.2[a]**	**0.0**	0.379	0.096	**1.297[a]**	**0.347**	**0.321[a]**	**0.034**	**7.3[b]**	**1.2**
Phialocephala sphaeroides	3	**2.5[b]**	**0.1**	0.452	0.030	**2.285[b]**	**0.187**	**0.432[b]**	**0.055**	**4.7[a]**	**0.6**
Group 2											
Control	3	2.1	0.2	0.446	0.127	2.122	0.160	**0.352[b]***	**0.019**	6.7	1.5
Hyaloscyphaceae sp. I	5	1.3	0.6	0.346	0.109	3.037	1.844	**0.301[a, b]***	**0.042**	6.4	2.6
Phialocephala fortinii	5	1.3	0.5	0.299	0.111	1.439	0.711	**0.290[a]***	**0.023**	6.6	3.8
Group 3											
Control	5	1.4	0.2	0.286	0.087	1.141	0.115	0.260	0.060	4.2	1.3
Cenococcum geophilum	5	1.1	0.6	0.314	0.131	1.403	0.270	0.277	0.036	3.2	1.8
Armillaria ostoyae	3	2.1	1.0	0.405	0.116	2.976	2.616	0.233	0.055	7.3	6.8
Helotiaceae sp. III	4	1.4	0.5	0.330	0.052	1.506	0.501	0.279	0.086	6.3	1.9

*p=0.056

Table 4. Average cortical cell size and root section size for *B. papyrifera* seedlings grown with fungal metabolites. No significant differences were observed.

	n	Cortical Cell Area (μm²)		Root Section Area (μm²)	
		Mean	SD	Mean	SD
Group 1					
Control	3	212.35	96.86	36298	1742
Phialocephala sphaeroides	3	245.75	163.03	63884	41435
Group 2					
Control	3	120.64	17.04	31679	7631
Hyaloscyphaceae sp. I	2	190.72	99.53	52041	116
Phialocephala fortinii	1	95.49	0	18121	0
Group 3					
Control	3	128.75	154.02	19329	19529
Armillaria ostoyae	3	75.85	49.34	13835	136
Cenococcum geophilum	3	43.45	30.22	8702	621
Helotiaceae sp. III	3	448.15	597.91	86633	66373

Table 5. Estimated concentration of indole compound ($\mu g \cdot L^{-1}$) produced per mg of fungal dry weight for different fungal species for the PC and S2 Salkowski reagents. Sample sizes are the same as in figures 2, 3 and 4 for attempts 1, 2 and 3 respectively. Standard deviation for *A. ostoyae* could not be calculated since the sample size is 1.

	Attempt #1				Attempt #2				Attempt #3			
	PC		S2		PC		S2		PC		S2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
A. ostoyae	0.18		2.08									
C. geophilum	0.00	0.00	0.66	0.53								
P. fortinii	0.07	0.09	0.82	1.00								
P. sphaeroides	0.05	0.01	1.03	0.56	0.06	0.09	0.12	0.20				
Hyaloscyphaceae sp. I	0.03	0.03	1.43	1.30	0.27	0.02	4.18	0.59	3.77	0.56	45.46	18.91
Helotiaceae sp. III	0.46	0.22	10.47	5.72	0.76	0.81	3.37	4.14	1.36	1.87	9.38	13.04

CHAPTER 4

RESEARCH SYNTHESIS AND CONCLUDING REMARKS

CHAPTER 4: CONCLUSIONS

Plant roots host a diverse microbial community, many of which are common to healthy plants. Many of these organisms, including some fungal root endophytes, promote plant growth or confer other benefits to their host under experimental conditions. The meta-analysis described in Chapter 2 indicates that a number of factors, particularly the identity of the host or endophyte, the addition of carbon to the media and the form of nitrogen are important factors related to a growth increase in endophyte inoculated plants. However, growth increases were the exception and on average endophyte inoculation seemed to have little effect on plant growth. Occasionally a decrease in biomass or nitrogen concentration was observed. These findings may be partially explained by the balanced antagonism theory (Schulz et al. 2002; Schulz and Boyle 2005). According to this theory, the endophyte and the host are never considered to have a neutral relationship. Instead, the characteristic symptomless colonization of the host is due to a balance in the competition between the virulence of the endophyte and the plant defense mechanisms. An endophyte can therefore be a transient stage of a weak latent pathogen or a saprophyte. In certain cases, the relationship can favor the host if the colonization confers benefits such as disease or environmental stress resistance or increased nutrient acquisition. This situation is not unlike the relationship between plants and their mycorrhizal partners, which can range from a mutualism to a parasitism (Karst et al. 2008; Hoeksema et al. 2010).

Conversely, findings from Chapter 3 do not readily support the balanced antagonism theory. Most of the fungi tested did not inhibit plant growth, even when the

plants and fungi were grown simultaneously. Furthermore, *Phialocephala sphaeroides* caused an increase in biomass and changed the root morphology of the host, but did not seem to produce any IAA. Why would a fungus produce a plant growth promoting substance when not colonizing the host if the interaction is bound to be pathogenic? Moreover, the theory does little to explain the variability in plant response observed in both Chapters 2 and 3. Finally, the simplicity of the balanced antagonism theory may be adequate to explain some of the interactions between a single endophytic species and its host, but would benefits observed *in vitro* hold true in nature? I believe that the balanced antagonism theory only holds true for latent pathogens. Rather than being virulent antagonists, endophytes may be minor pathogens, parasites, perthophytes or mutualists, better adapted to living within plant tissue than outside it. After all, the soil is a hostile environment bountiful with roots and even typically non-endophytic species are frequently isolated from surface sterilized plant roots. Benefits to the host may have evolved from these fungi as a means of increasing their survival by prolonging their evasion of soil. Colonization prior to plant senescence would also be an advantage for endophytes with saprophytic capabilities; they would be the first in line to decompose the root tissue. Production of phytohormones like IAA would also be beneficial to endophytic fungi through the modification of cell and root morphologies to ease the colonization process.

The overall neutral response *in vitro*, but ubiquity and diversity of these organisms in nature, lead me to believe that they are opportunistic organisms adept at

colonizing plant tissue without any real detriments to their host. Root systems are colonized by a diverse array of fungal endophytes, all of which interact with the plant and with each other. Only future research will validate or invalidate current theories regarding the true relationships involved. Until then, we can only speculate on the ecological functions of fungal root endophytes.

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APPENDIX 1

DATA COLLECTED FOR THE STUDIES USED IN THE META-ANALYSIS

Table 1. List of publications with associated study number (#). Full references are presented after this table.

#	Publication
1	Alberton et al. (2010)
2	Alberton et al. (2010)
3	Alberton et al. (2010)
4	Alberton et al. (2010)
5	Alberton et al. (2010)
6	Alberton et al. (2010)
7	Alberton et al. (2010)
8	Cameron (1998)
9	Currah et al. (1993)
10	Currah et al. (1993)
11	Fernando and Currah (1996)
12	Fernando and Currah (1996)
13	Fernando and Currah (1996)
14	Fernando and Currah (1996)
15	Fernando and Currah (1996)
16	Fernando and Currah (1996)
17	Fernando and Currah (1996)
18	Fernando and Currah (1996)
19	Fernando and Currah (1996)
20	Fernando and Currah (1996)
21	Fernando and Currah (1996)
22	Fernando and Currah (1996)
23	Fernando and Currah (1996)
24	Fernando and Currah (1996)
25	Fernando and Currah (1996)
26	Gasoni and deGurfinkel (1997)
27	Haselwandter and Read (1982)
28	Haselwandter and Read (1982)
29	Haselwandter and Read (1982)
30	Haselwandter and Read (1982)
31	Hashimoto and Hyakumachi (2001)
32	Hashimoto and Hyakumachi (2001)
33	Jumpponen et al. (1998)
34	Jumpponen et al. (1998)
35	Jumpponen et al. (1998)
36	Jumpponen et al. (1998)
37	Jumpponen and Trappe (1998)
38	Jumpponen and Trappe (1998)

Table 1 (continued from previous page).

#	Publication
39	Maciá-Vicente et al. (2008)
40	Maciá-Vicente et al. (2008)
41	Maciá-Vicente et al. (2008)
42	Maciá-Vicente et al. (2008)
43	Maciá-Vicente et al. (2008)
44	Maciá-Vicente et al. (2008)
45	Maciá-Vicente et al. (2008)
46	Maciá-Vicente et al. (2008)
47	Maciá-Vicente et al. (2008)
48	Maciá-Vicente et al. (2008)
49	Maciá-Vicente et al. (2008)
50	Maciá-Vicente et al. (2008)
51	Maciá-Vicente et al. (2008)
52	Maciá-Vicente et al. (2008)
53	Maciá-Vicente et al. (2008)
54	Mandyam et al. (2010)
55	Mandyam et al. (2010)
56	Mandyam et al. (2010)
57	Mandyam et al. (2010)
58	Mandyam et al. (2010)
59	Mandyam et al. (2010)
60	Mandyam et al. (2010)
61	Mandyam et al. (2010)
62	Mandyam et al. (2010)
63	Mandyam et al. (2010)
64	Mandyam et al. (2010)
65	Newsham (1994)
66	Newsham (1999)
67	Newsham (1999)
68	Perez-Naranjo (2010)
69	Perez-Naranjo (2010)
70	Perez-Naranjo (2010)
71	Perez-Naranjo (2010)
72	Perez-Naranjo (2010)
73	Perez-Naranjo (2010)
74	Perez-Naranjo (2010)
75	Perez-Naranjo (2010)
76	Perez-Naranjo (2010)
77	Perez-Naranjo (2010)

Table 1 (continued from previous page).

#	Publication
78	Perez-Naranjo (2010)
79	Perez-Naranjo (2010)
80	Perez-Naranjo (2010)
81	Perez-Naranjo (2010)
82	Perez-Naranjo (2010)
83	Richard and Fortin (1974)
84	Richard and Fortin (1974)
85	Richard and Fortin (1974)
86	Richard and Fortin (1974)
87	Richard and Fortin (1974)
88	Richard and Fortin (1974)
89	Richard and Fortin (1974)
90	Richard and Fortin (1974)
91	Richard et al. (1971)
92	Richard et al. (1971)
93	Ruotsalainen and Kytöviita (2004)
94	Schulz and Boyle (2006)
95	Schulz and Boyle (2006)
96	Schulz et al. (2002)
97	Schulz et al. (1999)
98	Stoyke and Currah (1993)
99	Upson et al. (2009)
100	Upson et al. (2009)
101	Upson et al. (2009)
102	Upson et al. (2009)
103	Upson et al. (2009)
104	Upson et al. (2009)
105	Upson et al. (2009)
106	Upson et al. (2009)
107	Upson et al. (2009)
108	Upson et al. (2009)
109	Upson et al. (2009)
110	Upson et al. (2009)
111	Usuki and Narisawa (2005)
112	Usuki and Narisawa (2005)
113	Usuki and Narisawa (2005)
114	Usuki and Narisawa (2005)
115	Usuki and Narisawa (2005)
116	Usuki and Narisawa (2007)

Table 1 (continued from previous page).

#	Publication
117	Usuki and Narisawa (2007)
118	Usuki and Narisawa (2007)
119	Usuki and Narisawa (2007)
120	Usuki and Narisawa (2007)
121	Usuki and Narisawa (2007)
122	Violi et al. (2007)
123	Vohník et al. (2005)
124	Vohník et al. (2005)
125	Vohník et al. (2005)
126	Vohník et al. (2003)
127	Vohník et al. (2003)
128	Vohník et al. (2003)
129	Vohník et al. (2003)
130	Wu and Guo (2008)
131	Wu et al. (2010)
132	Yu (2000)
133	Yu (2000)

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Table 2. Order, family, genus, species and strain of the root endophyte used in associated study (#).

#	Fungal order	Fungal family	Fungal genus	Fungal species	Fungal strain
1	Helotiales	*Incertae sedis*	*Cadophora*	*Cadophora finlandica*	CBS 444.86
2	Chaetosphaeriales	Chaetosphaeriaceae	*Chloridium*	*Chloridium paucisporum*	CBS 445.86
3	Helotiales	Helotiaceae	*Meliniomyces*	*Meliniomyces vraolstadiae*	UAMH 10111
4	Helotiales	Helotiaceae	*Meliniomyces*	*Meliniomyces variabilis*	UAMH 8861
5	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	CBS 109300
6	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	CBS 179.46
7	Helotiales	Incertae sedis	*Scytalidium*	*Scytalidium vaccinii*	CBS 652.89
8	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 8148
9	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	TMI 32109
10	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	TMI 32110
11	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 5422
12	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 5422
13	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 5422
14	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8149
15	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8149
16	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8149
17	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8151
18	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8151
19	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8151
20	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8152
21	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8152

DSE: Unidentified dark septate endophyte

Table 2 (continued from previous page).

#	Fungal order	Fungal family	Fungal genus	Fungal species	Fungal strain
22	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium orchidicola*	UAMH 8152
23	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 8148
30	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	C2
31	*Incertae sedis*	*Incertae sedis*	DSE	DSE	DSB-1
32	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	DSB-2
33	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	SE24
34	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	SE24
35	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	SE24
36	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	SE24
24	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 8148
25	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 8148
26	Sordariales	Lasiosphaeriaceae	*Cladorrhinum*	*Cladorrhinum foecundissimum*	S8 and A32
27	*Incertae sedis*	*Incertae sedis*	DSE	DSE	C1
28	*Incertae sedis*	*Incertae sedis*	DSE	DSE	C1
29	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	C2
37	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	CBS 443.86
38	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	SE24
39	Hypocreales	*Incertae sedis*	*Acremonium*	*Acremonium blochii*	14/1.2.1
40	Hypocreales	*Incertae sedis*	*Acremonium*	*Acremonium furcatum*	21/1.3.1
41	Hypocreales	*Incertae sedis*	*Aspergillus*	*Aspergillus fumigatus*	26/1.1.1
42	Hypocreales	*Incertae sedis*	*Cylindrocarpon*	*Cylindrocarpon* sp.	17/1.4.2
43	Hypocreales	*Incertae sedis*	*Cylindrocarpon*	*Cylindrocarpon destructans*	3/1.3.1

DSE: Unidentified dark septate endophyte

Table 2 (continued from previous page).

#	Fungal order	Fungal family	Fungal genus	Fungal species	Fungal strain
44	Helotiales	*Incertae sedis*	*Dactylaria*	*Dactylaria* sp.	10/1.3.1
45	Hypocreales	Nectriaceae	*Fusarium*	*Fusarium equiseti*	10/3.3.1
46	Hypocreales	Nectriaceae	*Fusarium*	*Fusarium equiseti*	28/3.2.1
47	Hypocreales	Nectriaceae	*Fusarium*	*Fusarium equiseti*	34/2.1.1
48	Hypocreales	Nectriaceae	*Fusarium*	*Fusarium equiseti*	45/1.2.1
49	Hypocreales	Nectriaceae	*Fusarium*	*Fusarium equiseti*	51/1.2.1
50	Pleosporales	*Incertae sedis*	*Phoma*	*Phoma herbarum*	9/3.6.1
51	Pleosporales	*Incertae sedis*	*Phoma*	*Phoma leveillei*	4/3.3.2
52	Pleosporales	*Incertae sedis*	*Phoma*	*Phoma leveillei*	61/3.2.1
53	*Incertae sedis*	*Incertae sedis*	Unk	Unk	10/1.5.1
54	*Incertae sedis*	*Incertae sedis*	DSE	DSE	KS0001
55	Xylariales	*Incertae sedis*	*Microdochium*	*Microdochium* sp.	KS0012
56	Xylariales	*Incertae sedis*	*Microdochium*	*Microdochium* sp.	KS0012
57	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0019
58	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0019
59	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0045
60	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0058
61	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0060
62	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0093
63	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0100
64	Pleosporales	*Incertae sedis*	*Periconia*	*Periconia macrospinosa*	KS0100

DSE: Unidentified dark septate endophyte
Unk: Unidentified endophyte

Table 2 (continued from previous page).

#	Fungal order	Fungal family	Fungal genus	Fungal species	Fungal strain
65	Pleosporales	*Incertae sedis*	*Phoma*	*Phoma fimeti*	IMI 353511
66	Chaetothyriales	Herpotrichiellaceae	*Phialophora*	*Phialophora graminicola*	*Phialophora graminicola*
67	Chaetothyriales	Herpotrichiellaceae	*Phialophora*	*Phialophora graminicola*	*Phialophora graminicola*
68	Helotiales	*Incertae sedis*	Unk	Unk	AC1
69	Helotiales	*Incertae sedis*	Unk	Unk	AC1
70	Helotiales	*Incertae sedis*	Unk	Unk	AC1
71	Pleosporales	*Incertae sedis*	Unk	Unk	AC4
72	Pleosporales	*Incertae sedis*	Unk	Unk	AC4
73	Pleosporales	*Incertae sedis*	Unk	Unk	AC4
74	Pleosporales	*Incertae sedis*	Unk	Unk	BG17
75	Pleosporales	*Incertae sedis*	Unk	Unk	BG17
76	Pleosporales	*Incertae sedis*	Unk	Unk	BG17
77	Pleosporales	*Incertae sedis*	Unk	Unk	PJ2
78	Pleosporales	*Incertae sedis*	Unk	Unk	PJ2
79	Pleosporales	*Incertae sedis*	Unk	Unk	PJ2
80	Pleosporales	*Incertae sedis*	Unk	Unk	PJ5
81	Pleosporales	*Incertae sedis*	Unk	Unk	PJ5
82	Pleosporales	*Incertae sedis*	Unk	Unk	PJ5
83	*Incertae sedis*	*Incertae sedis*	DSE2	DSE2	Mra 150
84	*Incertae sedis*	*Incertae sedis*	DSE	DSE	Mra 153
85	*Incertae sedis*	*Incertae sedis*	DSE	DSE	Mra 158

DSE: Unidentified dark septate endophyte
Unk: Unidentified endophyte

Table 2 (continued from previous page).

#	Fungal order	Fungal family	Fungal genus	Fungal species	Fungal strain
86	*Incertae sedis*	*Incertae sedis*	DSE	DSE	Mra 160
87	*Incertae sedis*	*Incertae sedis*	DSE	DSE	Mra 161
88	*Incertae sedis*	*Incertae sedis*	DSE	DSE	Mra 164
89	*Incertae sedis*	*Incertae sedis*	DSE	DSE	Mra 176
90	*Incertae sedis*	*Incertae sedis*	DSE	DSE	Mra 56
91	*Incertae sedis*	*Incertae sedis*	DSE	DSE	MRA
92	*Incertae sedis*	*Incertae sedis*	DSE	DSE	MRA
93	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	SE24
94	Helotiales	Dermateaceae	*Cryptosporiopsis*	*Cryptosporiopsis* sp.	*Cryptosporiopsis* sp.
95	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	*Phialocephala fortinii*
96	Chaetothyriales	Herpotrichiellaceae	*Phialophora*	*Phialophora* sp.	*Phialophora* sp.
97	Hypocreales	Nectriaceae	*Fusarium*	*Fusarium* sp.	*Fusarium* sp.
98	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 6677
99	*Incertae sedis*	*Incertae sedis*	DSE	DSE	C4
100	*Incertae sedis*	*Incertae sedis*	DSE	DSE	C4
101	*Incertae sedis*	*Incertae sedis*	*Mollisia*	*Mollisia* sp.	H3
102	*Incertae sedis*	*Incertae sedis*	*Mollisia*	*Mollisia* sp.	H3
103	Helotiales	Dermateaceae	*Mollisia*	*Mollisia* sp.	H4
104	Helotiales	Dermateaceae	*Mollisia*	*Mollisia* sp.	H4
105	Helotiales	Dermateaceae	*Oculimacula*	*Oculimacula yallundae*	I4
106	Helotiales	Dermateaceae	*Oculimacula*	*Oculimacula yallundae*	I4

DSE: Unidentified dark septate endophyte
MRA: *Mycelium radicis atrovirens*

Table 2 (continued from previous page).

#	Fungal order	Fungal family	Fungal genus	Fungal species	Fungal strain
107	Helotiales	Dermateaceae	*Tapesia*	*Tapesia* sp.	C7
108	Helotiales	Dermateaceae	*Tapesia*	*Tapesia* sp.	C7
109	Helotiales	Dermateaceae	*Tapesia*	*Tapesia* sp.	I9
110	Helotiales	Dermateaceae	*Tapesia*	*Tapesia* sp.	I9
111	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	BcaHE2
112	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	BPM3
113	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	H4007
114	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	OGR3
115	*Incertae sedis*	Myxotrichaceae	*Oidiodendron*	*Oidiodenron maius*	E97053
116	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	H4007
117	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	H4007
118	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	H4007
119	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	H4007
120	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	H4007
121	Capnodiales	Antennulariellaceae	*Heteroconium*	*Heteroconium chaetospira*	H4007
122	Sordariales	Chaetomiceae	*Chaetomium*	*Chaetomium elatum*	*Chaetomium elatum*
123	*Incertae sedis*	Myxotrichaceae	*Oidiodendron*	*Oidiodendron maius*	*Oidiodendron maius* B
124	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	*Phialocephala fortinii* F
125	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	*Phialocephala fortnii* H
126	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	CBS 554.86
127	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	CBS 554.86
128	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 8433
129	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 8433

Table 2 (continued from previous page).

#	Fungal order	Fungal family	Fungal genus	Fungal species	Fungal strain
130	Helotiales	*Incertae sedis*	*Leptodontidium*	*Leptodontidium* sp.	EF-M
131	Pleosporales	*Incertae sedis*	*Mycocentrospora*	*Mycocentrospora* sp.	EF-37
132	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 9525
133	Helotiales	Vibrisseaceae	*Phialocephala*	*Phialocephala fortinii*	UAMH 9525

Table 3. Growth habit, group, family, genus and species of host plant used in associated study (#).

#	Growth habit	Host group	Host family	Host genus	Host species
1	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus sylvestris*
2	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus sylvestris*
3	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus sylvestris*
4	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus sylvestris*
5	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus sylvestris*
6	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus sylvestris*
7	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus sylvestris*
8	Tree	Dicot	Salicaceae	*Populus*	*Populus tremuloides*
9	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron brachycarpum*
10	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron brachycarpum*
11	Shrub	Dicot	Rosaceae	*Dasiphora*	*Dasiphora fruticosa*
12	Shrub	Dicot	Rosaceae	*Dryas*	*Dryas octopetala*
13	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea glauca*
14	Shrub	Dicot	Rosaceae	*Dasiphora*	*Dasiphora fruticosa*
15	Shrub	Dicot	Rosaceae	*Dryas*	*Dryas octopetala*
16	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea glauca*
17	Shrub	Dicot	Rosaceae	*Dasiphora*	*Dasiphora fruticosa*
18	Shrub	Dicot	Rosaceae	*Dryas*	*Dryas octopetala*
19	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea glauca*
20	Shrub	Dicot	Rosaceae	*Dasiphora*	*Dasiphora fruticosa*
21	Shrub	Dicot	Rosaceae	*Dryas*	*Dryas octopetala*
22	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea glauca*
23	Shrub	Dicot	Rosaceae	*Dasiphora*	*Dasiphora fruticosa*
24	Shrub	Dicot	Rosaceae	*Dryas*	*Dryas octopetala*

Table 3 (continued from previous page).

#	Growth habit	Host group	Host family	Host genus	Host species
25	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea glauca*
26	Shrub	Dicot	Malvaceae	*Gossypium*	Gossypium hirsutum
27	Graminoid	Monocot	Cyperaceae	*Carex*	*Carex firma*
28	Graminoid	Monocot	Cyperaceae	*Carex*	*Carex sempervirens*
29	Graminoid	Monocot	Cyperaceae	*Carex*	*Carex firma*
30	Graminoid	Monocot	Cyperaceae	*Carex*	*Carex sempervirens*
31	Tree	Dicot	Betulaceae	*Betula*	*Betula platyphylla*
32	Tree	Dicot	Betulaceae	*Betula*	*Betula platyphylla*
33	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus contorta*
34	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus contorta*
35	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus contorta*
36	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus contorta*
37	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus contorta*
38	Tree	Gymnosperm	Pinaceae	*Pinus*	*Pinus contorta*
39	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
40	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
41	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
42	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
43	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
44	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
45	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
46	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
47	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
48	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*

Table 3 (continued from previous page).

#	Growth habit	Host group	Host family	Host genus	Host species
49	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
50	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
51	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
52	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
53	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
54	Forb/herb	Monocot	Liliaceae	*Allium*	*Allium porrum*
55	Forb/herb	Monocot	Liliaceae	*Allium*	*Allium porrum*
56	Graminoid	Monocot	Poaceae	*Andropogon*	*Andropogon gerardii*
57	Forb/herb	Monocot	Liliaceae	*Allium*	*Allium porrum*
58	Graminoid	Monocot	Poaceae	*Andropogon*	*Andropogon gerardii*
59	Graminoid	Monocot	Poaceae	*Andropogon*	*Andropogon gerardii*
60	Forb/herb	Monocot	Liliaceae	*Allium*	*Allium porrum*
61	Forb/herb	Monocot	Liliaceae	*Allium*	*Allium porrum*
62	Forb/herb	Monocot	Liliaceae	*Allium*	*Allium porrum*
63	Forb/herb	Monocot	Liliaceae	*Allium*	*Allium porrum*
64	Graminoid	Monocot	Poaceae	*Andropogon*	*Andropogon gerardii*
65	Graminoid	Monocot	Poaceae	*Vulpia*	Vulpia ciliata
66	Graminoid	Monocot	Poaceae	*Vulpia*	*Vulpia ciliata*
67	Graminoid	Monocot	Poaceae	*Vulpia*	*Vulpia ciliata*
68	Graminoid	Monocot	Poaceae	*Bouteloua*	*Bouteloua gracillis*
69	Graminoid	Monocot	Poaceae	*Agropyron*	*Agropyron cristatum*
70	Graminoid	Monocot	Poaceae	*Psathyrostachys*	*Psathyrostachys juncea*
71	Graminoid	Monocot	Poaceae	*Bouteloua*	*Bouteloua gracillis*
72	Graminoid	Monocot	Poaceae	*Agropyron*	*Agropyron cristatum*

Table 3 (continued from previous page).

#	Growth habit	Host group	Host family	Host genus	Host species
73	Graminoid	Monocot	Poaceae	*Psathyrostachys*	*Psathyrostachys juncea*
74	Graminoid	Monocot	Poaceae	*Bouteloua*	*Bouteloua gracillis*
75	Graminoid	Monocot	Poaceae	*Agropyron*	*Agropyron cristatum*
76	Graminoid	Monocot	Poaceae	*Psathyrostachys*	*Psathyrostachys juncea*
77	Graminoid	Monocot	Poaceae	*Bouteloua*	*Bouteloua gracillis*
78	Graminoid	Monocot	Poaceae	*Agropyron*	*Agropyron cristatum*
79	Graminoid	Monocot	Poaceae	*Psathyrostachys*	*Psathyrostachys juncea*
80	Graminoid	Monocot	Poaceae	*Bouteloua*	*Bouteloua gracillis*
81	Graminoid	Monocot	Poaceae	*Agropyron*	*Agropyron cristatum*
82	Graminoid	Monocot	Poaceae	*Psathyrostachys*	*Psathyrostachys juncea*
83	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
84	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
85	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
86	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
87	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
88	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
89	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
90	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
91	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
92	Tree	Gymnosperm	Pinaceae	*Picea*	*Picea mariana*
93	Forb/herb	Dicot	Asteraceae	*Omalotheca*	*Omalotheca norvegica*

Table 3 (continued from previous page).

#	Growth habit	Host group	Host family	Host genus	Host species
94	Tree	Gymnosperm	Pinaceae	*Larix*	*Larix decidua*
95	Tree	Gymnosperm	Pinaceae	*Larix*	*Larix decidua*
96	Tree	Gymnosperm	Pinaceae	*Larix*	*Larix decidua*
97	Graminoid	Monocot	Poaceae	*Hordeum*	*Hordeum vulgare*
98	Shrub	Dicot	Ericaceae	*Menziesia*	*Menziesia ferruginea*
99	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
100	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
101	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
102	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
103	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
104	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
105	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
106	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
107	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
108	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
109	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
110	Graminoid	Monocot	Poaceaea	*Deschampsia*	*Deschampsia antarctica*
111	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododenron obtusum*
112	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododenron obtusum*
113	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododenron obtusum*
114	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododenron obtusum*
115	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododenron obtusum*
116	Forb/herb	Dicot	Brassicaceae	*Brassica*	*Brassica rapa*
117	Forb/herb	Dicot	Brassicaceae	*Brassica*	*Brassica rapa*

Table 3 (continued from previous page).

#	Growth habit	Host group	Host family	Host genus	Host species
118	Forb/herb	Dicot	Brassicaceae	*Brassica*	*Brassica rapa*
119	Forb/herb	Dicot	Brassicaceae	*Brassica*	*Brassica rapa*
120	Forb/herb	Dicot	Brassicaceae	*Brassica*	*Brassica rapa*
121	Forb/herb	Dicot	Brassicaceae	*Brassica*	*Brassica rapa*
122	Tree	Dicot	Lauraceae	*Persea*	*Persea americana*
123	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron* sp.
124	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron* sp.
125	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron* sp.
126	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron* sp.
127	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron* sp.
128	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron* sp.
129	Shrub	Dicot	Ericaceae	*Rhododendron*	*Rhododendron* sp.
130	Forb/herb	Dicot	Asteraceae	*Saussurea*	*Saussurea involucrata*
131	Forb/herb	Dicot	Asteraceae	*Saussurea*	*Saussurea involucrata*
132	Forb/herb	Monocot	Liliaceae	*Asparagus*	*Asparagus officinalis*
133	Forb/herb	Monocot	Liliaceae	*Asparagus*	*Asparagus officinalis*

Table 4. Values for the factors 'isolation from host', 'colonization of host', 'system aeration', 'growth conditions', 'initial sterilization' and 'agar' for each associated study (#). Refer to Table 1 in Chapter 2 for more details on factors.

#	Isolation from host	Colonization of host	System aeration	Growth conditions	Initial Sterilization	Agar
1	Yes	Yes	Open	Sterile	Sterilized	No
2	No	Yes	Open	Sterile	Sterilized	No
3	No	Yes	Open	Sterile	Sterilized	No
4	No	Yes	Open	Sterile	Sterilized	No
5	Yes	Yes	Open	Sterile	Sterilized	No
6	Yes	Yes	Open	Sterile	Sterilized	No
7	No	Yes	Open	Sterile	Sterilized	No
8	No	Yes	Open	Growth chamber	Sterilized	No
9	No	Yes	Open	Growth chamber	Sterilized	No
10	No	Yes	Open	Growth chamber	Sterilized	No
11	No	Yes	Open	Greenhouse	Sterilized	No
12	No	Yes	Open	Greenhouse	Sterilized	No
13	No	Yes	Open	Greenhouse	Sterilized	No
14	No	Yes	Open	Greenhouse	Sterilized	No
15	No	Yes	Open	Greenhouse	Sterilized	No
16	No	Yes	Open	Greenhouse	Sterilized	No
17	No	Yes	Open	Greenhouse	Sterilized	No
18	No	Yes	Open	Greenhouse	Sterilized	No
19	No	Yes	Open	Greenhouse	Sterilized	No
20	No	Yes	Open	Greenhouse	Sterilized	No
21	No	Yes	Open	Greenhouse	Sterilized	No
22	No	Yes	Open	Greenhouse	Sterilized	No
23	No	Yes	Open	Greenhouse	Sterilized	No

Table 4 (continued from previous page).

#	Isolation from host	Colonization of host	System aeration	Growth conditions	Initial sterilization	Agar
24	No	Yes	Open	Greenhouse	Sterilized	No
25	No	Yes	Open	Greenhouse	Sterilized	No
26	No	Yes	Open	Growth chamber	Sterilized	No
27	Yes	Yes	Open	Growth chamber	Sterilized	No
28	Yes	Yes	Open	Growth chamber	Sterilized	No
29	Yes	Yes	Open	Growth chamber	Sterilized	No
30	Yes	Yes	Open	Growth chamber	Sterilized	No
31	Yes	Yes	Closed	Sterile	Sterilized	Yes
32	Yes	Yes	Closed	Sterile	Sterilized	Yes
33	No	Yes	Open	Growth chamber	Pasteurized	No
34	No	Yes	Open	Growth chamber	Pasteurized	No
35	No	Yes	Open	Growth chamber	Pasteurized	No
36	No	Yes	Open	Growth chamber	Pasteurized	No
37	No	Yes	Open	Growth chamber	No	No
38	No	Yes	Open	Growth chamber	No	No
39	No	Yes	Closed	Sterile	Sterilized	No
40	No	Yes	Closed	Sterile	Sterilized	No
41	No	Yes	Closed	Sterile	Sterilized	No
42	No	Yes	Closed	Sterile	Sterilized	No
43	No	Yes	Closed	Sterile	Sterilized	No
44	No	Yes	Closed	Sterile	Sterilized	No
45	No	Yes	Closed	Sterile	Sterilized	No
46	No	Yes	Closed	Sterile	Sterilized	No
47	No	Yes	Closed	Sterile	Sterilized	No

Table 4 (continued from previous page).

#	Isolation from host	Colonization of host	System aeration	Growth conditions	Initial sterilization	Agar
48	No	Yes	Closed	Sterile	Sterilized	No
49	No	Yes	Closed	Sterile	Sterilized	No
50	No	Yes	Closed	Sterile	Sterilized	No
51	No	Yes	Closed	Sterile	Sterilized	No
52	No	Yes	Closed	Sterile	Sterilized	No
53	No	Yes	Closed	Sterile	Sterilized	No
54	No	Yes	Open	Sterile	Sterilized	Yes
55	No	Yes	Open	Sterile	Sterilized	Yes
56	Unknown	Yes	Open	Sterile	Sterilized	Yes
57	No	Yes	Open	Sterile	Sterilized	Yes
58	Unknown	Yes	Open	Sterile	Sterilized	Yes
59	Unknown	Yes	Open	Sterile	Sterilized	Yes
60	No	Yes	Open	Sterile	Sterilized	Yes
61	No	Yes	Open	Sterile	Sterilized	Yes
62	No	Yes	Open	Sterile	Sterilized	Yes
63	No	Yes	Open	Sterile	Sterilized	Yes
64	Unknown	Yes	Open	Sterile	Sterilized	Yes
65	Yes	Yes	Open	Growth chamber	Sterilized	No
66	Yes	Yes	Open	Growth chamber	Sterilized	No
67	Yes	Yes	Open	Greenhouse	Sterilized	No
68	No	Unknown	Open	Growth chamber	Sterilized	No
69	Yes	Yes	Open	Growth chamber	Sterilized	No
70	No	Yes	Open	Growth chamber	Sterilized	No
71	No	Unknown	Open	Growth chamber	Sterilized	No

Table 4 (continued from previous page).

#	Isolation from host	Colonization of host	System aeration	Growth conditions	Initial sterilization	Agar
72	Yes	Unknown	Open	Growth chamber	Sterilized	No
73	No	Unknown	Open	Growth chamber	Sterilized	No
74	Yes	Unknown	Open	Growth chamber	Sterilized	No
75	No	Unknown	Open	Growth chamber	Sterilized	No
76	No	Unknown	Open	Growth chamber	Sterilized	No
77	No	Unknown	Open	Growth chamber	Sterilized	No
78	No	Unknown	Open	Growth chamber	Sterilized	No
79	Yes	Unknown	Open	Growth chamber	Sterilized	No
80	No	Unknown	Open	Growth chamber	Sterilized	No
81	No	Yes	Open	Growth chamber	Sterilized	No
82	Yes	Yes	Open	Growth chamber	Sterilized	No
83	No	Unknown	Open	Growth chamber	Sterilized	No
84	No	Unknown	Open	Growth chamber	Sterilized	No
85	No	Unknown	Open	Growth chamber	Sterilized	No
86	No	Unknown	Open	Growth chamber	Sterilized	No
87	No	Unknown	Open	Growth chamber	Sterilized	No
88	No	Unknown	Open	Growth chamber	Sterilized	No
89	Yes	Unknown	Open	Growth chamber	Sterilized	No
90	Yes	Unknown	Open	Growth chamber	Sterilized	No
91	Yes	Yes	Open	Growth chamber	Sterilized	No
92	Yes	Yes	Open	Growth chamber	Sterilized	No

Table 4 (continued from previous page).

#	Isolation from host	Colonization of host	System aeration	Growth conditions	Initial sterilization	Agar
93	No	No	Open	Growth chamber	Sterilized	No
94	Yes	Yes	Open	Growth chamber	Sterilized	No
95	Yes	Yes	Open	Growth chamber	Sterilized	No
96	Yes	Yes	Open	Growth chamber	Sterilized	No
97	Yes	Yes	Open	Growth chamber	Sterilized	No
98	No	Yes	Closed	Sterile	Sterilized	Yes
99	Yes	Yes	Open	Sterile	Sterilized	No
100	Yes	Yes	Open	Sterile	Sterilized	No
101	Yes	No	Open	Sterile	Sterilized	No
102	Yes	No	Open	Sterile	Sterilized	No
103	Yes	Yes	Open	Sterile	Sterilized	No
104	Yes	Yes	Open	Sterile	Sterilized	No
105	Yes	Yes	Open	Sterile	Sterilized	No
106	Yes	Yes	Open	Sterile	Sterilized	No
107	Yes	No	Open	Sterile	Sterilized	No
108	Yes	No	Open	Sterile	Sterilized	No
109	Yes	Yes	Open	Sterile	Sterilized	No
110	Yes	Yes	Open	Sterile	Sterilized	No
111	No	Yes	Open	Growth chamber	Sterilized	No
112	No	Yes	Open	Growth chamber	Sterilized	No
113	No	Yes	Open	Growth chamber	Sterilized	No
114	No	Yes	Open	Growth chamber	Sterilized	No
115	Yes	Yes	Open	Growth chamber	Sterilized	No
116	Yes	Unknown	Open	Sterile	Sterilized	Yes

Table 4 (continued from previous page).

#	Isolation from host	Colonization of host	System aeration	Growth conditions	Initial sterilization	Agar
117	Yes	Unknown	Open	Sterile	Sterilized	Yes
118	Yes	Unknown	Open	Sterile	Sterilized	Yes
119	Yes	Unknown	Open	Sterile	Sterilized	Yes
120	Yes	Unknown	Open	Sterile	Sterilized	Yes
121	Yes	Unknown	Open	Sterile	Sterilized	Yes
122	No	Yes	Open	Green House	Sterilized	No
123	Yes	Slightly	Open	Sterile	Sterilized	No
124	No	Slightly	Open	Sterile	Sterilized	No
125	Yes	Yes	Open	Sterile	Sterilized	No
126	No	Yes	Open	Growth chamber	Sterilized	No
127	No	Yes	Open	Growth chamber	Sterilized	No
128	No	Yes	Open	Growth chamber	Sterilized	No
129	No	Yes	Open	Growth chamber	Sterilized	No
130	Yes	Yes	Open	Sterile	Sterilized	No
131	Yes	Yes	Open	Sterile	Sterilized	No
132	No	Yes	Open	Growth chamber	Sterilized	No
133	No	Yes	Open	Growth chamber	Sterilized	No

Table 5. Types of pH stabilizers and carbon sources added to the growing medium for each associated study (#). Refer to Table 1 in Chapter 2 for more details on factors.

#	pH stabilizer (detailed)	pH stabilizer (binomial)	Carbon (detailed)	Carbon (binomial)	Simple sugar
1	Vermiculite	Yes	Peat	Yes	No
2	Vermiculite	Yes	Peat	Yes	No
3	Vermiculite	Yes	Peat	Yes	No
4	Vermiculite	Yes	Peat	Yes	No
5	Vermiculite	Yes	Peat	Yes	No
6	Vermiculite	Yes	Peat	Yes	No
7	Vermiculite	Yes	Peat	Yes	No
8	Buffer	Yes	Simple sugar	Yes	Yes
9	No	No	Peat and plant material	Yes	No
10	No	No	Peat and plant material	Yes	No
11	No	No	Peat	Yes	No
12	No	No	Peat	Yes	No
13	No	No	Peat	Yes	No
14	No	No	Peat	Yes	No
15	No	No	Peat	Yes	No
16	No	No	Peat	Yes	No
17	No	No	Peat	Yes	No
18	No	No	Peat	Yes	No
19	No	No	Peat	Yes	No
20	No	No	Peat	Yes	No
21	No	No	Peat	Yes	No
22	No	No	Peat	Yes	No
23	No	No	Peat	Yes	No

Table 5 (continued from previous page).

#	pH stabilizer (detailed)	pH stabilizer (binomial)	Carbon (detailed)	Carbon (binomial)	Simple sugar
24	No	No	Peat	Yes	No
25	No	No	Peat	Yes	No
26	No	No	Peat	Yes	No
27	No	No	No	No	No
29	No	No	No	No	No
30	No	No	No	No	No
31	No	No	Simple sugar	Yes	Yes
32	No	No	Simple sugar	Yes	Yes
33	No	No	No	No	No
34	No	No	Peat	Yes	No
35	No	No	Urea	Yes	No
36	No	No	Peat and urea	Yes	No
37	Vermiculite	Yes	Peat	Yes	No
38	Vermiculite	Yes	Peat	Yes	No
39	Vermiculite	Yes	No	No	No
40	Vermiculite	Yes	No	No	No
41	Vermiculite	Yes	No	No	No
42	Vermiculite	Yes	No	No	No
43	Vermiculite	Yes	No	No	No
44	Vermiculite	Yes	No	No	No
45	Vermiculite	Yes	No	No	No
46	Vermiculite	Yes	No	No	No
47	Vermiculite	Yes	No	No	No
48	Vermiculite	Yes	No	No	No

Table 5 (continued from previous page).

#	pH stabilizer (detailed)	pH stabilizer (binomial)	Carbon (detailed)	Carbon (binomial)	Simple sugar
49	Vermiculite	Yes	No	No	No
50	Vermiculite	Yes	No	No	No
51	Vermiculite	Yes	No	No	No
52	Vermiculite	Yes	No	No	No
53	Vermiculite	Yes	No	No	No
54	Vermiculite	Yes	No	No	No
55	Vermiculite	Yes	No	No	No
56	Vermiculite	Yes	No	No	No
57	Vermiculite	Yes	No	No	No
58	Vermiculite	Yes	No	No	No
59	Vermiculite	Yes	No	No	No
60	Vermiculite	Yes	No	No	No
61	Vermiculite	Yes	No	No	No
62	Vermiculite	Yes	No	No	No
63	Vermiculite	Yes	No	No	No
64	Vermiculite	Yes	No	No	No
65	No	No	Plant material	Yes	No
66	No	No	Plant material	Yes	No
67	No	No	Plant material	Yes	No
68	No	No	No	No	No
69	No	No	No	No	No
70	No	No	No	No	No
71	No	No	No	No	No
72	No	No	No	No	No

Table 5 (continued from previous page).

#	pH stabilizer (detailed)	pH stabilizer (binomial)	Carbon (detailed)	Carbon (binomial)	Simple sugar
73	No	No	No	No	No
74	No	No	No	No	No
75	No	No	No	No	No
76	No	No	No	No	No
77	No	No	No	No	No
78	No	No	No	No	No
79	No	No	No	No	No
80	No	No	No	No	No
81	No	No	No	No	No
82	No	No	No	No	No
83	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
84	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
85	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
86	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
87	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
88	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
89	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
90	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
91	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
92	Vermiculite	Yes	Peat and simple sugar	Yes	Yes
93	No	No	Bone meal	Yes	No
94	Expanded clay medium	Yes	Simple sugar	Yes	Yes
95	Expanded clay medium	Yes	Simple sugar	Yes	Yes
96	Expanded clay medium	Yes	Simple sugar	Yes	Yes

Table 5 (continued from previous page).

#	pH stabilizer (detailed)	pH stabilizer (binomial)	Carbon (detailed)	Carbon (binomial)	Simple sugar
97	Expanded clay medium	Yes	Simple sugar	Yes	Yes
98	Cellulose	Yes	Cellulose	Yes	No
99	No	No	No	No	No
100	No	No	Protein and amino acids	Yes	No
101	No	No	No	No	No
102	No	No	Protein and amino acids	Yes	No
103	No	No	No	No	No
104	No	No	Protein and amino acids	Yes	No
105	No	No	No	No	No
106	No	No	Protein and amino acids	Yes	No
107	No	No	No	No	No
108	No	No	Protein and amino acids	Yes	No
109	No	No	No	No	No
110	No	No	Protein and amino acids	Yes	No
111	Vermiculite	No	Peat	Yes	No
112	Vermiculite	No	Peat	Yes	No
113	Vermiculite	No	Peat	Yes	No
114	Vermiculite	No	Peat	Yes	No
115	Vermiculite	No	Peat	Yes	No
116	No	No	Simple sugar	Yes	Yes
117	No	No	Simple sugar	Yes	Yes
118	No	No	Simple sugar	Yes	Yes

Table 5 (continued from previous page).

#	pH stabilizer (detailed)	pH stabilizer (binomial)	Carbon (detailed)	Carbon (binomial)	Simple sugar
119	No	No	Simple sugar, protein and amino acids	Yes	Yes
120	No	No	Simple sugar, protein and amino acids	Yes	Yes
121	No	No	Simple sugar	Yes	Yes
122	Buffer	Yes	No	No	No
123	No	No	Peat	Yes	No
124	No	No	Peat	Yes	No
125	No	No	Peat	Yes	No
126	No	No	Plant material	Yes	No
127	No	No	Peat	Yes	No
128	No	No	Plant material	Yes	No
129	No	No	Peat	Yes	No
130	Vermiculite	Yes	Plant material	Yes	No
131	Vermiculite	Yes	Plant material	Yes	No
132	Vermiculite	Yes	No	No	No
133	Vermiculite	Yes	No	No	No

Table 6. Nitrogen sources and phosphorus added to the growing medium for each associated study (#). Refer to Table 1 in Chapter 2 for more details on factors.

#	Organic nitrogen	Peat moss	Protein and amino acids	Other organic nitrogen	Inorganic nitrogen	Ammonium	Nitrate	Phosphorus
1	Yes	Yes	No	No	Yes	Yes	No	Yes
2	Yes	Yes	No	No	Yes	Yes	No	Yes
3	Yes	Yes	No	No	Yes	Yes	No	Yes
4	Yes	Yes	No	No	Yes	Yes	No	Yes
5	Yes	Yes	No	No	Yes	Yes	No	Yes
6	Yes	Yes	No	No	Yes	Yes	No	Yes
7	Yes	Yes	No	No	Yes	Yes	No	Yes
8	Yes	No	No	Yes	Yes	Yes	Yes	Yes
9	Yes	Yes	No	Yes	No	No	No	No
10	Yes	Yes	No	Yes	No	No	No	No
11	Yes	Yes	No	No	No	No	No	No
12	Yes	Yes	No	No	No	No	No	No
13	Yes	Yes	No	No	No	No	No	No
14	Yes	Yes	No	No	No	No	No	No
15	Yes	Yes	No	No	No	No	No	No
16	Yes	Yes	No	No	No	No	No	No
17	Yes	Yes	No	No	No	No	No	No
18	Yes	Yes	No	No	No	No	No	No
19	Yes	Yes	No	No	No	No	No	No
20	Yes	Yes	No	No	No	No	No	No
21	Yes	Yes	No	No	No	No	No	No
22	Yes	Yes	No	No	No	No	No	No

Table 6 (continued from previous page).

#	Organic nitrogen	Peat moss	Protein and amino acids	Other organic nitrogen	Inorganic nitrogen	Ammonium	Nitrate	Phosphorus
23	Yes	Yes	No	No	No	No	No	No
24	Yes	Yes	No	No	No	No	No	No
25	Yes	Yes	No	No	No	No	No	No
26	Yes	Yes	No	No	Yes	Yes	No	Yes
27	Yes	Yes	No	No	Yes	Yes	No	Yes
28	No	No	No	No	Yes	No	Yes	Yes
29	No	No	No	No	Yes	No	Yes	Yes
30	No	No	No	No	Yes	No	Yes	Yes
31	No	No	No	No	Yes	Yes	No	Yes
32	No	No	No	No	Yes	Yes	No	Yes
33	No	No	No	No	No	No	No	No
34	Yes	Yes	No	No	No	No	No	No
35	No	No	No	Yes	No	No	No	No
36	Yes	Yes	No	Yes	No	No	No	No
37	Yes	Yes	No	No	No	No	No	No
38	Yes	Yes	No	No	No	No	No	No
39	No	No	No	No	No	No	No	No
40	No	No	No	No	No	No	No	No
41	No	No	No	No	No	No	No	No
42	No	No	No	No	No	No	No	No
43	No	No	No	No	No	No	No	No
44	No	No	No	No	No	No	No	No
45	No	No	No	No	No	No	No	No

Table 6 (continued from previous page).

#	Organic nitrogen	Peat moss	Protein and amino acids	Other organic nitrogen	Inorganic nitrogen	Ammonium	Nitrate	Phosphorus
46	No	No	No	No	No	No	No	No
47	No	No	No	No	No	No	No	No
48	No	No	No	No	No	No	No	No
49	No	No	No	No	No	No	No	No
50	No	No	No	No	No	No	No	No
51	No	No	No	No	No	No	No	No
52	No	No	No	No	No	No	No	No
53	No	No	No	No	No	No	No	No
54	No	No	No	No	Yes	Yes	Yes	Yes
55	No	No	No	No	Yes	Yes	Yes	Yes
56	No	No	No	No	Yes	Yes	Yes	Yes
57	No	No	No	No	Yes	Yes	Yes	Yes
58	No	No	No	No	Yes	Yes	Yes	Yes
59	No	No	No	No	Yes	Yes	Yes	Yes
60	No	No	No	No	Yes	Yes	Yes	Yes
61	No	No	No	No	Yes	Yes	Yes	Yes
62	No	No	No	No	Yes	Yes	Yes	Yes
63	No	No	No	No	Yes	Yes	Yes	Yes
64	No	No	No	No	Yes	Yes	Yes	Yes
65	Yes	No	No	Yes	No	No	No	No
66	Yes	No	No	Yes	No	No	No	No
67	Yes	No	No	Yes	No	No	No	No
68	No	No	No	No	Yes	Yes	Yes	Yes

Table 6 (continued from previous page).

#	Organic nitrogen	Peat moss	Protein and amino acids	Other organic nitrogen	Inorganic nitrogen	Ammonium	Nitrate	Phosphorus
69	No	No	No	No	Yes	Yes	Yes	Yes
70	No	No	No	No	Yes	Yes	Yes	Yes
71	No	No	No	No	Yes	Yes	Yes	Yes
72	No	No	No	No	Yes	Yes	Yes	Yes
73	No	No	No	No	Yes	Yes	Yes	Yes
74	No	No	No	No	Yes	Yes	Yes	Yes
75	No	No	No	No	Yes	Yes	Yes	Yes
76	No	No	No	No	Yes	Yes	Yes	Yes
77	No	No	No	No	Yes	Yes	Yes	Yes
78	No	No	No	No	Yes	Yes	Yes	Yes
79	No	No	No	No	Yes	Yes	Yes	Yes
80	No	No	No	No	Yes	Yes	Yes	Yes
81	No	No	No	No	Yes	Yes	Yes	Yes
82	No	No	No	No	Yes	Yes	Yes	Yes
83	Yes	Yes	No	Yes	Yes	Yes	No	Yes
84	Yes	Yes	No	Yes	Yes	Yes	No	Yes
85	Yes	Yes	No	Yes	Yes	Yes	No	Yes
86	Yes	Yes	No	Yes	Yes	Yes	No	Yes
87	Yes	Yes	No	Yes	Yes	Yes	No	Yes
88	Yes	Yes	No	Yes	Yes	Yes	No	Yes
89	Yes	Yes	No	Yes	Yes	Yes	No	Yes
90	Yes	Yes	No	Yes	Yes	Yes	No	Yes
91	Yes	Yes	No	Yes	Yes	Yes	No	Yes

Table 6 (continued from previous page).

#	Organic nitrogen	Peat moss	Protein and amino acids	Other organic nitrogen	Inorganic nitrogen	Ammonium	Nitrate	Phosphorus
88	Yes	Yes	No	Yes	Yes	Yes	No	Yes
89	Yes	Yes	No	Yes	Yes	Yes	No	Yes
90	Yes	Yes	No	Yes	Yes	Yes	No	Yes
91	Yes	Yes	No	Yes	Yes	Yes	No	Yes
92	Yes	Yes	No	Yes	Yes	Yes	No	Yes
93	Yes	Yes	No	Yes	No	No	No	No
94	Yes	No	No	Yes	Yes	Yes	No	Yes
95	Yes	No	No	Yes	Yes	Yes	No	Yes
96	Yes	No	No	Yes	Yes	Yes	No	Yes
97	Yes	No	No	Yes	Yes	Yes	No	Yes
98	No	No	No	No	Yes	No	Yes	Yes
99	No	No	No	No	Yes	Yes	No	Yes
100	Yes	No	Yes	No	No	No	No	Yes
101	No	No	No	No	Yes	Yes	No	Yes
102	Yes	No	Yes	No	No	No	No	Yes
103	No	No	No	No	Yes	Yes	No	Yes
104	Yes	No	Yes	No	No	No	No	Yes
105	No	No	No	No	Yes	Yes	No	Yes
106	Yes	No	Yes	No	No	No	No	Yes
107	No	No	No	No	Yes	Yes	No	Yes
108	Yes	No	Yes	No	No	No	No	Yes
109	No	No	No	No	Yes	Yes	No	Yes
110	Yes	No	Yes	No	No	No	No	Yes

Table 6 (continued from previous page).

#	Organic nitrogen	Peat moss	Protein and amino acids	Other organic nitrogen	Inorganic nitrogen	Ammonium	Nitrate	Phosphorus
111	Yes	Yes	No	No	No	No	No	No
112	Yes	Yes	No	No	No	No	No	No
113	Yes	Yes	No	No	No	No	No	No
114	Yes	Yes	No	No	No	No	No	No
115	Yes	Yes	No	No	No	No	No	No
116	No	No	No	No	No	No	No	Yes
117	No	No	No	No	Yes	No	Yes	Yes
118	No	No	No	No	Yes	Yes	No	Yes
119	Yes	No	Yes	No	No	No	No	Yes
120	Yes	No	Yes	No	No	No	No	Yes
121	No	No	No	No	Yes	No	Yes	Yes
122	No	No	No	No	Yes	Yes	Yes	Yes
123	Yes	Yes	No	No	Yes	Yes	Yes	Yes
124	Yes	Yes	No	No	Yes	Yes	Yes	Yes
125	Yes	Yes	No	No	Yes	Yes	Yes	Yes
126	Yes	No	No	Yes	No	No	No	No
127	Yes	Yes	No	No	No	No	No	Yes
128	Yes	No	No	Yes	No	No	No	No
129	Yes	Yes	No	No	No	No	No	Yes
130	Yes	No	No	Yes	Yes	Yes	Yes	Yes
131	Yes	No	No	Yes	Yes	Yes	Yes	Yes
132	No	No	No	No	No	No	No	No
133	No	No	No	No	No	No	No	Yes

Table 7. Natural log of the response ratio (ln RR = endophyte-inoculated host mean/control mean) with parametric variance (Para) and non-parametric variance (Non-P) for total biomass. Means, standard deviations (SD) and sample sizes (n) for inoculated plants (I) and controls (C) are given. The factor 'measurement type' is also included. See Methods section in Chapter 2 for more details. Only studies which reported total biomass data are included. Parametric variance could not be calculated without standard deviation.

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
1	0.0578	0.0098	0.3333	1.78	0.34	6	1.78	0.25	6	Dry weight
2	-0.0241	0.0093	0.3333	1.64	0.3	6	1.64	0.25	6	Dry weight
3	0.1490	0.0060	0.3333	1.95	0.23	6	1.95	0.25	6	Dry weight
4	0.0745	0.0053	0.3333	1.81	0.18	6	1.81	0.25	6	Dry weight
5	-0.1335	0.0071	0.3333	1.47	0.21	6	1.47	0.25	6	Dry weight
6	0.0465	0.0092	0.3333	1.76	0.32	6	1.76	0.25	6	Dry weight
7	0.0800	0.0092	0.3333	1.82	0.33	6	1.82	0.25	6	Dry weight
...										
9	0.0249		0.0833	1.19		24	1.19		24	Dry weight
10	-0.4224		0.0833	1.19		24	1.19		24	Dry weight
...										
27	1.6888	0.0734	0.5833	17.43	3.85	3	17.43	1.54	4	Dry weight
28	-0.0604	0.0103	0.3667	26.32	4.04	5	26.32	5.12	6	Dry weight
29	1.7132	0.0615	0.5000	17.86	2.35	4	17.86	1.54	4	Dry weight
30	0.1006	0.0349	0.5000	30.92	9.17	3	30.92	5.12	6	Dry weight
...										
33	-0.0807	0.1581	0.2000	48.80	28.27	10	48.80	59.04	10	Dry weight
34	0.0664	0.0876	0.2111	43.10	30.42	10	43.10	23.52	9	Dry weight
35	0.4627	0.1344	0.2111	129.90	106.35	10	129.90	63.66	9	Dry weight
36	0.3396	0.1646	0.2000	146.20	135.91	10	146.20	92.02	10	Dry weight
37	0.1009	0.0200	0.2000	95.30	28.46	10	95.30	28.65	10	Dry weight

Table 7 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
38	0.0352	0.0358	0.2000	89.24	44.37	10	89.24	28.65	10	Dry weight
...										
54	0.3596		0.2000	48.80		10	48.80		10	Dry weight
55	-0.0207		0.2000	43.10		10	43.10		10	Dry weight
56	0.8149		0.2000	129.90		10	129.90		10	Dry weight
57	-0.3417		0.2000	146.20		10	146.20		10	Dry weight
58	0.0526		0.2000	0.027		10	0.027		10	Dry weight
59	0.8197		0.2000	0.059		10	0.059		10	Dry weight
60	0.2610		0.2000	0.031		10	0.031		10	Dry weight
61	0.0974		0.2000	0.026		10	0.026		10	Dry weight
62	-0.0634		0.2000	0.022		10	0.022		10	Dry weight
63	-0.6253		0.2000	0.013		10	0.013		10	Dry weight
64	0.9306		0.2000	0.066		10	0.066		10	Dry weight
...										
66	0.7117	0.0515	0.3333	0.17	0.17	6	0.17	0.16	6	Dry weight
67	0.5203	0.0421	0.2857	10.58	10.58	7	10.58	6.61	7	Dry weight
...										
83	-0.7765		0.1333	9.2		15	9.2		15	Dry weight
84	-0.7444		0.1333	9.5		15	9.5		15	Dry weight
85	-1.1239		0.1333	6.5		15	6.5		15	Dry weight
86	-1.1712		0.1333	6.2		15	6.2		15	Dry weight
87	-0.6931		0.1333	10.0		15	10.0		15	Dry weight
88	-0.4155		0.1333	13.2		15	13.2		15	Dry weight
89	-0.6349		0.1333	10.6		15	10.6		15	Dry weight

Table 7 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
90	-0.9943		0.1333	7.4		15	7.4		15	Dry weight
91	-0.2822	0.0703	0.2679	46	32	7	46	6	8	Dry weight
92	-0.7282	0.0210	0.0590	9.8	6.6	30	9.8	9.7	39	Dry weight
...										
116	0.0000	0.0217	0.4000	5.15	0.49	5	5.15	1.62	5	Dry weight
117	-0.0450	0.0010	0.4000	59.94	1.63	5	59.94	4.06	5	Dry weight
118	-1.4321	0.0199	0.4000	2.32	0.49	5	2.32	2.27	5	Dry weight
119	1.6410	0.0053	0.4000	39.70	2.75	5	39.70	1.14	5	Dry weight
120	2.2281	0.0132	0.4000	43.14	8.36	5	43.14	0.78	5	Dry weight
121	0.8076		0.4000	11.21		5	11.21		5	Dry weight
122	0.1331	0.0256	0.2500	66.53	14.96	8	66.53	22.90	8	Dry weight
123	-0.1904	0.0030	0.3095	1.24	0.13	6	1.24	0.14	7	Dry weight
124	0.0066	0.0019	0.2857	1.51	0.11	7	1.51	0.14	7	Dry weight
125	0.0328	0.0019	0.2857	1.55	0.11	7	1.55	0.14	7	Dry weight
126	-0.1862	0.1138	0.1667	13.58	13.82	12	13.58	9.39	12	Fresh weight
127	0.0000	0.0069	0.1667	18.08	1.39	12	18.08	5.02	12	Fresh weight
128	-0.4425	0.1487	0.1667	10.51	12.68	12	10.51	9.39	12	Fresh weight
129	-0.0866	0.0182	0.1667	16.58	6.24	12	16.58	5.02	12	Fresh weight
...										
131	0.6021	0.0754	0.0333	29.8	39.6	60	29.8	27.11	60	Dry weight
132	-0.0455	0.0354	0.1333	120.2	45.3	15	120.2	78.5	15	Fresh weight
133	0.1936	0.0522	0.1333	143.0	79.2	15	143.0	81.2	15	Fresh weight

Table 8. Natural log of the response ratio, other statistics and the factor 'measurement type' for root biomass. Only studies which reported root biomass data are included. See Table 7 for more details.

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
1	0.0684	0.0234	0.3333	1.21	0.33	6	1.21	0.29	6	Dry weight
2	-0.0546	0.0187	0.3333	1.07	0.23	6	1.07	0.29	6	Dry weight
3	0.1324	0.0163	0.3333	1.29	0.23	6	1.29	0.29	6	Dry weight
4	0.0175	0.0155	0.3333	1.15	0.19	6	1.15	0.29	6	Dry weight
5	-0.2615	0.0147	0.3333	0.87	0.13	6	0.87	0.29	6	Dry weight
6	0.0766	0.0224	0.3333	1.22	0.32	6	1.22	0.29	6	Dry weight
7	0.1009	0.0199	0.3333	1.25	0.29	6	1.25	0.29	6	Dry weight
8	0.2397	0.0029	0.2000	50.547	6.753	10	50.547	4.234	10	Root length
...										
11	-0.4000		0.1111	0.1832		18	0.1832		18	Dry weight
12	-0.5750		0.1111	0.0341		18	0.0341		18	Dry weight
13	0.3129		0.1111	0.0294		18	0.0294		18	Dry weight
14	-0.3536		0.1111	0.1919		18	0.1919		18	Dry weight
15	-0.0718		0.1111	0.0564		18	0.0564		18	Dry weight
16	-1.9367		0.1111	0.0310		18	0.0310		18	Dry weight
17	0.1391		0.1111	0.3141		18	0.3141		18	Dry weight
18	-0.5432		0.1111	0.0352		18	0.0352		18	Dry weight
19	0.2958		0.1111	0.0289		18	0.0289		18	Dry weight
20	-0.2256		0.1111	0.2181		18	0.2181		18	Dry weight
21	-0.5125		0.1111	0.0363		18	0.0363		18	Dry weight
22	-0.0379		0.1111	0.0207		18	0.0207		18	Dry weight
23	-0.3248		0.1111	0.1975		18	0.1975		18	Dry weight
24	0.1696		0.1111	0.0718		18	0.0718		18	Dry weight

Table 8 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
25	0.2053		0.1111	0.0264		18	0.0264		18	Dry weight
...										
27	1.9494	0.2177	0.5833	8.57	2.95	3	8.57	1.03	4	Dry weight
28	0.0043	0.0192	0.3667	18.74	3.88	5	18.74	4.72	6	Dry weight
29	2.1439	0.1864	0.5000	10.41	1.89	4	10.41	1.03	4	Dry weight
30	0.1379	0.0476	0.5000	21.42	7.13	3	21.42	4.72	6	Dry weight
33	-0.1126	0.1629	0.2000	19.30	13.50	10	19.30	23.05	10	Dry weight
34	0.1018	0.1003	0.2111	15.50	12.93	10	15.50	7.35	9	Dry weight
35	0.4318	0.2526	0.2111	47.40	57.14	10	47.40	30.24	9	Dry weight
36	0.3047	0.2895	0.2000	43.40	62.58	10	43.40	28.90	10	Dry weight
37	0.0162	0.0301	0.2000	42.43	14.42	10	42.43	17.99	10	Dry weight
38	-0.0823	0.0509	0.2000	38.45	21.85	10	38.45	17.99	10	Dry weight
39[1]	-0.2314	0.0174	0.2000	0.08	0.02	10	0.08	0.03	10	Fresh weight
40[1]	-0.1199	0.0166	0.2000	0.09	0.03	10	0.09	0.03	10	Fresh weight
41[1]	0.0574	0.0158	0.2000	0.10	0.03	10	0.10	0.03	10	Fresh weight
42[1]	-0.1172	0.0134	0.2000	0.09	0.02	10	0.09	0.03	10	Fresh weight
43[1]	0.0544	0.0153	0.2000	0.10	0.03	10	0.10	0.03	10	Fresh weight
44[1]	0.0872	0.0135	0.2000	0.11	0.03	10	0.11	0.03	10	Fresh weight
45[1]	-0.2516	0.0126	0.2000	0.08	0.02	10	0.08	0.03	10	Fresh weight
46[1]	-0.0556	0.0113	0.2000	0.09	0.02	10	0.09	0.03	10	Fresh weight
47[1]	-0.0703	0.0114	0.2000	0.09	0.02	10	0.09	0.03	10	Fresh weight
48[1]	-0.0091	0.0135	0.2000	0.10	0.02	10	0.10	0.03	10	Fresh weight

[1] Data obtained by contacting primary author. They were only mentioned in the publication as not significant.

Table 8 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
49[1]	-0.0686	0.0148	0.2000	0.09	0.02	10	0.09	0.03	10	Fresh weight
50[1]	-0.1614	0.0139	0.2000	0.08	0.02	10	0.08	0.03	10	Fresh weight
51[1]	-0.1463	0.0098	0.2000	0.09	0.01	10	0.09	0.03	10	Fresh weight
52[1]	-0.1359	0.0189	0.2000	0.09	0.03	10	0.09	0.03	10	Fresh weight
53[1]	0.0624	0.0130	0.2000	0.11	0.02	10	0.11	0.03	10	Fresh weight
...										
65	1.2528	0.0451	0.3333	19.30	0.1	6	19.30	0.1	6	Dry weight
66	0.7116	0.0899	0.3333	15.50	0.16	6	15.50	0.14	6	Dry weight
67	0.7129	0.0761	0.2857	47.40	7.14	7	47.40	3.97	7	Dry weight
...										
93	0.6402	0.0294	0.1538	19.30	26.357	13	19.30	10.784	13	Fresh weight
94	1.6377	0.0114	0.0690	15.50	19.95	29	15.50	4.76	29	Dry weight
95	1.6759	0.0081	0.0690	47.40	10.78	29	47.40	4.76	29	Dry weight
...										
99	-0.4269	0.0040	0.4000	3.408	0.447	5	3.408	0.268	5	Dry weight
100	0.5717	0.0559	0.4000	2.485	0.984	5	2.485	0.492	5	Dry weight
101	0.1435	0.0047	0.4000	6.029	0.872	5	6.029	0.268	5	Dry weight
102	1.2463	0.0261	0.4000	4.879	0.425	5	4.879	0.492	5	Dry weight
103	-1.2543	0.0135	0.4000	1.490	0.380	5	1.490	0.268	5	Dry weight
104	0.3225	0.0375	0.4000	1.937	0.492	5	1.937	0.492	5	Dry weight
105	-0.4781	0.0150	0.4000	3.238	0.872	5	3.238	0.268	5	Dry weight
106	0.9509	0.0268	0.4000	3.631	0.380	5	3.631	0.492	5	Dry weight
107	-0.1255	0.0066	0.4000	4.607	0.805	5	4.607	0.268	5	Dry weight
108	1.0318	0.0269	0.4000	3.937	0.425	5	3.937	0.492	5	Dry weight

Table 8 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
109	-0.4072	0.0061	0.4000	3.476	0.581	5	3.476	0.268	5	Dry weight
110	1.0231	0.0263	0.4000	3.903	0.358	5	3.903	0.492	5	Dry weight
...										
123	-0.3102	0.0102	0.3095	0.11	0.023	6	0.11	0.020	7	Dry weight
124	0.0000	0.0053	0.2857	0.15	0.020	7	0.15	0.020	7	Dry weight
125	0.0000	0.0043	0.2857	0.15	0.016	7	0.15	0.020	7	Dry weight
126	-0.0230	0.1956	0.1667	3.44	4.23	12	3.44	3.22	12	Fresh weight
127	0.0205	0.0263	0.1667	4.44	1.56	12	4.44	1.91	12	Fresh weight
128	-0.5261	0.1998	0.1667	2.08	2.60	12	2.08	3.22	12	Fresh weight
129	0.0405	0.0512	0.1667	4.53	2.94	12	4.53	1.91	12	Fresh weight
130	0.1823	0.0024	0.0333	4.50	1.29	60	4.50	0.95	60	Dry weight
131	0.6012	0.0620	0.0333	6.75	10.22	60	6.75	4.4	60	Dry weight
132	-0.0274	0.0622	0.1333	0.60	0.29	15	0.60	0.52	15	Fresh weight
133	0.2564	0.0682	0.1333	0.83	0.52	15	0.83	0.51	15	Fresh weight

Table 9. Natural log of the response ratio, other statistics and the factor 'measurement type' for shoot biomass. Only studies which reported shoot biomass data are included. See Table 7 for more details.

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
1	0.0180	0.0058	0.3333	0.56	0.05	6	0.55	0.09	6	Dry weight
2	0.0357	0.0086	0.3333	0.57	0.09	6	0.55	0.09	6	Dry weight
3	0.1823	0.0058	0.3333	0.66	0.06	6	0.55	0.09	6	Dry weight
4	0.1974	0.0075	0.3333	0.67	0.09	6	0.55	0.09	6	Dry weight
5	0.0870	0.0082	0.3333	0.60	0.09	6	0.55	0.09	6	Dry weight
6	-0.0183	0.0073	0.3333	0.54	0.07	6	0.55	0.09	6	Dry weight
7	0.0357	0.0086	0.3333	0.57	0.09	6	0.55	0.09	6	Dry weight
8	0.1203	0.0031	0.2000	1.50	0.185	10	1.33	0.167	10	Dry weight
...										
11	-0.2244		0.0667	0.1073		30	0.1073		30	Dry weight
12	-0.7104		0.0667	0.0947		30	0.0947		30	Dry weight
...										
14	-0.2301		0.0667	0.1067		30	0.1067		30	Dry weight
15	-0.1735		0.0667	0.1620		30	0.1620		30	Dry weight
...										
17	0.1875		0.0667	0.1620		30	0.1620		30	Dry weight
18	-0.5364		0.0667	0.1127		30	0.1127		30	Dry weight
...										
20	-0.0045		0.0667	0.1337		30	0.1337		30	Dry weight
21	-0.4964		0.0667	0.1173		30	0.1173		30	Dry weight
...										
23	-0.3151		0.0667	0.0980		30	0.0980		30	Dry weight
24	-0.1473		0.0667	0.1663		30	0.1663		30	Dry weight

Table 9 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
26	0.4196		0.0208	32.1		96	32.1		96	Plant height
27	1.4845	0.0524	0.5833	8.87	1.03	3	8.87	0.88	4	Dry weight
28	-0.2069	0.0039	0.3667	7.57	0.53	5	7.57	1.24	6	Dry weight
29	1.3101	0.0503	0.5000	7.45	0.73	4	7.45	0.88	4	Dry weight
30	0.0213	0.0198	0.5000	32.1	2.14	3	32.1	1.24	6	Dry weight
31	-0.0388	0.0034	0.2500	8.87	0.65	8	8.87	1.02	8	Dry weight
32	-0.1181	0.0063	0.2500	7.57	1.16	8	7.57	1.02	8	Dry weight
33	-0.0660	0.2281	0.2000	7.45	19.67	10	7.45	42.34	10	Dry weight
34	0.0471	0.1158	0.2111	9.51	23.97	10	9.51	15.87	9	Dry weight
35	0.4810	0.1369	0.2111	7.08	62.61	10	7.08	43.08	9	Dry weight
36	0.3586	0.1686	0.2000	6.54	94.27	10	6.54	66.53	10	Dry weight
37	0.1744	0.0217	0.2000	29.30	14.96	10	29.30	16.44	10	Dry weight
38	0.1343	0.0349	0.2000	27.60	23.37	10	27.60	16.44	10	Dry weight
39[1]	0.0886	0.0112	0.2000	82.50	0.02	10.00	82.50	0.03	10.00	Fresh weight
40[1]	0.0730	0.0148	0.2000	103.20	0.03	10.00	103.20	0.03	10.00	Fresh weight
41[1]	0.1391	0.0133	0.2000	52.86	0.03	10.00	52.86	0.03	10.00	Fresh weight
42[1]	0.0531	0.0125	0.2000	50.78	0.02	10.00	50.78	0.03	10.00	Fresh weight
43[1]	0.1469	0.0163	0.2000	0.11	0.04	10.00	0.11	0.03	10.00	Fresh weight
44[1]	0.1911	0.0172	0.2000	0.11	0.04	10.00	0.11	0.03	10.00	Fresh weight
45[1]	-0.0032	0.0138	0.2000	0.11	0.03	10.00	0.11	0.03	10.00	Fresh weight
46[1]	0.0263	0.0105	0.2000	0.10	0.02	10.00	0.10	0.03	10.00	Fresh weight
47[1]	0.0739	0.0156	0.2000	0.12	0.03	10.00	0.12	0.03	10.00	Fresh weight
48[1]	0.0915	0.0104	0.2000	0.12	0.02	10.00	0.12	0.03	10.00	Fresh weight

[1] Data obtained by contacting primary author. They were only mentioned in publication as not significant.

Table 9 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
49[1]	0.0116	0.0164	0.2000	0.10	0.03	10.00	0.10	0.03	10.00	Fresh weight
49[1]	0.0116	0.0164	0.2000	0.10	0.03	10.00	0.10	0.03	10.00	Fresh weight
50[1]	0.0322	0.0111	0.2000	0.10	0.02	10.00	0.10	0.03	10.00	Fresh weight
51[1]	0.0950	0.0140	0.2000	0.11	0.03	10.00	0.11	0.03	10.00	Fresh weight
52[1]	-0.0577	0.0172	0.2000	0.11	0.03	10.00	0.11	0.03	10.00	Fresh weight
53[1]	0.1021	0.0164	0.2000	0.10	0.03	10.00	0.10	0.03	10.00	Fresh weight
...										
65	1.0986	0.0335	0.3333	0.3	0.1	6	0.3	0.03	6	Dry weight
66	0.7073	0.0159	0.3333	0.213	0.037	6	0.213	0.027	6	Dry weight
67	0.3455	0.0199	0.2857	13.52	3.44	7	13.52	2.62	7	Dry weight
68[1]	-0.3392	0.0323	0.4000			5			5	Dry weight
69[1]	0.2291	0.0097	0.4000			5			5	Dry weight
70[1]	0.1360	0.0049	0.4000			5			5	Dry weight
71[1]	-0.3392	0.0432	0.4000			5			5	Dry weight
72[1]	0.0174	0.0081	0.4000			5			5	Dry weight
73[1]	0.3352	0.1503	0.4000			5			5	Dry weight
74[1]	-0.3148	0.0006	0.6667			3			3	Dry weight
75[1]	0.2251	0.0284	0.4000			5			5	Dry weight
76[1]	0.1821	0.1333	0.4000			5			5	Dry weight
77[1]	-0.5549	0.0849	0.5000			4			4	Dry weight
78[1]	-0.0824	0.1213	0.4000			5			5	Dry weight
79[1]	0.1327	0.0570	0.4000			5			5	Dry weight
80[1]	-0.1575	0.0284	0.4000			5			5	Dry weight

[1] Data obtained by contacting primary author. They were only mentioned in publication as not significant.

Table 9 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
81[1]	0.0969	0.0570	0.4000			5			5	Dry weight
82[1]	0.0224	0.0557	0.4000			5			5	Dry weight
...										
93	0.5949	0.0322	0.1538	10.830	5.394	13	10.830	2.466	13	Dry weight
94	0.6097	0.0019	0.0690	21.75	3.88	29	21.75	1.78	29	Dry weight
95	0.6791	0.0015	0.0690	23.31	3.38	29	23.31	1.78	29	Dry weight
96	0.7577	0.0013	0.0690	0.96	0.11	29	0.96	0.07	29	Plant height
97	0.1064	0.0029	0.1000	41.6	2.7	20	41.6	8.7	20	Shoot length
98	-0.1007		0.0819	21.7		23	21.7		26	Fresh weight
99	-0.2953	0.0108	0.4000	2.649	0.470	5	2.649	0.537	5	Dry weight
100	0.4101	0.0145	0.4000	1.941	0.425	5	1.941	0.201	5	Dry weight
101	0.1756	0.0058	0.4000	4.242	0.335	5	4.242	0.537	5	Dry weight
102	1.0164	0.0067	0.4000	3.559	0.335	5	3.559	0.201	5	Dry weight
103	-0.5844	0.0082	0.4000	1.984	0.268	5	1.984	0.537	5	Dry weight
123	-0.1779	0.0026	0.3095	1.13	0.11	6	1.35	0.12	7	Dry weight
124	0.0074	0.0017	0.2857	1.36	0.09	7	1.35	0.12	7	Dry weight
125	0.0364	0.0017	0.2857	1.40	0.09	7	1.35	0.12	7	Dry weight
126	-0.0557	0.1175	0.1667	3.14	3.01	12	3.32	2.32	12	Dry weight
127	0.0151	0.0070	0.1667	4.01	0.48	12	3.95	1.04	12	Dry weight

[1] Data presented as a response ratio in the publication (individual numerical values of the control and experimental means were not given)

Table 9 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
128	-0.3498	0.1576	0.1667	2.34	2.77	12	3.32	2.32	12	Dry weight
129	-0.1707	0.0209	0.1667	3.33	1.42	12	3.95	1.04	12	Dry weight
130	0.2719	0.0002	0.0222	15.75	0.96	90	12.00	1.41	90	Dry weight
131	0.4888	0.1115	0.0133	22.5	59.2	150	13.8	43.2	150	Dry weight
132	-0.0644	0.0346	0.1333	0.036	0.013	15	0.038	0.023	15	Dry weight
133	0.1103	0.0417	0.1333	0.045	0.023	15	0.040	0.024	15	Dry weight

Table 10. Natural log of the response ratio, other statistics and the factor 'measurement type' for plant nitrogen concentration. Only studies which reported nitrogen concentration data are included. See Table 7 for more details.

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
1	0.0901	0.0056	0.3333	9.75	1.33	6	8.91	1.08	6	Shoot nitrogen concentration
2	-0.0818	0.0082	0.3333	8.21	1.53	6	8.91	1.08	6	Shoot nitrogen concentration
3	0.1421	0.0056	0.3333	10.27	1.42	6	8.91	1.08	6	Shoot nitrogen concentration
4	0.0993	0.0032	0.3333	9.84	0.65	6	8.91	1.08	6	Shoot nitrogen concentration
5	-0.0239	0.0039	0.3333	8.7	0.8	6	8.91	1.08	6	Shoot nitrogen concentration
6	0.2144	0.0143	0.3333	11.04	2.95	6	8.91	1.08	6	Shoot nitrogen concentration
7	0.2595	0.0041	0.3333	11.55	1.16	6	8.91	1.08	6	Shoot nitrogen concentration
...										
33	-0.1265	0.0420	0.6667	0.608	0.197	3	0.690	0.099	3	Plant nitrogen concentration
34	-0.0254	0.0063	0.6667	0.623	0.068	3	0.639	0.054	3	Plant nitrogen concentration
35	0.1495	0.0025	0.6667	1.642	0.042	3	1.414	0.116	3	Plant nitrogen concentration
36	0.1701	0.0143	0.6667	2.110	0.312	3	1.780	0.258	3	Plant nitrogen concentration
37	-0.0481	0.0535	0.2000	0.629	0.459	10	0.66	0.038	10	Plant nitrogen concentration
38	0.0531	0.0163	0.2000	0.696	0.278	10	0.66	0.038	10	Plant nitrogen concentration
...										
67	-0.0857	0.0009	0.2857	3.029	0.188	7	3.300	0.167	7	Shoot nitrogen concentration
...										
93	-0.1227	0.0105	0.1538	3.60	0.72	13	4.07	1.26	13	Plant nitrogen concentration
...										
99	-0.0051	0.0105	0.4000	9.85	1.83	5	9.90	1.32	5	Shoot nitrogen concentration
100	-0.1203	0.0151	0.4000	13.93	0.67	5	15.71	4.25	5	Shoot nitrogen concentration
101	-0.0821	0.0281	0.4000	9.12	3.20	5	9.90	1.32	5	Shoot nitrogen concentration
102	-0.3803	0.0176	0.4000	10.74	1.32	5	15.71	4.25	5	Shoot nitrogen concentration

Table 10 (continued from previous page).

#	ln RR	Para	Non-P	Mean (I)	SD (I)	n (I)	Mean (C)	SD (C)	n (C)	Measurement Type
103	0.2892	0.0060	0.4000	13.22	1.48	5	9.90	1.32	5	Shoot nitrogen concentration
104	-0.0705	0.0194	0.4000	14.64	2.26	5	15.71	4.25	5	Shoot nitrogen concentration
105	0.2427	0.0085	0.4000	12.62	1.99	5	9.90	1.32	5	Shoot nitrogen concentration
106	-0.0383	0.0191	0.4000	15.12	2.26	5	15.71	4.25	5	Shoot nitrogen concentration
107	-0.0561	0.0077	0.4000	9.36	1.34	5	9.90	1.32	5	Shoot nitrogen concentration
108	-0.2326	0.0190	0.4000	12.45	1.83	5	15.71	4.25	5	Shoot nitrogen concentration
109	0.4268	0.0051	0.4000	15.17	1.32	5	9.90	1.32	5	Shoot nitrogen concentration
110	-0.2570	0.0176	0.4000	12.15	1.48	5	15.71	4.25	5	Shoot nitrogen concentration
...										
123	0.2160	0.0012	0.3095	1.39	0.07	6	1.12	0.08	7	Foliar nitrogen concentration
124	0.0773	0.0009	0.2857	1.21	0.03	7	1.12	0.08	7	Foliar nitrogen concentration
125	0.0606	0.0010	0.2857	1.19	0.05	7	1.12	0.08	7	Foliar nitrogen concentration

APPENDIX 2

DETAILED RESULTS FOR THE META-ANALYSIS:

ASCOMYCETES

Table 1. Among-study heterogeneity (Q_M= Q for the model) of all 31 factors plus 'measurement type' used in the categorical analyses on the response of plant root biomass (with parametric variance) to the inoculation of an ascomycetous root endophyte. P-values were generated by testing the homogeneity statistic against a chi-square distribution. A significant value ($p<0.05$) indicates heterogeneity in the studies greater than expected by random results. A p-value using randomization tests (rand) was also generated as an additional test for significance. Degrees of freedom (df) = number of studies -1. Refer to methods section in Chapter 2 for more information on the heterogeneity statistic (Q).

Factor	df	Q_M	p	p (rand)
Measurement type	1	25.7125	0	0.3464
Publication	10	610.8883	0	0.0096
Fungal order	4	67.4359	0	0.5912
Fungal family	5	60.9056	0	0.727
Fungal genus	10	116.7412	0	0.8156
Fungal species	7	113.9003	0	0.6986
Fungal strain	12	162.6023	0	0.9404
Growth habit	3	184.3614	0	0.0622
Host group	2	173.4024	0	0.0242
Host family	5	203.5081	0	0.1894
Host genus	8	646.7985	0	0.0012
Host species	10	679.836	0	0.0018
Isolation from host	1	18.2952	0.00002	0.4112
Colonization of host	2	24.4897	0	0.4638
System aeration	1	37.7877	0	0.2218
Growth conditions	1	275.3782	0	0.0002
Initial sterilization	2	0.6695	0.71552	0.9688
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	2	559.913	0	0.0008
pH stabilizer (binomial)	1	42.9134	0	0.2164
Carbon (detailed)	4	560.8597	0	0.0006
Carbon (binomial)	1	252.9067	0	0.0002
Simple sugars	1	303.4353	0	0.0044
Nitrogen	1	36.5829	0	0.2358
Organic nitrogen	1	251.6022	0	0.0002
Peat moss	1	12.9647	0.00032	0.501
Proteins and amino acids	1	140.6661	0	0.0238
Other organic nitrogen	1	292.2753	0	0.0016

Table 1 (continued from previous page).

Inorganic nitrogen	1	1.1459	0.2844	0.847
Ammonium	1	2.3279	0.12708	0.7706
Nitrate	1	1.3392	0.24717	0.7972
Phosphorus	1	17.7408	0.00003	0.4308

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 2. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant root biomass (with parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	59	1083.6162	0	60	1109.3287	0
Publication	46	444.9531	0	56	1055.8414	0
Fungal order	56	1049.3784	0	60	1116.8143	0
Fungal family	54	1038.6479	0	59	1099.5535	0
Fungal genus	41	759.8171	0	51	876.5584	0
Fungal species	36	718.3434	0	43	832.2437	0
Fungal strain	17	298.026	0	29	460.6283	0
Growth habit	58	933.5554	0	61	1117.9169	0
Host group	59	944.5144	0	61	1117.9169	0
Host family	55	905.8206	0	60	1109.3287	0
Host genus	51	451.5887	0	59	1098.3872	0
Host species	49	418.5512	0	59	1098.3872	0
Isolation from host	60	1099.6217	0	61	1117.9169	0
Colonization of host	59	1093.4272	0	61	1117.9169	0
System aeration	60	1080.1292	0	61	1117.9169	0
Growth conditions	59	837.3941	0	60	1112.7723	0
Initial sterilization	59	837.3941	0	60	1112.7723	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	58	549.4157	0	60	1109.3287	0
pH stabilizer (binomial)	60	1075.0034	0	61	1117.9169	0
Carbon (detailed)	54	546.1197	0	58	1106.9794	0
Carbon (binomial)	60	865.0101	0	61	1117.9169	0
Simple sugars	60	814.4816	0	61	1117.9169	0
Nitrogen	60	1081.334	0	61	1117.9169	0
Organic nitrogen	60	866.3147	0	61	1117.9169	0
Peat moss	60	1104.9521	0	61	1117.9169	0
Proteins and amino acids	60	977.2507	0	61	1117.9169	0
Other organic nitrogen	60	825.6416	0	61	1117.9169	0
Inorganic nitrogen	60	1116.7709	0	61	1117.9169	0
Ammonium	60	1115.589	0	61	1117.9169	0
Nitrate	60	1116.5776	0	61	1117.9169	0
Phosphorus	60	1100.176	0	61	1117.9169	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 3. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric root biomass analyses of the Ascomycetes. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	38	0.1271	-0.0724	0.3841
	Fresh weight	21	-0.0458	-0.1039	0.0216
Publication	Alberton et al. (2010)	6	-0.0001	-0.1128	0.0911
	Haselwandter and Read (1982)	3	**0.2661**	**0.0488**	**2.064**
	Jumpponen et al. (1998)	3	0.1307	-0.0395	0.3719
	Jumpponen and Trappe (1998)	1	-0.0204	-0.0823	0.0162
	Maciá-Vicente et al. (2008)	14	**-0.0732**	**-0.1245**	**-0.0219**
	Newsham (1999)	1	**0.7123**	**0.7116**	**0.7129**
	Schulz and Boyle (2006)	1	**1.66**	**1.6377**	**1.6759**
	Upson et al. (2009)	11	-0.0964	-0.3685	0.295
	Vohník et al. (2003)	3	-0.0174	-0.2719	0.0326
	Vohník et al. (2005)	2	-0.062	-0.3102	0
	Yu (2000)	1	0.108	-0.0274	0.2564
Fungal order	Helotiales	35	0.1785	-0.0306	0.4313
	Incertae sedis	7	-0.051	-0.2981	0.362
	Hypocreales	9	**-0.0807**	**-0.1439**	**-0.0249**
	Pleosporales	4	0.0149	-0.1502	0.5267
	Chaetothyriales	1	**0.7123**	**0.7116**	**0.7129**
Fungal family	*Incertae sedis*	20	0.0367	-0.1314	0.1809
	Helotiaceae	1	**0.0735**	**0.0175**	**0.1324**
	Vibrisseaceae	20	**0.2546**	**0.0046**	**0.645**
	Nectriaceae	4	**-0.0909**	**-0.1758**	**-0.0331**

Table 3. Categorical parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal family	Herpotrichiellaceae	1	**0.7123**	**0.7116**	**0.7129**
	Dermataceae	8	0.0797	-0.411	0.8084
Fungal genus	*Meliniomyces*	1	**0.0735**	**0.0175**	**0.1324**
	Phialocephala	20	**0.2546**	**0.0005**	**0.66**
	Unidentified dark septate endophyte	3	-0.2765	-0.4036	0.8101
	Acremonium	1	**-0.1738**	**-0.2305**	**-0.1194**
	Fusarium	4	**-0.0909**	**-0.1758**	**-0.0331**
	Phoma	3	-0.0232	-0.1563	0.518
	Phialophora	1	**0.7123**	**0.7116**	**0.7129**
	Mollisia	3	-0.0171	-0.8866	0.8672
	Oculimacula	1	0.0347	-0.4781	0.9509
	Tapesia	3	-0.0218	-0.3061	1.0274
Fungal species	*Phialocephala fortinii*	20	**0.2546**	**0.0003**	**0.6777**
	Unidentified dark septate endophyte	3	-0.2765	-0.4036	0.8101
	Fusarium equiseti	4	**-0.0909**	**-0.1712**	**-0.0331**
	Phoma leveillei	1	**-0.1425**	**-0.1461**	**-0.1356**
	Phialophora graminicola	1	**0.7123**	**0.7116**	**0.7129**
	Mollisia sp.	3	-0.0171	-0.8866	0.8672
	Oculimacula yallundae	1	0.0347	-0.4781	0.9509
	Tapesia sp.	3	-0.0218	-0.3061	1.0274
Fungal strain	C1	1	**0.1391**	**0.0043**	**1.9494**
	C2	1	**0.4909**	**0.1379**	**2.1439**
	SE24	5	0.3022	-0.0402	0.5553
	Phialophora graminicola	1	**0.7123**	**0.7116**	**0.7129**

Table 3. Categorical parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal strain	C4	1	-0.3602	-0.4269	0.5717
	H3	1	**0.3118**	**0.1435**	**1.2463**
	H4	1	-0.8369	-1.2543	0.3225
	I4	1	0.0347	-0.4781	0.9509
	C7	1	0.1025	-0.1255	1.0318
	I9	1	-0.1379	-0.4072	1.0231
	CBS 554.86	1	0.0153	-0.023	0.0205
	UAMH 8433	1	-0.0751	-0.5261	0.0405
Growth habit	Tree	15	**0.4279**	**0.0276**	**0.8978**
	Shrub	6	-0.0569	-0.2351	0.0054
	Graminoid	33	-0.0513	-0.1941	0.1143
Host group	Gymnosperm	14	0.5244	-0.0301	1.0408
	Dicot	10	0.1111	-0.0373	0.2082
	Monocot	35	-0.0492	-0.1907	0.1174
Host family	Pinaceae	14	0.5244	-0.0271	1.0222
	Ericaceae	6	-0.0569	-0.2351	0.0044
	Cyperaceae	3	**0.2661**	**0.0488**	**2.064**
	Poaceae	29	-0.0632	-0.2044	0.101
	Liliaceae	1	0.108	-0.0274	0.2564
	Asteraceae	2	**0.2301**	**0.1823**	**0.6402**
Host genus	*Pinus*	12	0.0041	-0.0906	0.0838
	Rhododendron	6	-0.0569	-0.2352	0.0053
	Carex	3	**0.2661**	**0.0488**	**2.064**
	Hordeum	14	**-0.0732**	**-0.1244**	**-0.0234**

Table 3. Categorical parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host genus	*Vulpia*	2	**0.9704**	**0.7116**	**1.2528**
	Larix	1	**1.66**	**1.6377**	**1.6759**
	Deschampsia	11	-0.0964	-0.3673	0.2885
	Saussurea	1	**0.1979**	**0.1823**	**0.6012**
	Asparagus	1	0.108	-0.0274	0.2564
Host species	*Pinus sylvestris*	6	-0.0001	-0.1103	0.0918
	Carex firma	1	**2.064**	**1.9494**	**2.1439**
	Carex sempervirens	1	**0.0488**	**0.0043**	**0.1379**
	Pinus contorta	5	0.0254	-0.0429	0.1709
	Hordeum vulgare	14	**-0.0732**	**-0.1255**	**-0.0237**
	Vulpia ciliata	2	**0.9704**	**0.7116**	**1.2528**
	Larix decidua	1	**1.66**	**1.6377**	**1.6759**
	Deschampsia antarctica	11	-0.0964	-0.38	0.278
	Rhododendron sp.	6	-0.0569	-0.2298	0.0054
	Saussurea involucrata	1	**0.1979**	**0.1823**	**0.6012**
	Asparagus officinalis	1	0.108	-0.0274	0.2564
Isolation from host	Yes	27	0.1478	-0.1047	0.4782
	No	33	0.0192	-0.0593	0.0969
Colonization of host	Yes	54	0.0829	-0.0865	0.267
	Slightly	1	-0.1111	-0.3102	0
	No	4	**0.252**	**0.0059**	**1.0486**
System aeration	Open	46	0.1408	-0.0445	0.3623
	Closed	14	**-0.0732**	**-0.1242**	**-0.0214**

Table 3. Categorical parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Growth conditions	Sterile	38	-0.0379	-0.1521	0.0712
	Growth chamber	21	**0.5864**	**0.2033**	**1.1378**
Colonization of host	Yes	54	0.0829	-0.0865	0.267
	Slightly	1	-0.1111	-0.3102	0
	No	4	**0.252**	**0.0059**	**1.0486**
System aeration	Open	46	0.1408	-0.0445	0.3623
	Closed	14	**-0.0732**	**-0.1242**	**-0.0214**
Growth conditions	Sterile	38	-0.0379	-0.1521	0.0712
	Growth chamber	21	**0.5864**	**0.2033**	**1.1378**
Initial sterilization	Sterilized	55	0.0892	-0.058	0.2448
	Pasteurized	3	0.1307	-0.0395	0.3719
	No	1	-0.0204	-0.0823	0.0162
pH stabilizer (detailed)	Vermiculite	27	0.0039	-0.0787	0.0761
	Expanded clay medium	1	**1.66**	**1.6377**	**1.6759**
	No	30	-0.0258	-0.2035	0.2072
pH stabilizer (binomial)	Yes	30	0.1728	-0.0037	0.38
	No	30	-0.0258	-0.2064	0.2003
Carbon (detailed)	Peat moss	14	-0.0303	-0.1153	0.0338
	Simple sugars	2	**0.7792**	**0.2397**	**1.6759**
	Plant material	6	**0.2615**	**0.1846**	**0.9558**
	Protein and amino acids	5	**0.9178**	**0.6489**	**1.1013**
	No	27	**-0.1604**	**-0.2887**	**-0.0326**

Table 3. Categorical parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Carbon (binomial)	Yes	33	**0.3172**	**0.1341**	**0.5887**
	No	27	**-0.1601**	**-0.2832**	**-0.0359**
Simple sugars	Yes	2	**0.7792**	**0.2397**	**1.6759**
	No	58	-0.0106	-0.1201	0.0939
Nitrogen	Yes	42	0.1412	-0.0406	0.3686
	No	18	**-0.0668**	**-0.1155**	**-0.0138**
Organic nitrogen	Yes	32	**0.317**	**0.1321**	**0.5929**
	No	28	**-0.1591**	**-0.2859**	**-0.032**
Peat moss	Yes	16	-0.0079	-0.0933	0.0818
	No	44	0.1185	-0.07	0.3239
Proteins and amino acids	Yes	5	**0.9178**	**0.6413**	**1.0961**
	No	55	0.05	-0.0947	0.2052
Other organic nitrogen	Yes	12	**0.539**	**0.2396**	**1.4132**
	No	48	-0.0576	-0.1588	0.0507
Inorganic nitrogen	Yes	24	0.0764	-0.1414	0.2991
	No	36	0.1101	-0.0016	0.2528
Ammonium	Yes	20	0.0707	-0.1458	0.3096
	No	40	**0.1182**	**0.0122**	**0.2583**
Nitrate	Yes	9	0.1139	-0.0403	0.2155
	No	51	0.0764	-0.1055	0.2964
Phosphorus	Yes	33	0.1282	-0.0655	0.3556
	No	27	-0.0114	-0.08	0.0802

Table 4. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant root biomass (with non-parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	3.8195	0.05066	0.3314
Publication	11	100.284	0	0.001
Fungal order	4	8.9166	0.06322	0.5832
Fungal family	5	24.7206	0.00016	0.272
Fungal genus	11	22.2087	0.02281	0.644
Fungal species	8	27.6894	0.00054	0.394
Fungal strain	17	38.641	0.002	0.3974
Growth habit	3	25.1489	0.00001	0.0972
Host group	2	8.0796	0.0176	0.4008
Host family	6	32.6012	0.00001	0.1988
Host genus	11	108.5628	0	0.0002
Host species	13	116.9395	0	0.0002
Isolation from host	1	52.0372	0	0.0002
Colonization of host	2	4.221	0.12118	0.3666
System aeration	1	3.8081	0.05101	0.3408
Growth conditions	2	41.0861	0	0.0008
Initial sterilization	2	0.3174	0.85323	0.8898
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	2	74.173	0	0.0002
pH stabilizer (binomial)	1	14.293	0.00016	0.0632
Carbon (detailed)	4	92.4418	0	0.0002
Carbon (binomial)	1	3.8983	0.04833	0.341
Simple sugars	1	63.5707	0	0.0002
Nitrogen	1	3.0904	0.07875	0.4008
Organic nitrogen	1	3.2409	0.07182	0.392
Peat moss	1	28.0432	0	0.002
Proteins and amino acids	1	8.1597	0.00428	0.166
Other organic nitrogen	1	49.4517	0	0.0002
Inorganic nitrogen	1	28.8698	0	0.0032
Ammonium	1	22.7448	0	0.0136
Nitrate	1	6.1777	0.01294	0.1946
Phosphorus	1	37.7658	0	0.0002

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 5. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant root biomass (with non-parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	74	177.9825	0	75	181.802	0
Publication	60	68.0458	0.22236	71	168.3298	0
Fungal order	71	172.8382	0	75	181.7547	0
Fungal family	69	156.3933	0	74	181.1139	0
Fungal genus	56	116.6306	0	67	138.8393	0
Fungal species	49	105.2922	0.00001	57	132.9817	0
Fungal strain	28	52.9778	0.00295	45	91.6189	0.00005
Growth habit	73	156.7114	0	76	181.8603	0
Host group	74	173.7807	0	76	181.8603	0
Host family	69	149.2008	0	75	181.802	0
Host genus	63	71.5299	0.21568	74	180.0927	0
Host species	61	63.1532	0.40016	74	180.0927	0
Isolation from host	75	129.8231	0.00009	76	181.8603	0
Colonization of host	74	177.6393	0	76	181.8603	0
System aeration	75	178.0522	0	76	181.8603	0
Growth conditions	74	140.7742	0	76	181.8603	0
Initial sterilization	74	181.5428	0	76	181.8603	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	73	107.629	0.00522	75	181.802	0
pH stabilizer (binomial)	75	167.5673	0	76	181.8603	0
Carbon (detailed)	69	87.0976	0.06957	73	179.5394	0
Carbon (binomial)	75	177.962	0	76	181.8603	0
Simple sugars	75	118.2896	0.00106	76	181.8603	0
Nitrogen	75	178.7699	0	76	181.8603	0
Organic nitrogen	75	178.6194	0	76	181.8603	0
Peat moss	75	153.8171	0	76	181.8603	0
Proteins and amino acids	75	173.7006	0	76	181.8603	0
Other organic nitrogen	75	132.4086	0.00005	76	181.8603	0
Inorganic nitrogen	75	152.9905	0	76	181.8603	0
Ammonium	75	159.1155	0	76	181.8603	0
Nitrate	75	175.6826	0	76	181.8603	0
Phosphorus	75	144.0945	0	76	181.8603	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 6. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the non-parametric root biomass analyses of the Ascomycetes. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	53	0.1864	-0.0577	0.4359
	Fresh weight	21	-0.0214	-0.1196	0.0822
Publication	Alberton et al. (2010)	6	0.0114	-0.0882	0.0891
	Fernando and Currah (1996)	14	**-0.2572**	**-0.552**	**-0.0207**
	Haselwandter and Read (1982)	3	**0.9379**	**0.0608**	**2.0541**
	Jumpponen et al. (1998)	3	0.1791	-0.0083	0.3665
	Jumpponen and Trappe (1998)	1	-0.0331	-0.0823	0.0162
	Maciá-Vicente et al. (2008)	14	**-0.0737**	**-0.1241**	**-0.0228**
	Newsham (1999)	1	**0.7123**	**0.7116**	**0.7129**
	Schulz and Boyle (2006)	1	**1.6568**	**1.6377**	**1.6759**
	Upson et al. (2009)	11	0.2165	-0.2116	0.6176
	Vohník et al. (2003)	3	-0.122	-0.3894	0.0305
	Vohník et al. (2005)	2	-0.098	-0.3102	0
	Yu (2000)	1	0.1145	-0.0274	0.2564
Fungal order	Helotiales	50	0.1041	-0.1358	0.343
	Incertae sedis	7	0.2867	-0.0761	0.7751
	Hypocreales	9	**-0.0812**	**-0.1435**	**-0.0217**
	Pleosporales	4	0.408	-0.1503	0.6478
	Chaetothyriales	1	**0.7123**	**0.7116**	**0.7129**
Fungal family	Incertae sedis	32	-0.0143	-0.2733	0.1986
	Helotiaceae	1	**0.0749**	**0.0175**	**0.1324**

Table 6. Categorical non-parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal family	Vibrisseaceae	23	**0.2604**	**0.0018**	**0.5965**
	Nectriaceae	4	**-0.091**	**-0.1761**	**-0.0332**
	Herpotrichiellaceae	1	**0.7123**	**0.7116**	**0.7129**
	Dermataceae	8	0.7652	-0.2631	1.3133
Fungal genus	*Meliniomyces*	1	**0.0749**	**0.0175**	**0.1324**
	Phialocephala	23	0.2604	-0.0006	0.5911
	Leptodontidium	12	-0.2152	-0.5835	0.0345
	Unidentified dark septate endophyte	3	0.3936	-0.2019	1.2754
	Acremonium	1	**-0.1757**	**-0.2314**	**-0.1199**
	Cylindrocarpon	1	-0.0314	-0.1172	0.0544
	Fusarium	4	**-0.091**	**-0.1761**	**-0.0329**
	Phoma	3	0.0856	-0.155	0.7532
	Phialophora	1	**0.7123**	**0.7116**	**0.7129**
	Mollisia	3	0.1145	-0.8601	0.9706
	Oculimacula	1	0.2364	-0.4781	0.9509
	Tapesia	3	0.3805	-0.2664	1.0274
Fungal species	*Phialocephala fortinii*	22	0.2671	-0.0068	0.6007
	Leptodontidium orchidicola	11	**-0.3257**	**-0.6899**	**-0.0444**
	Unidentified dark septate endophyte	3	0.3936	-0.2019	1.2754
	Fusarium equiseti	4	**-0.091**	**-0.1761**	**-0.0329**
	Phoma leveillei	1	**-0.1411**	**-0.1463**	**-0.1359**
	Phialophora graminicola	1	**0.7123**	**0.7116**	**0.7129**
	Mollisia sp.	3	0.1145	-0.8601	0.9706

Table 6. Categorical non-parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal species	*Oculimacula yallundae*	1	0.2364	-0.4781	0.9509
	Tapesia sp.	3	0.3805	-0.2664	1.0274
Fungal strain	UAMH 8148	3	0.0515	-0.2012	0.2176
	UAMH 5422	2	-0.2207	-0.575	0.3129
	UAMH 8149	2	**-0.7874**	**-1.9367**	**-0.0718**
	UAMH 8151	2	-0.0361	-0.5432	0.2958
	UAMH 8152	2	**-0.2587**	**-0.5125**	**-0.0379**
	C1	1	**0.7551**	**0.0043**	**1.9494**
	C2	1	**1.1409**	**0.1379**	**2.1439**
	SE24	5	**0.2337**	**0.0019**	**0.4569**
	Phialophora graminicola	1	**0.7123**	**0.7116**	**0.7129**
	C4	1	0.0724	-0.4269	0.5717
	H3	1	**0.6949**	**0.1435**	**1.2463**
	H4	1	-0.4659	-1.2543	0.3225
	I4	1	0.2364	-0.4781	0.9509
Fungal strain	C7	1	0.4532	-0.1255	1.0318
	I9	1	0.3079	-0.4072	1.0231
	CBS 554.86	1	-0.0012	-0.023	0.0205
	UAMH 8433	1	-0.2428	-0.5261	0.0405
	UAMH 9525	1	0.1145	-0.0274	0.2564

Table 6. Categorical non-parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal strain	C7	1	0.4532	-0.1255	1.0318
	I9	1	0.3079	-0.4072	1.0231
	CBS 554.86	1	-0.0012	-0.023	0.0205
	UAMH 8433	1	-0.2428	-0.5261	0.0405
	UAMH 9525	1	0.1145	-0.0274	0.2564
Growth habit	Tree	20	0.3257	-0.2234	0.7992
	Shrub	16	**-0.2271**	**-0.3495**	**-0.0934**
	Graminoid	33	0.1405	-0.0091	0.3261
	Forb/herb	4	**0.3606**	**0.1484**	**0.5754**
Host group	Gymnosperm	19	0.3292	-0.2601	0.8144
	Dicot	20	0.0035	-0.2309	0.2046
	Monocot	35	**0.1377**	**0.0054**	**0.2951**
Host family	Pinaceae	19	0.3292	-0.2287	0.8146
	Ericaceae	6	-0.1148	-0.3014	0.0138
	Rosaceae	9	**-0.2698**	**-0.4166**	**-0.1052**
	Cyperaceae	3	**0.9379**	**0.0608**	**2.0541**
	Poaceae	29	0.0817	-0.0627	0.2447
	Liliaceae	1	0.1145	-0.0274	0.2564
	Asteraceae	2	**0.416**	**0.1823**	**0.6402**
Host genus	*Pinus*	12	0.0673	-0.0296	0.1706
	Rhododendron	6	-0.1148	-0.2948	0.0153
	Dasiphora	4	**-0.233**	**-0.3664**	**-0.0324**
	Dryas	4	**-0.3066**	**-0.5498**	**-0.0212**
	Picea	4	-0.2321	-1.107	0.2811

Table 6. Categorical non-parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host genus	*Carex*	3	**0.9379**	**0.0608**	**2.0541**
	Hordeum	14	**-0.0737**	**-0.1269**	**-0.0205**
	Vulpia	2	**0.883**	**0.7116**	**1.2528**
	Larix	1	**1.6568**	**1.6377**	**1.6759**
	Deschampsia	11	0.2165	-0.2138	0.6254
	Saussurea	1	**0.3917**	**0.1823**	**0.6012**
	Asparagus	1	0.1145	-0.0274	0.2564
Host species	*Pinus sylvestris*	6	0.0114	-0.0887	0.0889
	Dasiphora fruticosa	4	**-0.233**	**-0.3664**	**-0.0417**
	Dryas octopetala	4	**-0.3066**	**-0.5498**	**-0.0212**
	Picea glauca	4	-0.2321	-1.107	0.2845
	Carex firma	1	**2.0541**	**1.9494**	**2.1439**
	Carex sempervirens	1	**0.0608**	**0.0043**	**0.1379**
	Pinus contorta	5	0.1071	-0.0415	0.2748
	Hordeum vulgare	14	**-0.0737**	**-0.1249**	**-0.0228**
	Vulpia ciliata	2	**0.883**	**0.7116**	**1.2528**
	Larix decidua	1	**1.6568**	**1.6377**	**1.6759**
	Deschamps antarcticaia	11	0.2165	-0.2175	0.628
	Rhododendron sp.	6	-0.1148	-0.2988	0.0161
	Saussurea involucrata	1	**0.3917**	**0.1823**	**0.6012**
	Asparagus officinalis	1	0.1145	-0.0274	0.2564
Isolation from host	Yes	27	**0.609**	**0.2814**	**0.9793**
	No	48	-0.1059	-0.2536	0.0128

Table 6. Categorical non-parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Colonization of host	Yes	69	0.1189	-0.0712	0.3141
	Slightly	1	-0.1489	-0.3102	0
	No	4	**0.6001**	**0.2027**	**0.975**
System aeration	Open	61	0.1727	-0.0485	0.3859
	Closed	14	**-0.0737**	**-0.1244**	**-0.0217**
Initial sterilization	Sterilized	70	0.1341	-0.0654	0.3331
	Pasteurized	3	0.1791	-0.0083	0.3665
	No	1	-0.0331	-0.0823	0.0162
pH stabilizer (detailed)	Vermiculite	27	0.1084	-0.0551	0.265
	Expanded clay medium	1	**1.6568**	**1.6377**	**1.6759**
	No	45	-0.0338	-0.2312	0.1573
pH stabilizer (binomial)	Yes	30	**0.3201**	**0.0354**	**0.5951**
	No	45	-0.0338	-0.2296	0.1535
Growth conditions	Sterile	38	0.1209	-0.0525	0.2705
	Growth chamber	21	**0.5603**	**0.1493**	**0.9378**
	Greenhouse	15	-0.2327	-0.5195	0.0101
Carbon (detailed)	Peat moss	29	**-0.1812**	**-0.3911**	**-0.0081**
	Simple sugars	2	**1.4483**	**0.2397**	**1.6759**
	Plant material	6	**0.351**	**0.0294**	**0.6326**
	Protein and amino acids	5	**0.8577**	**0.599**	**1.0898**
	No	27	-0.0239	-0.1355	0.1064
Carbon (binomial)	Yes	48	0.1868	-0.0532	0.424
	No	27	-0.0239	-0.1376	0.106

Table 6. Categorical non-parametric root biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Simple sugars	Yes	2	**1.4483**	**0.2397**	**1.6759**
	No	73	0.0269	-0.1168	0.1584
Nitrogen	Yes	57	0.1757	-0.0585	0.4022
	No	18	-0.0234	-0.0919	0.0535
Organic nitrogen	Yes	47	0.1833	-0.0642	0.4193
	No	28	-0.0064	-0.1241	0.1252
Peat moss	Yes	31	-0.1432	-0.3531	0.03
	No	44	**0.3544**	**0.1113**	**0.5933**
Protein and amino acids	Yes	5	**0.8577**	**0.587**	**1.0884**
	No	70	0.1078	-0.0849	0.2944
Other organic nitrogen	Yes	12	**0.6494**	**0.277**	**1.0955**
	No	63	-0.0764	-0.2187	0.0448
Inorganic nitrogen	Yes	24	**0.4944**	**0.0966**	**0.8623**
	No	51	-0.0417	-0.1942	0.0916
Ammonium	Yes	20	**0.4678**	**0.0126**	**0.8485**
	No	55	-0.0157	-0.1677	0.1216
Nitrate	Yes	9	**0.3779**	**0.1298**	**0.6522**
	No	66	0.0774	-0.1161	0.2968
Phosphorus	Yes	33	**0.4841**	**0.1797**	**0.7984**
	No	42	-0.102	-0.2699	0.0385

Table 7. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant shoot biomass (with parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	35.818	0	0.4838
Publication	13	693.1115	0	0.04
Fungal order	5	742.3015	0	0.0072
Fungal family	7	464.6718	0	0.3112
Fungal genus	13	732.4844	0	0.1718
Fungal species	9	330.1674	0	0.5428
Fungal strain	17	416.0864	0	0.8528
Growth habit	3	470.0586	0	0.0584
Host group	2	427.0406	0	0.0514
Host family	6	614.5513	0	0.067
Host genus	12	1214.2618	0	0.0002
Host species	15	1301.95	0	0.0006
Isolation from host	1	52.2853	0	0.4746
Colonization of host	3	514.4507	0	0.024
System aeration	1	28.5653	0	0.556
Growth conditions	1	4.7576	0.02917	0.8414
Initial sterilization	2	0.094	0.9541	0.9976
Agar	1	23.7397	0	0.252
pH stabilizer (detailed)	2	646.0407	0	0.0016
pH stabilizer (binomial)	1	425.18	0	0.0134
Carbon (detailed)	4	990.9977	0	0.0004
Carbon (binomial)	1	465.3893	0	0.0084
Simple sugars	1	322.8956	0	0.0472
Nitrogen	1	10.1744	0.00142	0.755
Organic nitrogen	1	508.8093	0	0.0028
Peat moss	1	127.5724	0	0.2126
Proteins and amino acids	1	202.9017	0	0.0818
Other organic nitrogen	1	614.3926	0	0.0002
Inorganic nitrogen	1	0.5004	0.47931	0.9416
Ammonium	1	0.0395	0.84246	0.9814
Nitrate	1	91.367	0	0.2978
Phosphorus	1	33.7418	0	0.5606

Table 8. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant shoot biomass (with parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	82	1427.1424	0	83	1462.9604	0
Publication	65	593.8205	0	78	1286.932	0
Fungal order	79	1006.4051	0	84	1748.7066	0
Fungal family	77	1284.0348	0	84	1748.7066	0
Fungal genus	64	794.4616	0	77	1526.9459	0
Fungal species	56	758.6053	0	65	1088.7727	0
Fungal strain	27	379.426	0	44	795.5124	0
Growth habit	82	1280.4422	0	85	1750.5008	0
Host group	83	1323.4601	0	85	1750.5008	0
Host family	78	1135.4443	0	84	1749.9956	0
Host genus	71	529.8559	0	83	1744.1177	0
Host species	68	442.1677	0	83	1744.1177	0
Isolation from host	84	1698.2154	0	85	1750.5008	0
Colonization of host	82	1236.0501	0	85	1750.5008	0
System aeration	84	1721.9355	0	85	1750.5008	0
Growth conditions	83	1744.0004	0	84	1748.7579	0
Initial sterilization	83	1750.4068	0	85	1750.5008	0
Agar	84	1726.7611	0	85	1750.5008	0
pH stabilizer (detailed)	82	1103.955	0	84	1749.9956	0
pH stabilizer (binomial)	84	1325.3207	0	85	1750.5008	0
Carbon (detailed)	78	752.6104	0	82	1743.6081	0
Carbon (binomial)	84	1285.1115	0	85	1750.5008	0
Simple sugars	84	1427.6051	0	85	1750.5008	0
Nitrogen	84	1740.3263	0	85	1750.5008	0
Organic nitrogen	84	1241.6914	0	85	1750.5008	0
Peat moss	84	1622.9283	0	85	1750.5008	0
Proteins and amino acids	84	1547.5991	0	85	1750.5008	0
Other organic nitrogen	84	1136.1082	0	85	1750.5008	0
Inorganic nitrogen	84	1750.0003	0	85	1750.5008	0
Ammonium	84	1750.4613	0	85	1750.5008	0
Nitrate	84	1659.1337	0	85	1750.5008	0
Phosphorus	84	1716.7589	0	85	1750.5008	0

Table 9. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric shoot biomass analyses of the Ascomycetes. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	63	0.1553	-0.0351	0.2797
	Fresh weight	19	0.0369	-0.0281	0.0937
Publication	Alberton et al. (2010)	6	**0.0797**	**0.0207**	**0.1437**
	Hashimoto and Hyakumachi (2001)	1	**-0.0666**	**-0.1181**	**-0.0388**
	Haselwandter and Read (1982)	3	0.0069	-0.1693	1.3955
	Jumpponen et al. (1998)	3	**0.2193**	**0.009**	**0.4262**
	Jumpponen and Trappe (1998)	1	**0.159**	**0.1343**	**0.1744**
	Maciá-Vicente et al. (2008)	14	**0.0694**	**0.0412**	**0.0967**
	Newsham (1999)	1	**0.5466**	**0.3455**	**0.7073**
	Perez-Naranjo (2010)	14	-0.2106	-0.2946	0.1179
	Schulz and Boyle (2006)	1	**0.6484**	**0.6097**	**0.679**
	Upson et al. (2009)	11	0.2624	-0.0244	0.5584
	Usuki and Narisawa (2005)	4	0.0192	-0.0726	0.1095
	Vohník et al. (2003)	3	-0.0423	-0.2217	0.0111
	Vohník et al. (2005)	2	-0.0273	-0.1779	0.0364
	Yu (2000)	1	0.0159	-0.0623	0.1101
Fungal order	Helotiales	39	**0.2428**	**0.0894**	**0.3379**
	Incertae sedis	9	0.005	-0.1298	0.3068
	Hypocreales	10	**0.0809**	**0.0493**	**0.1009**
	Pleosporales	16	-0.217	-0.2883	0.1724

Table 9. Categorical parametric shoot biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal order	Chaetothyriales	2	**0.7306**	**0.3455**	**0.7577**
	Capnodiales	3	**0.0758**	**0.0277**	**0.1265**
Fungal family	Incertae sedis	36	0.1196	-0.1628	0.2564
	Helotiaceae	1	**0.1889**	**0.1823**	**0.1974**
	Vibrisseaceae	21	**0.1846**	**0.0153**	**0.4211**
	Nectriaceae	5	**0.0723**	**0.0203**	**0.0973**
	Herpotrichiellaceae	2	**0.7306**	**0.3455**	**0.7577**
	Dermataceae	8	0.3489	-0.0587	0.5739
	Antennulariellaceae	3	**0.0758**	**0.0277**	**0.1265**
	Myxotrichaceae	1	**-0.1568**	**-0.1779**	**-0.1414**
Fungal genus	*Meliniomyces*	1	**0.1889**	**0.1823**	**0.1974**
	Phialocephala	21	**0.1846**	**0.0131**	**0.4158**
	Unidentified dark septate endophyte	4	-0.0481	-0.1847	0.3196
	Acremonium	1	**0.0816**	**0.0727**	**0.0884**
	Cylindrocarpon	1	**0.0935**	**0.0528**	**0.1465**
	Fusarium	5	**0.0723**	**0.019**	**0.0973**
	Phoma	3	0.1568	-0.0133	0.6449
	Unidentified endophyte	15	-0.2026	-0.2875	0.1169
	Phialophora	2	**0.7306**	**0.3455**	**0.7577**
	Mollisia	3	0.2514	-0.341	0.7827
	Oculimacula	1	0.5726	-0.2777	0.8243
	Tapesia	3	0.2602	-0.2394	0.6698
	Heteroconium	3	**0.0758**	**0.0277**	**0.1265**
	Oidiodendron	1	**-0.1568**	**-0.1779**	**-0.1414**

Table 9. Categorical parametric shoot biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal species	*Phialocephala fortinii*	21	**0.1846**	**0.0145**	**0.4239**
	Unidentified dark septate endophyte	4	-0.0481	-0.1847	0.3196
	Fusarium equiseti	4	**0.0422**	**0.0093**	**0.0748**
	Phoma leveillei	1	0.0266	-0.0579	0.0949
	Unidentified endophyte	15	-0.2026	-0.2889	0.1189
	Phialophora graminicola	1	**0.5466**	**0.3455**	**0.7073**
	Mollisia sp.	3	0.2514	-0.341	0.7827
	Oculimacula yallundae	1	0.5726	-0.2777	0.8243
	Tapesia sp.	3	0.2602	-0.2394	0.6698
	Heteroconium chaetospira	3	**0.0758**	**0.0277**	**0.1265**
	Myxotrichaceae	1	**-0.1568**	**-0.1779**	**-0.1414**
Fungal strain	C1	1	-0.0897	-0.2069	1.4845
	C2	1	**0.3853**	**0.0213**	**1.3101**
	SE24	5	**0.3267**	**0.1024**	**0.5282**
	Phialophora graminicola	1	**0.5466**	**0.3455**	**0.7073**
	AC1	2	0.1209	-0.3392	0.2291
	AC4	2	-0.0227	-0.3392	0.3352
	BG17	2	-0.3015	-0.3148	0.2251
	PJ2	2	-0.1301	-0.5549	0.1327
	PJ5	2	-0.0487	-0.1575	0.0969
	C4	1	0.0058	-0.2953	0.4101
	H3	1	**0.5657**	**0.1756**	**1.0164**
	H4	1	-0.1362	-0.5844	0.2573
	I4	1	0.5726	-0.2777	0.8243

Table 9. Categorical parametric shoot biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal strain	C7	1	0.196	-0.1176	0.6454
	I9	1	0.3369	-0.54	0.6865
	CBS 554.86	1	0.0111	-0.0557	0.0151
	UAMH 8433	1	**-0.1917**	**-0.3498**	**-0.1707**
	UAMH 9525	1	0.0159	-0.0623	0.1101
Growth habit	Tree	18	**0.3834**	**0.0681**	**0.5537**
	Shrub	11	-0.0033	-0.0749	0.0586
	Graminoid	49	0.0171	-0.1392	0.247
	Forb/herb	4	**0.2716**	**0.053**	**0.465**
Host group	Gymnosperm	15	**0.4785**	**0.0978**	**0.6199**
	Dicot	17	0.1436	-0.0386	0.2239
	Monocot	51	0.0171	-0.1411	0.2515
Host family	Pinaceae	15	**0.4785**	**0.1031**	**0.6169**
	Ericaceae	11	-0.0033	-0.0724	0.058
	Betulaceae	1	**-0.0666**	**-0.1181**	**-0.0388**
	Cyperaceae	3	0.0069	-0.1693	1.3955
	Poaceae	45	0.0178	-0.1487	0.2645
	Liliaceae	1	0.0159	-0.0623	0.1101
	Asteraceae	2	**0.2743**	**0.2719**	**0.5949**
Host genus	*Pinus*	12	**0.0886**	**0.0368**	**0.1474**
	Rhododendron	11	-0.0033	-0.0711	0.0586
	Betula	1	**-0.0666**	**-0.1181**	**-0.0388**

Table 9. Categorical parametric shoot biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host genus	*Carex*	3	0.0069	-0.1693	1.3955
	Hordeum	15	**0.0783**	**0.0497**	**0.1**
	Vulpia	2	**0.6618**	**0.3455**	**1.0986**
	Bouteloua	4	**-0.314**	**-0.3896**	**-0.2246**
	Agropyron	4	**0.1207**	**0.0165**	**0.2214**
	Psathyrostachys	4	**0.1343**	**0.0706**	**0.2076**
	Larix	2	**0.6913**	**0.6097**	**0.7577**
	Deschampsia	11	0.2624	-0.0456	0.5424
	Saussurea	1	**0.2723**	**0.2719**	**0.4888**
	Asparagus	1	0.0159	-0.0623	0.1101
Host species	*Pinus sylvestris*	6	**0.0797**	**0.0192**	**0.1393**
	Betula platyphylla	1	**-0.0666**	**-0.1181**	**-0.0388**
	Carex firma	1	**1.3955**	**1.3101**	**1.4845**
	Carex sempervirens	1	-0.1693	-0.2069	0.0213
	Pinus contorta	5	**0.1747**	**0.1024**	**0.2859**
	Hordeum vulgare	15	**0.0783**	**0.0495**	**0.1002**
	Vulpia ciliata	2	**0.6618**	**0.3455**	**1.0986**
	Bouteloua gracillis	4	**-0.314**	**-0.3896**	**-0.227**
	Agropyron cristatum	4	**0.1207**	**0.0181**	**0.2203**
	Psathyrostachys juncea	4	**0.1343**	**0.0739**	**0.2076**
	Larix decidua	2	**0.6913**	**0.6097**	**0.7577**
	Deschampsia antarctica	11	0.2624	-0.0491	0.5505
	Rhododenron obtusum	4	0.0192	-0.0806	0.1062
	Rhododendron sp.	6	-0.0291	-0.1572	0.0271

Table 9. Categorical parametric shoot biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host species	*Saussurea involucrata*	1	**0.2723**	**0.2719**	**0.4888**
	Asparagus officinalis	1	0.0159	-0.0623	0.1101
Isolation from host	Yes	37	0.1913	-0.017	0.354
	No	47	**0.07**	**0.0422**	**0.0987**
System aeration	Open	68	**0.1715**	**0.0124**	**0.2976**
	Closed	16	0.0298	-0.0103	0.0809
Colonization of host	Yes	67	**0.2217**	**0.0944**	**0.315**
	Unknown	10	-0.2745	-0.3103	0.0322
	Slightly	1	-0.0659	-0.1779	0.0074
	No	4	**0.4026**	**0.0494**	**0.871**
Growth conditions	Sterile	40	**0.1729**	**0.015**	**0.242**
	Growth chamber	43	0.1403	-0.0862	0.3946
Initial sterilization	Sterilized	79	**0.1594**	**0.0098**	**0.2724**
	Pasteurized	3	**0.2193**	**0.009**	**0.4262**
	No	1	**0.159**	**0.1343**	**0.1744**
Agar	Yes	1	**-0.0666**	**-0.1181**	**-0.0388**
	No	83	**0.1652**	**0.0099**	**0.2797**
pH stabilizer (detailed)	Vermiculite	32	**0.1701**	**0.0116**	**0.2363**
	Expanded clay medium	3	**0.6038**	**0.3308**	**0.7302**
	No	47	-0.0113	-0.1421	0.1881
pH stabilizer (binomial)	Yes	32	**0.3011**	**0.1679**	**0.4465**
	No	52	-0.0041	-0.1218	0.144

Table 9. Categorical parametric shoot biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Carbon (detailed)	Peat moss	19	0.0165	-0.0396	0.0691
	Simple sugars	6	**0.4547**	**0.1422**	**0.6441**
	Plant material	6	**0.2818**	**0.2706**	**0.7483**
	Protein and amino acids	5	**0.6637**	**0.4297**	**0.8454**
	No	42	-0.1211	-0.2205	0.0545
Carbon (Binomial)	Yes	42	**0.2499**	**0.1283**	**0.3554**
	No	42	-0.1211	-0.2225	0.0574
Simple sugars	Yes	6	**0.4547**	**0.1537**	**0.644**
	No	78	0.0999	-0.062	0.2078
Nitrogen	Yes	66	**0.1657**	**0.0016**	**0.2879**
	No	18	**0.0691**	**0.0415**	**0.0967**
Organic nitrogen	Yes	39	**0.2604**	**0.1361**	**0.3832**
	No	45	-0.1152	-0.2135	0.0429

Table 10. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant total biomass (with parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	4.0549	0.04404	0.7204
Publication	9	119.2308	0	0.9518
Fungal order	3	92.3212	0	0.457
Fungal family	4	60.1613	0	0.7556
Fungal genus	4	65.0248	0	0.7682
Fungal species	3	59.7964	0	0.77
Fungal strain	8	80.7188	0	0.9962
Growth habit	3	88.3186	0	0.5674
Host group	2	19.9062	0.00005	0.8308
Host family	5	92.0714	0	0.739
Host genus	6	118.4997	0	0.7516
Host species	8	190.8606	0	0.7448
Isolation from host	1	7.0374	0.00798	0.713
Colonization of host	2	67.1805	0	0.3156
System aeration	N/A	N/A	N/A	N/A
Growth conditions	2	3.6646	0.16005	0.912
Initial sterilization	2	0.2758	0.87119	0.9866
Agar	1	58.3127	0	0.189
pH stabilizer (detailed)	1	9.8126	0.00173	0.6724
pH stabilizer (binomial)	1	9.3307	0.00225	0.6804
Carbon (detailed)	5	889.0047	0	0.0002
Carbon (binomial)	1	4.2763	0.03865	0.755
Simple sugars	1	37.3187	0	0.3058
Nitrogen	1	0.2133	0.64419	0.9152
Organic nitrogen	1	36.9486	0	0.3668
Peat moss	1	81.7715	0	0.1572
Proteins and amino acids	1	828.2604	0	0.0012
Other organic nitrogen	1	2.146	0.14294	0.8378
Inorganic nitrogen	1	321.9319	0	0.0006
Ammonium	1	105.3462	0	0.101
Nitrate	1	69.726	0	0.1654
Phosphorus	1	0.9921	0.31922	0.8894

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 11. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant total biomass (with parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	35	1109.1316	0	36	1113.1865	0
Publication	25	990.4558	0	34	1109.6866	0
Fungal order	30	1015.8774	0	33	1108.1986	0
Fungal family	29	1021.6117	0	33	1081.773	0
Fungal genus	26	1013.0794	0	30	1078.1043	0
Fungal species	24	1012.5392	0	27	1072.3356	0
Fungal strain	15	962.7125	0	23	1043.4313	0
Growth habit	33	1024.8679	0	36	1113.1865	0
Host group	34	1093.2803	0	36	1113.1865	0
Host family	29	1017.6152	0	34	1109.6866	0
Host genus	28	991.1869	0	34	1109.6866	0
Host species	26	918.826	0	34	1109.6866	0
Isolation from host	35	1106.1491	0	36	1113.1865	0
Colonization of host	34	1046.006	0	36	1113.1865	0
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	34	1109.5219	0	36	1113.1865	0
Initial sterilization	34	1112.9107	0	36	1113.1865	0
Agar	35	1054.8738	0	36	1113.1865	0
pH stabilizer (detailed)	34	1103.3136	0	35	1113.1262	0
pH stabilizer (binomial)	35	1103.8558	0	36	1113.1865	0
Carbon (detailed)	29	222.7996	0	34	1111.8043	0
Carbon (binomial)	35	1108.9102	0	36	1113.1865	0
Simple sugars	35	1075.8678	0	36	1113.1865	0
Nitrogen	35	1112.9732	0	36	1113.1865	0
Organic nitrogen	35	1076.2379	0	36	1113.1865	0
Peat moss	35	1031.415	0	36	1113.1865	0
Proteins and amino acids	35	284.9261	0	36	1113.1865	0
Other organic nitrogen	35	1111.0405	0	36	1113.1865	0
Inorganic nitrogen	35	791.2545	0	36	1113.1865	0
Ammonium	35	1007.8403	0	36	1113.1865	0
Nitrate	35	1043.4605	0	36	1113.1865	0
Phosphorus	35	1112.1944	0	36	1113.1865	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 12. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric total biomass analyses of the Helotiales. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	15	**0.0509**	**0.0112**	**0.1296**
	Fresh weight	5	-0.0264	-0.1337	0.0299
Publication	Alberton et al. (2010)	5	0.0487	-0.0382	0.1116
	Haselwandter and Read (1982)	1	**0.6844**	**0.1006**	**1.7132**
	Jumpponen et al. (1998)	3	**0.1841**	**0.014**	**0.4074**
	Jumpponen and Trappe (1998)	1	**0.0774**	**0.0352**	**0.1009**
	Vohník et al. (2003)	3	**-0.0435**	**-0.2973**	**-0.0067**
	Vohník et al. (2005)	1	**0.0197**	**0.0066**	**0.0328**
	Yu (2000)	1	0.0511	-0.0455	0.1936
Fungal family	*Incertae sedis*	1	**0.0693**	**0.0578**	**0.08**
	Helotiaceae	1	**0.1094**	**0.0745**	**0.149**
	Vibrisseaceae	17	0.0248	-0.0228	0.0988
Fungal genus	*Meliniomyces*	1	**0.1094**	**0.0745**	**0.149**
	Phialocephala	17	0.0248	-0.0211	0.1018
Fungal strain	C2	1	**0.6844**	**0.1006**	**1.7132**
	SE24	4	**0.1138**	**0.0213**	**0.3148**
	CBS 554.86	1	-0.0106	-0.1862	0
	UAMH 8433	1	**-0.1254**	**-0.4425**	**-0.0866**
	UAMH 9525	1	0.0511	-0.0455	0.1936
Growth habit	Tree	11	0.0557	-0.0208	0.1131
	Shrub	5	0.009	-0.0606	0.0254
	Graminoid	1	**0.6844**	**0.1006**	**1.7132**

Table 12. Categorical parametric total biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Growth habit	Forb/herb	1	0.0511	-0.0455	0.1936
Host group	Gymnosperm	11	0.0557	-0.0202	0.1131
	Dicot	5	0.009	-0.0617	0.0254
	Monocot	3	0.3592	-0.0014	1.1165
Host family	Pinaceae	11	0.0557	-0.0203	0.1151
	Ericaceae	5	0.009	-0.0606	0.0254
	Cyperaceae	1	**0.6844**	**0.1006**	**1.7132**
	Liliaceae	1	0.0511	-0.0455	0.1936
Host genus	*Pinus*	11	0.0557	-0.0193	0.1136
	Rhododendron	5	0.009	-0.0617	0.0257
	Carex	1	**0.6844**	**0.1006**	**1.7132**
	Asparagus	1	0.0511	-0.0455	0.1936
Host species	*Pinus sylvestris*	5	0.0487	-0.0345	0.1108
	Pinus contorta	5	**0.1079**	**0.0438**	**0.2299**
	Rhododendron sp.	5	0.009	-0.0617	0.0257
	Asparagus officinalis	1	0.0511	-0.0455	0.1936
Isolation from host	Yes	5	0.0435	-0.0391	0.241
	No	15	**0.041**	**0.0048**	**0.0945**
Growth conditions	Sterile	7	0.0324	-0.0059	0.0791
	Growth chamber	13	0.0853	-0.0182	0.3401
Initial sterilization	Sterilized	15	0.0387	-0.0008	0.096
	Pasteurized	3	**0.1841**	**0.014**	**0.4074**
	No	1	**0.0774**	**0.0352**	**0.1009**

Table 12. Categorical parametric total biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
pH stabilizer (detailed)	Vermiculite	9	0.0512	-0.0216	0.1053
	No	11	0.0356	-0.0056	0.2014
pH stabilizer (binomial)	Yes	9	0.0512	-0.0228	0.1059
	No	11	0.0356	-0.0063	0.1794
Carbon (detailed)	Peat moss	12	0.029	-0.0072	0.067
	Plant material	1	**-0.2973**	**-0.4425**	**-0.1862**
	No	4	0.331	-0.0072	1.0261
Carbon (binomial)	Yes	16	0.029	-0.0063	0.0681
	No	4	0.331	-0.0072	1.0261
Nitrogen	Yes	17	**0.0408**	**0.0031**	**0.0999**
	No	3	0.0876	-0.0519	0.3384
Organic nitrogen	Yes	15	0.0275	-0.0089	0.0654
	No	5	**0.3402**	**0.0166**	**0.9685**
Peat moss	Yes	13	0.0298	-0.0065	0.0671
	No	7	0.2589	-0.063	0.7883
Other organic nitrogen	Yes	3	0.0308	-0.2973	0.4074
	No	17	**0.0422**	**0.0045**	**0.1007**
Inorganic nitrogen	Yes	9	**0.0477**	**0.0058**	**0.126**
	No	11	0.013	-0.0415	0.0865

Table 12. Categorical parametric total biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Ammonium	Yes	7	0.0324	-0.0066	0.0778
	No	13	0.0853	-0.0146	0.3262
Nitrate	Yes	3	**0.0469**	**0.0115**	**0.6844**
	No	17	0.0375	-0.0238	0.0891
Phosphorus	Yes	12	**0.0423**	**0.0023**	**0.1039**
	No	8	0.0385	-0.0706	0.124

Table 13. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses for the response of plant total biomass (with non-parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	0.034	0.85361	0.9206
Publication	12	60.9406	0	0.0002
Fungal order	5	52.1353	0	0.0002
Fungal family	4	10.8772	0.02798	0.4448
Fungal genus	6	41.8765	0	0.0002
Fungal species	5	41.4258	0	0.0004
Fungal strain	11	23.3477	0.01578	0.4664
Growth habit	3	47.0222	0	0.0004
Host group	2	32.9822	0	0.0016
Host family	5	42.1591	0	0.0002
Host genus	8	66.313	0	0.0002
Host species	11	72.4991	0	0.0002
Isolation from host	2	17.1828	0.00019	0.0502
Colonization of host	2	24.1605	0.00001	0.0072
System aeration	N/A	N/A	N/A	N/A
Growth conditions	2	28.6058	0	0.0034
Initial sterilization	2	1.4813	0.4768	0.7258
Agar	1	9.8054	0.00174	0.0702
pH stabilizer (detailed)	1	4.8588	0.02751	0.2332
pH stabilizer (binomial)	1	4.6986	0.03019	0.2408
Carbon (detailed)	6	78.0194	0	0.0002
Carbon (binomial)	1	8.8254	0.00297	0.105
Simple sugars	1	36.2352	0	0.0004
Nitrogen	1	0.764	0.38207	0.6004
Organic nitrogen	1	8.9708	0.00274	0.093
Peat moss	1	38.6495	0	0.0004
Proteins and amino acids	1	20.0787	0.00001	0.0008
Other organic nitrogen	1	16.3939	0.00005	0.019
Inorganic nitrogen	1	3.5356	0.06006	0.3102
Ammonium	1	8.2035	0.00418	0.11
Nitrate	1	26.2369	0	0.0016
Phosphorus	1	0.2449	0.62067	0.7874

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 14. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant total biomass (with non-parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	57	122.7104	0	58	122.7444	0
Publication	44	47.2991	0.33945	56	108.2398	0.00004
Fungal order	51	70.4645	0.03676	56	122.5998	0
Fungal family	51	111.664	0	55	122.5412	0
Fungal genus	46	66.0882	0.02764	52	107.9647	0.00001
Fungal species	44	66.0761	0.01725	49	107.5019	0
Fungal strain	19	38.0183	0.0059	30	61.3661	0.00063
Growth habit	55	75.7222	0.03341	58	122.7444	0
Host group	56	89.7623	0.00281	58	122.7444	0
Host family	51	66.0806	0.07611	56	108.2398	0.00004
Host genus	48	41.9268	0.71879	56	108.2398	0.00004
Host species	45	35.7407	0.83664	56	108.2398	0.00004
Isolation from host	56	105.5617	0.00007	58	122.7444	0
Colonization of host	56	98.584	0.00039	58	122.7444	0
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	56	94.1387	0.00108	58	122.7444	0
Initial sterilization	56	121.2631	0	58	122.7444	0
Agar	57	112.939	0.00001	58	122.7444	0
pH stabilizer (detailed)	56	117.7441	0	57	122.6029	0
pH stabilizer (binomial)	57	118.0458	0	58	122.7444	0
Carbon (detailed)	50	42.6251	0.76104	56	120.6445	0
Carbon (binomial)	57	113.919	0.00001	58	122.7444	0
Simple sugars	57	86.5092	0.00707	58	122.7444	0
Nitrogen	57	121.9804	0	58	122.7444	0
Organic nitrogen	57	113.7737	0.00001	58	122.7444	0
Peat moss	57	84.0949	0.0113	58	122.7444	0
Proteins and amino acids	57	102.6657	0.0002	58	122.7444	0
Other organic nitrogen	57	106.3506	0.00008	58	122.7444	0
Inorganic nitrogen	57	119.2088	0	58	122.7444	0
Ammonium	57	114.5409	0.00001	58	122.7444	0
Nitrate	57	96.5076	0.00084	58	122.7444	0
Phosphorus	57	122.4995	0	58	122.7444	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 15. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the non-parametric total biomass analyses of the Ascomycetes. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	52	-0.05	-0.2599	0.1617
	Fresh weight	5	-0.0815	-0.2501	0.0633
Publication	Alberton et al. (2010)	6	0.0357	-0.0303	0.0918
	Currah et al. (1993)	1	-0.1988	-0.4224	0.0249
	Haselwandter and Read (1982)	3	**0.7532**	**0.0077**	**1.7019**
	Jumpponen et al. (1998)	3	0.1952	-0.0091	0.3995
	Jumpponen and Trappe (1998)	1	**0.0681**	**0.0352**	**0.1009**
	Mandyam et al. (2010)	10	0.2077	-0.071	0.4841
	Newsham (1999)	1	**0.6086**	**0.5203**	**0.7117**
	Richard et al. (1971)	1	**-0.6477**	**-0.7282**	**-0.2822**
	Richard and Fortin (1974)	7	**-0.8192**	**-0.9849**	**-0.6523**
	Usuki and Narisawa (2007)	5	0.5333	-0.45	1.5146
	Vohník et al. (2003)	3	**-0.1788**	**-0.3535**	**-0.0433**
	Vohník et al. (2005)	2	-0.0466	-0.1904	0.0328
	Yu (2000)	1	0.0741	-0.0455	0.1936
Fungal order	Helotiales	23	0.0092	-0.1069	0.1415
	Incertae sedis	13	**-0.6281**	**-0.8034**	**-0.3972**
	Pleosporales	8	0.3389	-0.0987	0.5577
	Xylariales	1	0.3971	-0.0207	0.8149
	Chaetothyriales	1	**0.6086**	**0.5203**	**0.7117**
	Capnodiales	5	0.5333	-0.4494	1.4243

Table 15. Categorical non-parametric total biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal family	*Incertae sedis*	25	-0.1698	-0.4958	0.1548
	Helotiaceae	1	**0.1117**	**0.0745**	**0.149**
	Vibrisseaceae	19	0.0003	-0.1269	0.1484
	Herpotrichiellaceae	1	**0.6086**	**0.5203**	**0.7117**
	Antennulariellaceae	5	0.5333	-0.3865	1.5146
Fungal genus	*Meliniomyces*	1	**0.1117**	**0.0745**	**0.149**
	Phialocephala	19	0.0003	-0.1287	0.1423
	Unidentified dark septate endophyte	12	**-0.6438**	**-0.8249**	**-0.3947**
	Microdochium	1	0.3971	-0.0207	0.8149
	Periconia	7	0.1414	-0.1934	0.481
	Phialophora	1	**0.6086**	**0.5203**	**0.7117**
	Heteroconium	5	0.5333	-0.4425	1.461
Fungal species	*Phialocephala fortinii*	18	-0.0008	-0.1325	0.1502
	Unidentified dark septate endophyte	12	**-0.6438**	**-0.8268**	**-0.3857**
	Microdochium sp.	1	0.3971	-0.0207	0.8149
	Periconia macrospinosa	7	0.1414	-0.1947	0.4951
	Phialophora graminicola	1	**0.6086**	**0.5203**	**0.7117**
	Heteroconium chaetospira	5	0.5333	-0.45	1.4243
Fungal strain	C1	1	0.6148	-0.0604	1.6888
	C2	1	**0.9069**	**0.1006**	**1.7132**
	SE24	4	0.1625	-0.0057	0.349
	KS0012	1	0.3971	-0.0207	0.8149
	KS0019	1	-0.1446	-0.3417	0.0526
	KS0100	1	0.1527	-0.6253	0.9306

Table 15. Categorical non-parametric total biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal strain	*Phialophora graminicola*	1	**0.6086**	**0.5203**	**0.7117**
	MRA	1	**-0.6477**	**-0.7282**	**-0.2822**
	H4007	5	0.5333	-0.4488	1.4817
	CBS 554.86	1	-0.0931	-0.1862	0
	UAMH 8433	1	**-0.2646**	**-0.4425**	**-0.0866**
	UAMH 9525	1	0.0741	-0.0455	0.1936
Growth habit	Tree	23	**-0.4202**	**-0.6093**	**-0.1856**
	Shrub	8	**-0.1638**	**-0.3053**	**-0.0244**
	Graminoid	9	**0.6698**	**0.3793**	**0.9585**
	Forb/herb	15	0.2686	-0.087	0.5088
Host group	Gymnosperm	22	**-0.4371**	**-0.6203**	**-0.2135**
	Dicot	16	0.1592	-0.1764	0.4361
	Monocot	18	**0.269**	**0.0696**	**0.4953**
Host family	Pinaceae	22	**-0.4371**	**-0.621**	**-0.2066**
	Ericaceae	8	**-0.1638**	**-0.3072**	**-0.0256**
	Cyperaceae	3	**0.7532**	**0.0077**	**1.7019**
	Poaceae	5	**0.6432**	**0.3547**	**0.8469**
	Liliaceae	8	-0.0111	-0.2054	0.1463
	Brassicaceae	5	0.5333	-0.4494	1.461
Host genus	*Pinus*	12	**0.1037**	**0.013**	**0.2009**
	Rhododendron	8	**-0.1638**	**-0.3068**	**-0.0223**
	Picea	9	**-0.7753**	**-0.9257**	**-0.6375**
	Carex	3	**0.7532**	**0.0077**	**1.7019**

Table 15. Categorical non-parametric total biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host genus	*Allium*	6	-0.0476	-0.2915	0.1708
	Andropogon	3	**0.6544**	**0.2444**	**0.9017**
	Vulpia	1	**0.6086**	**0.5203**	**0.7117**
	Brassica	5	0.5333	-0.4425	1.4779
	Asparagus	1	0.0741	-0.0455	0.1936
Host species	*Pinus sylvestris*	6	0.0357	-0.03	0.0909
	Rhododendron brachycarpum	1	-0.1988	-0.4224	0.0249
	Carex firma	1	**1.7019**	**1.6888**	**1.7132**
	Carex sempervirens	1	0.0077	-0.0604	0.1006
	Pinus contorta	5	**0.152**	**0.0107**	**0.3079**
	Allium porrum	6	-0.0476	-0.2908	0.1712
	Andropogon gerardii	3	**0.6544**	**0.2444**	**0.9017**
	Vulpia ciliata	1	**0.6086**	**0.5203**	**0.7117**
	Picea mariana	9	**-0.7753**	**-0.9139**	**-0.6402**
	Brassica rapa	5	0.5333	-0.4544	1.4653
	Rhododendron sp.	6	**-0.1393**	**-0.2694**	**-0.0249**
	Asparagus officinalis	1	0.0741	-0.0455	0.1936
Isolation from host	Yes	21	0.0915	-0.3478	0.4843
	No	32	**-0.2119**	**-0.3661**	**-0.0561**
	Unknown	3	**0.6544**	**0.2444**	**0.9017**
Colonization of host	Yes	42	0.1008	-0.09	0.2847
	Slightly	1	-0.088	-0.1904	0.0066
	Unknown	13	**-0.5488**	**-0.8216**	**-0.1418**
Isolation from host	Yes	21	0.0915	-0.3478	0.4843

Table 15. Categorical non-parametric total biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Isolation from host	No	32	**-0.2119**	**-0.3661**	**-0.0561**
	Unknown	3	**0.6544**	**0.2444**	**0.9017**
Colonization of host	Yes	42	0.1008	-0.09	0.2847
	Slightly	1	-0.088	-0.1904	0.0066
	Unknown	13	**-0.5488**	**-0.8216**	**-0.1418**
Growth conditions	Sterile	27	**0.2878**	**0.0395**	**0.4742**
	Growth chamber	28	**-0.3117**	**-0.4875**	**-0.1063**
	Greenhouse	1	**0.3138**	**0.1331**	**0.5203**
Initial sterilization	Sterilized	52	-0.0745	-0.2793	0.136
	Pasteurized	3	0.1952	-0.0091	0.3995
	No	1	**0.0681**	**0.0352**	**0.1009**
Agar	Yes	16	0.2775	-0.0156	0.6011
	No	41	-0.1454	-0.3657	0.0772
pH stabilizer (detailed)	Vermiculite	32	-0.1441	-0.42	0.1226
	No	24	0.1168	-0.0819	0.3668
pH stabilizer (binomial)	Yes	33	-0.139	-0.3997	0.1126
	No	24	0.1168	-0.0824	0.3754
Carbon (detailed)	Peat moss	14	0.0129	-0.0317	0.0533
	Peat moss and plant material	1	-0.1988	-0.4224	0.0249
	Simple sugars	3	-0.1674	-1.0741	0.5944
	Plant material	4	0.3764	-0.2573	0.6074
	Peat moss and simple sugars	9	**-0.7753**	**-0.9202**	**-0.6355**
	Simple sugars and protein and amino acids	1	**1.9346**	**1.641**	**2.2281**

Table 15. Categorical non-parametric total biomass analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Carbon (detailed)	No	18	**0.2175**	**0.018**	**0.4424**
Carbon (binomial)	Yes	39	-0.1544	-0.3881	0.0976
	No	18	**0.2175**	**0.0249**	**0.4352**
Simple sugars	Yes	15	**-0.5702**	**-0.7871**	**-0.2263**
	No	42	**0.1632**	**0.0083**	**0.3127**
Nitrogen	Yes	53	-0.0686	-0.2742	0.1407
	No	4	0.1064	-0.0542	0.2854
Organic nitrogen	Yes	34	-0.167	-0.4195	0.0979
	No	23	0.1912	-0.006	0.3979
Peat moss	Yes	27	**-0.387**	**-0.5454**	**-0.2032**
	No	30	**0.3049**	**0.0897**	**0.4875**
Protein and amino acids	Yes	1	**1.9346**	**1.641**	**2.2281**
	No	56	-0.0851	-0.2754	0.1063
Other organic nitrogen	Yes	18	-0.2772	-0.6248	0.0686
	No	39	**0.1731**	**0.0299**	**0.3226**
Inorganic nitrogen	Yes	39	-0.1271	-0.3939	0.1462
	No	18	0.0954	-0.0708	0.3214
Ammonium	Yes	33	-0.1761	-0.4659	0.0975
	No	24	0.1536	-0.0211	0.3773
Nitrate	Yes	21	**0.3356**	**0.0799**	**0.5158**
	No	36	**-0.2622**	**-0.4354**	**-0.0635**
Phosphorus	Yes	45	-0.0695	-0.3138	0.1692
	No	12	-0.0056	-0.1666	0.1805

Table 16. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant nitrogen concentration (with parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	2	9.0781	0.01068	0.5678
Publication	4	1.1197	0.89113	0.9968
Fungal order	1	1.5636	0.21113	0.6058
Fungal family	3	5.0751	0.16638	0.6964
Fungal genus	5	5.5551	0.35194	0.9248
Fungal species	4	4.6151	0.32912	0.9142
Fungal strain	6	34.0919	0.00001	0.433
Growth habit	2	18.145	0.00011	0.3518
Host group	2	16.6763	0.00024	0.3976
Host family	2	18.145	0.00011	0.3616
Host genus	2	0.748	0.68799	0.9396
Host species	3	0.7741	0.85564	0.9902
Isolation from host	1	1.8546	0.17325	0.6738
Colonization of host	2	27.2073	0	0.1648
System aeration	N/A	N/A	N/A	N/A
Growth conditions	1	0.8844	0.34701	0.6826
Initial sterilization	2	0.7386	0.69121	0.9336
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	1	1.1707	0.27926	0.72
pH stabilizer (binomial)	1	1.1707	0.27926	0.7156
Carbon (detailed)	2	33.6064	0	0.0112
Carbon (binomial)	1	12.7816	0.00035	0.2362
Simple sugars	N/A	N/A	N/A	N/A
Nitrogen	1	1.8709	0.17137	0.5406
Organic nitrogen	1	16.0961	0.00006	0.1814
Peat moss	1	10.4193	0.00125	0.318
Proteins and amino acids	1	22.7453	0	0.099
Other organic nitrogen	1	17.8094	0.00002	0.135
Inorganic nitrogen	1	43.1363	0	0.0066
Ammonium	1	43.1363	0	0.0084
Nitrate	1	8.4319	0.00369	0.2716
Phosphorus	1	21.3998	0	0.1198

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 17. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant nitrogen concentration (with parametric variance) to the inoculation of an ascomycetous root endophyte. See Table 1 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	27	128.0813	0	29	137.1594	0
Publication	23	99.8071	0	27	100.9268	0
Fungal order	26	100.0544	0	27	101.618	0
Fungal family	23	83.7423	0	26	88.8174	0
Fungal genus	19	75.21	0	24	80.7651	0
Fungal species	18	75.0019	0	22	79.617	0
Fungal strain	11	41.3307	0.00002	17	75.4226	0
Growth habit	26	115.4496	0	28	133.5947	0
Host group	27	120.4831	0	29	137.1594	0
Host family	26	115.4496	0	28	133.5947	0
Host genus	25	100.1788	0	27	100.9268	0
Host species	24	100.1527	0	27	100.9268	0
Isolation from host	28	135.3047	0	29	137.1594	0
Colonization of host	27	109.952	0	29	137.1594	0
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	27	104.7224	0	28	105.6067	0
Initial sterilization	27	136.4207	0	29	137.1594	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	28	135.9887	0	29	137.1594	0
pH stabilizer (binomial)	28	135.9887	0	29	137.1594	0
Carbon (detailed)	23	65.9254	0.00001	25	99.5318	0
Carbon (binomial)	28	124.3777	0	29	137.1594	0
Simple sugars	N/A	N/A	N/A	N/A	N/A	N/A
Nitrogen	28	135.2885	0	29	137.1594	0
Organic nitrogen	28	121.0633	0	29	137.1594	0
Peat moss	28	126.74	0	29	137.1594	0
Proteins and amino acids	28	114.4141	0	29	137.1594	0
Other organic nitrogen	28	119.3499	0	29	137.1594	0
Inorganic nitrogen	28	94.0231	0	29	137.1594	0
Ammonium	28	94.0231	0	29	137.1594	0
Nitrate	28	128.7275	0	29	137.1594	0
Phosphorus	28	115.7596	0	29	137.1594	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 18. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric nitrogen concentration analyses of the Ascomycetes. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect Size	-95% BS CI	+95% BS CI
Measurement type	Shoot nitrogen concentration	19	0.0358	-0.042	0.1481
	Plant nitrogen concentration	6	0.0668	-0.0655	0.1333
	Foliar nitrogen concentration	2	**0.1109**	**0.0606**	**0.216**
Publication	Alberton et al. (2010)	6	**0.0989**	**0.0194**	**0.1825**
	Jumpponen et al. (1998)	3	0.0991	-0.0386	0.1526
	Jumpponen & Trappe (1998)	1	0.0295	-0.0481	0.0531
	Upson et al. (2010)	11	0.0814	-0.1067	0.2216
	Vohník et al. (2005)	2	**0.1109**	**0.0606**	**0.216**
Fungal order	Helotiales	22	**0.0934**	**0.0515**	**0.1447**
	Incertae sedis	4	0.1352	-0.2272	0.2003
Fungal family	*Incertae sedis*	5	0.0686	-0.1662	0.1922
	Helotiaceae	1	**0.1149**	**0.0993**	**0.1421**
	Vibrisseaceae	10	**0.0645**	**0.0156**	**0.098**
	Dermataceae	7	0.1465	-0.0705	0.2941
Fungal genus	*Meliniomyces*	1	**0.1149**	**0.0993**	**0.1421**
	Phialocephala	10	**0.0645**	**0.0137**	**0.0982**
	Unidentified dark septate endophyte	1	**-0.0523**	**-0.1203**	**-0.0051**
	Mollisia	3	0.0645	-0.3084	0.2556
	Oculimacula	1	0.1562	-0.0383	0.2427
	Tapesia	3	0.1138	-0.2453	0.3666
Fungal species	*Phialocephala fortinii*	10	**0.0645**	**0.0151**	**0.098**
	Unidentified dark septate endophyte	1	**-0.0523**	**-0.1203**	**-0.0051**

Table 18. Parametric nitrogen concentration analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect Size	-95% BS CI	+95% BS CI
Fungal species	*Mollisia* sp.	3	0.0645	-0.3084	0.2556
	Oculimacula yallundae	1	0.1562	-0.0383	0.2427
	Tapesia sp.	3	0.1138	-0.2453	0.3666
Fungal strain	SE 24	5	0.0695	-0.0656	0.1378
	C4	1	**-0.0523**	**-0.1203**	**-0.0051**
	H3	1	**-0.2655**	**-0.3803**	**-0.0821**
	H4	1	0.2042	-0.0705	0.2892
	I4	1	0.1562	-0.0383	0.2427
	C7	1	**-0.107**	**-0.2326**	**-0.0561**
	I9	1	0.2732	-0.257	0.4268
Growth habit	Tree	12	**0.0963**	**0.0287**	**0.1536**
	Shrub	2	**0.1109**	**0.0606**	**0.216**
	Graminoid	12	-0.0034	-0.0935	0.1858
Host group	Gymnosperm	12	**0.0963**	**0.0322**	**0.152**
	Dicot	3	**0.1036**	**0.0364**	**0.1813**
	Monocot	12	-0.0034	-0.0951	0.1883
Host family	Pinaceae	12	**0.0963**	**0.0292**	**0.1542**
	Ericaceae	2	**0.1109**	**0.0606**	**0.216**
	Poaceae	12	-0.0034	-0.097	0.1863
Host genus	*Pinus*	12	**0.0963**	**0.0316**	**0.1548**
	Rhododendron	2	**0.1109**	**0.0606**	**0.216**
	Deschampsia	11	0.0814	-0.1081	0.2253
Host species	*Pinus sylvestris*	6	**0.0989**	**0.0196**	**0.1838**
	Pinus contorta	5	0.0915	-0.0282	0.1429

Table 18. Parametric nitrogen concentration analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect Size	-95% BS CI	+95% BS CI
Host species	*Deschampsia antarctica*	11	0.0814	-0.1032	0.222
	Rhododendron sp.	2	**0.1109**	**0.0606**	**0.216**
Isolation of host	Yes	17	0.057	-0.0386	0.1605
	No	11	**0.0898**	**0.035**	**0.1442**
Colonization of host	Yes	22	0.0597	-0.0093	0.1455
	Slightly	1	**0.1367**	**0.0773**	**0.216**
	No	4	**-0.1506**	**-0.2788**	**-0.0753**
Growth conditions	Sterile	21	**0.1019**	**0.0449**	**0.1612**
	Growth Chamber	6	0.0668	-0.0633	0.1335
Initial sterilization	Sterilized	23	0.0671	-0.0053	0.1399
	Pasteurized	3	0.0991	-0.0386	0.1526
	No	1	0.0295	-0.0481	0.0531
pH stabilizer (detailed)	Vermiculite	8	**0.095**	**0.0151**	**0.1723**
	No	20	0.0632	-0.0156	0.1424
pH Stabilizer (binomial)	Yes	8	**0.095**	**0.0195**	**0.1712**
	No	20	0.0632	-0.0154	0.1442
Carbon (detailed)	Peat moss	12	**0.1011**	**0.0502**	**0.1582**
	Protein and amino acids	5	**-0.1845**	**-0.2845**	**-0.0964**
	No	6	**0.1918**	**0.0004**	**0.3218**
Carbon (binomial)	Yes	22	0.0552	-0.0128	0.1187
	No	6	0.1918	-0.0036	0.3229
Nitrogen	Yes	27	0.0655	-0.0018	0.1349
	No	1	0.134	-0.1265	0.1495

Table 18. Parametric nitrogen concentration analyses of the Ascomycetes (continued from previous page).

Factor	Category	df	ln Effect Size	-95% BS CI	+95% BS CI
Organic nitrogen	Yes	21	0.0491	-0.0234	0.1176
	No	7	**0.1773**	**0.0506**	**0.2912**
Peat moss	Yes	14	**0.0976**	**0.047**	**0.1544**
	No	14	0.0189	-0.0766	0.1779
Protein and amino acids	Yes	5	**-0.1845**	**-0.2846**	**-0.0964**
	No	23	**0.0817**	**0.0137**	**0.1529**
Other organic nitrogen	Yes	3	-0.021	-0.0886	0.1526
	No	25	**0.0964**	**0.038**	**0.1491**
Inorganic nitrogen	Yes	15	**0.121**	**0.0689**	**0.1872**
	No	13	-0.0448	-0.1234	0.0603
Ammonium	Yes	15	**0.121**	**0.0704**	**0.188**
	No	13	-0.0448	-0.1187	0.0647
Nitrate	Yes	2	**0.1109**	**0.0606**	**0.216**
	No	26	0.0417	-0.0298	0.1334
Phosphorus	Yes	21	**0.1019**	**0.0442**	**0.1601**
	No	7	-0.0206	-0.0817	0.1192

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APPENDIX 3

DETAILED RESULTS FOR THE META-ANALYSIS:

HELOTIALES

Table 1. Among-study heterogeneity (Q_M) of the factors used in the categorical analyses on the response of plant root biomass (with parametric variance) to the inoculation of a root endophyte of the Helotiales. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	0.1114	0.73853	1
Publication	8	557.992	0	8
Fungal family	3	15.5734	0.00139	3
Fungal genus	4	123.6224	0	4
Fungal species	3	123.328	0	3
Fungal strain	8	88.3715	0	8
Growth habit	3	143.0121	0	3
Host group	2	150.9284	0	2
Host family	5	177.6937	0	5
Host genus	5	557.5912	0	5
Host species	5	554.2237	0	5
Isolation from host	1	3.6929	0.05464	1
Colonization of host	1	0.0143	0.90472	1
System aeration	N/A	N/A	N/A	N/A
Growth conditions	1	198.8059	0	1
Initial sterilization	2	2.197	0.33337	2
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	2	527.0003	0	2
pH stabilizer (binomial)	1	103.7804	0	1
Carbon (detailed)	3	281.2686	0	3
Carbon (binomial)	1	72.8897	0	1
Simple sugars	1	254.2829	0	1
Nitrogen	1	0.8618	0.35322	1
Organic nitrogen	1	183.945	0	1
Peat moss	1	30.735	0	1
Proteins and amino acids	1	70.6366	0	1
Other organic nitrogen	1	193.6215	0	1
Inorganic nitrogen	1	17.3599	0.00003	1
Ammonium	1	20.6456	0.00001	1
Nitrate	1	2.8232	0.09291	1
Phosphorus	1	0.5739	0.44872	1

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 2. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant root biomass (with parametric variance) to the inoculation of a root endophyte of the Helotiales. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	33	857.5326	0	34	857.644	0
Publication	23	291.4066	0	31	849.3986	0
Fungal family	32	843.5568	0	35	859.1301	0
Fungal genus	26	540.6383	0	30	664.2607	0
Fungal species	25	540.2232	0	28	663.5512	0
Fungal strain	13	228.7142	0	21	317.0856	0
Growth habit	32	716.118	0	35	859.1301	0
Host group	33	708.2017	0	35	859.1301	0
Host family	29	679.9503	0	34	857.644	0
Host genus	26	291.8074	0	31	849.3986	0
Host species	24	274.0004	0	29	828.2241	0
Isolation from host	34	855.4372	0	35	859.1301	0
Colonization of host	33	852.6401	0	34	852.6545	0
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	34	660.3242	0	35	859.1301	0
Initial sterilization	33	856.9331	0	35	859.1301	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	32	330.6437	0	34	857.644	0
pH stabilizer (binomial)	34	755.3497	0	35	859.1301	0
Carbon (detailed)	28	570.1404	0	31	851.409	0
Carbon (binomial)	34	786.2405	0	35	859.1301	0
Simple sugars	34	604.8472	0	35	859.1301	0
Nitrogen	34	858.2683	0	35	859.1301	0
Organic nitrogen	34	675.1851	0	35	859.1301	0
Peat moss	34	828.3952	0	35	859.1301	0
Proteins and amino acids	34	788.4935	0	35	859.1301	0
Other organic nitrogen	34	665.5086	0	35	859.1301	0
Inorganic nitrogen	34	841.7703	0	35	859.1301	0
Ammonium	34	838.4846	0	35	859.1301	0
Nitrate	34	856.307	0	35	859.1301	0
Phosphorus	34	858.5563	0	35	859.1301	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 3. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric root biomass analyses of the Helotiales. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	26	0.1715	-0.0799	0.4901
	Fresh weight	7	0.1471	-0.0111	0.3681
Publication	Alberton et al. (2010)	5	0.0087	-0.1249	0.1044
	Haselwandter and Read (1982)	1	**0.4909**	**0.1379**	**2.1439**
	Jumpponen et al. (1998)	3	0.1307	-0.0395	0.3719
	Jumpponen and Trappe (1998)	1	-0.0204	-0.0823	0.0162
	Schulz and Boyle (2006)	1	**1.66**	**1.6377**	**1.6759**
	Upson et al. (2009)	7	-0.1498	-0.5291	0.4333
	Vohník et al. (2003)	3	-0.0174	-0.2719	0.0326
	Vohník et al. (2005)	1	0	0	0
	Yu (2000)	1	0.108	-0.0274	0.2564
Fungal family	*Incertae sedis*	3	**0.1549**	**0.0776**	**0.1785**
	Helotiaceae	1	**0.0735**	**0.0175**	**0.1324**
	Vibrisseaceae	20	**0.2546**	**0.0003**	**0.6716**
	Dermataceae	8	0.0797	-0.4064	0.8049
Fungal genus	*Meliniomyces*	1	**0.0735**	**0.0175**	**0.1324**
	Phialocephala	20	**0.2546**	**0.0081**	**0.6667**
	Mollisia	1	-0.8369	-1.2543	0.3225
	Oculimacula	1	0.0347	-0.4781	0.9509
	Tapesia	3	-0.0218	-0.3061	1.0274
Fungal species	*Phialocephala fortinii*	20	**0.2546**	**0.0081**	**0.6671**
	Mollisia sp.	1	-0.8369	-1.2543	0.3225

Table 3. Categorical parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal species	*Oculimacula yallundae*	1	0.0347	-0.4781	0.9509
	Tapesia sp.	3	-0.0218	-0.3061	1.0274
Fungal strain	C2	1	**0.4909**	**0.1379**	**2.1439**
	SE24	5	0.3022	-0.0402	0.5573
	H4	1	-0.8369	-1.2543	0.3225
	I4	1	0.0347	-0.4781	0.9509
	C7	1	0.1025	-0.1255	1.0318
	C7	1	0.1025	-0.1255	1.0318
	I9	1	-0.1379	-0.4072	1.0231
	CBS 554.86	1	0.0153	-0.023	0.0205
	UAMH 8433	1	-0.0751	-0.5261	0.0405
	UAMH 9525	1	0.108	-0.0274	0.2564
Growth habit	Tree	14	**0.4547**	**0.0465**	**0.9664**
	Shrub	5	-0.0024	-0.0409	0.0105
	Graminoid	10	-0.0968	-0.4352	0.375
	Forb/herb	3	**0.2099**	**0.108**	**0.5493**
Host group	Gymnosperm	13	0.5745	-0.0221	1.1016
	Dicot	8	**0.1395**	**0.0056**	**0.228**
	Monocot	12	-0.0882	-0.406	0.3654
Host family	Pinaceae	13	0.5745	-0.0275	1.0906
	Ericaceae	5	-0.0024	-0.0505	0.0105
	Cyperaceae	1	**0.4909**	**0.1379**	**2.1439**
	Poaceae	8	-0.1236	-0.459	0.3577
	Asteraceae	1	**0.2169**	**0.1823**	**0.6402**

Table 3. Categorical parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host family	Liliaceae	1	0.108	-0.0274	0.2564
Host genus	*Pinus*	11	0.0118	-0.0936	0.0952
	Rhododendron	5	-0.0024	-0.0427	0.0098
	Carex	1	**0.4909**	**0.1379**	**2.1439**
	Larix	1	**1.66**	**1.6377**	**1.6759**
	Deschampsia	7	-0.1498	-0.5307	0.4101
	Asparagus	1	0.108	-0.0274	0.2564
Host species	*Pinus sylvestris*	5	0.0087	-0.1224	0.1044
	Pinus contorta	5	0.0254	-0.0429	0.1837
	Larix decidua	1	**1.66**	**1.6377**	**1.6759**
	Deschampsia antarctica	7	-0.1498	-0.5302	0.4055
	Rhododendron sp.	5	-0.0024	-0.0498	0.0105
	Asparagus officinalis	1	0.108	-0.0274	0.2564
Isolation from host	Yes	16	0.2076	-0.1283	0.6195
	No	18	**0.1303**	**0.0273**	**0.2112**
Colonization of host	Yes	31	0.193	-0.0617	0.4825
	No	2	0.1846	-0.1255	1.0318
Growth conditions	Sterile	17	-0.0021	-0.2028	0.1593
	Growth chamber	17	**0.5964**	**0.1709**	**1.2134**
Background sterilization	Sterilized	29	0.183	-0.0394	0.436
	Pasteurized	3	0.1307	-0.0395	0.3719
	No	1	-0.0204	-0.0823	0.0162
pH stabilizer (detailed)	Vermiculite	11	0.0966	-0.0439	0.155
	Expanded clay medium	1	**1.66**	**1.6377**	**1.6759**

Table 3. Categorical parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
	No	20	-0.0432	-0.2726	0.2285
pH stabilizer (binomial)	Yes	14	**0.3562**	**0.0952**	**0.776**
	No	20	-0.0432	-0.2843	0.2325
Carbon (detailed)	Peat moss	12	0.005	-0.0509	0.0541
	Simple sugars	2	**0.7792**	**0.2397**	**1.6759**
	Protein and amino acids	3	**0.8718**	**0.5475**	**1.0274**
	Plant material	2	0.1715	-0.5261	0.1823
	No	9	-0.3121	-0.6427	0.0039
Carbon (binomial)	Yes	25	**0.3225**	**0.1265**	**0.6446**
	No	9	**-0.3121**	**-0.6316**	**-0.0065**
Simple sugars	Yes	2	**0.7792**	**0.2397**	**1.6759**
	No	32	0.0178	-0.148	0.1614
Nitrogen	Yes	30	0.1824	-0.031	0.4351
	No	4	0.0938	-0.0122	0.2354
Organic nitrogen	Yes	24	**0.3223**	**0.1216**	**0.6307**
	No	10	-0.3073	-0.6451	0.0018
Peat	Yes	14	0.0298	-0.0364	0.1268
	No	20	0.257	-0.0691	0.6546
Proteins and amino acids	Yes	3	**0.8718**	**0.5475**	**1.0274**
	No	31	0.1398	-0.0848	0.3943
Other organic nitrogen	Yes	8	**0.5184**	**0.2038**	**1.4928**
	No	26	-0.0378	-0.2035	0.133

Table 3. Categorical parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Inorganic nitrogen	Yes	17	0.1431	-0.1078	0.4217
	No	17	**0.3645**	**0.1292**	**0.6078**
Ammonium	Yes	15	0.1382	-0.1214	0.424
	No	19	**0.373**	**0.1565**	**0.6149**
Nitrate	Yes	5	**0.1431**	**0.0171**	**0.2344**
	No	29	0.2088	-0.1459	0.6267
Phosphorus	Yes	24	0.1828	-0.0493	0.4607
	No	10	0.1284	-0.0418	0.3384

Table 4. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant root biomass (with non-parametric variance) to the inoculation of a root endophyte of the Helotiales. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	0.0728	0.78726	0.8886
Publication	9	93.3991	0	0.0072
Fungal family	3	31.6149	0	0.0936
Fungal genus	5	18.3322	0.00256	0.3822
Fungal species	4	23.6134	0.0001	0.2216
Fungal strain	13	28.8928	0.00678	0.421
Growth habit	3	21.2623	0.00009	0.2548
Host group	2	14.0265	0.0009	0.2654
Host family	6	25.7291	0.00025	0.4832
Host genus	8	93.1051	0	0.0048
Host species	8	88.6291	0	0.0042
Isolation from host	1	37.5625	0	0.0008
Colonization of host	1	2.4545	0.11719	0.2744
System aeration	NA	NA	NA	NA
Growth conditions	2	38.1445	0	0.0064
Initial sterilization	2	0.2977	0.86168	0.9
Agar	NA	NA	NA	NA
pH stabilizer (detailed)	2	79.3693	0	0.0004
pH stabilizer (binomial)	1	27.7753	0	0.0122
Carbon (detailed)	3	78.343	0	0.0028
Carbon (binomial)	1	0.3306	0.56528	0.8212
Simple sugars	1	68.5093	0	0.0006
Nitrogen	1	0.0108	0.91713	0.9436
Organic nitrogen	1	0.1071	0.74344	0.8814
Peat moss	1	30.3108	0	0.0032
Proteins and amino acids	1	5.4665	0.01938	0.223
Other organic nitrogen	1	37.0021	0	0.0058
Inorganic nitrogen	1	26.5063	0	0.0148
Ammonium	1	22.1511	0	0.0292
Nitrate	1	1.05	0.30551	0.5444
Phosphorus	1	32.6983	0	0.001

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 5. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant root biomass (with non-parametric variance) to the inoculation of a root endophyte of the Helotiales. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	33	857.5326	0	34	857.644	0
Publication	23	291.4066	0	31	849.3986	0
Fungal family	32	843.5568	0	35	859.1301	0
Fungal genus	26	540.6383	0	30	664.2607	0
Fungal species	25	540.2232	0	28	663.5512	0
Fungal strain	13	228.7142	0	21	317.0856	0
Growth habit	32	716.118	0	35	859.1301	0
Host group	33	708.2017	0	35	859.1301	0
Host family	29	679.9503	0	34	857.644	0
Host genus	26	291.8074	0	31	849.3986	0
Host species	24	274.0004	0	29	828.2241	0
Isolation from host	34	855.4372	0	35	859.1301	0
Colonization of host	33	852.6401	0	34	852.6545	0
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	34	660.3242	0	35	859.1301	0
Initial sterilization	33	856.9331	0	35	859.1301	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	32	330.6437	0	34	857.644	0
pH stabilizer (binomial)	34	755.3497	0	35	859.1301	0
Carbon (detailed)	28	570.1404	0	31	851.409	0
Carbon (binomial)	34	786.2405	0	35	859.1301	0
Simple sugars	34	604.8472	0	35	859.1301	0
Nitrogen	34	858.2683	0	35	859.1301	0
Organic nitrogen	34	675.1851	0	35	859.1301	0
Peat moss	34	828.3952	0	35	859.1301	0
Proteins and amino acids	34	788.4935	0	35	859.1301	0
Other organic nitrogen	34	665.5086	0	35	859.1301	0
Inorganic nitrogen	34	841.7703	0	35	859.1301	0
Ammonium	34	838.4846	0	35	859.1301	0
Nitrate	34	856.307	0	35	859.1301	0
Phosphorus	34	858.5563	0	35	859.1301	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 6. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the non-parametric root biomass analyses of the Helotiales. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	41	0.1084	-0.1693	0.391
	Fresh weight	7	0.0671	-0.1447	0.2799
Publication	Alberton et al. (2010)	5	0.0224	-0.0982	0.1018
	Fernando and Currah (1996)	14	-0.2572	-0.5536	-0.0185
	Haselwandter and Read (1982)	1	1.1409	0.1379	2.1439
	Jumpponen et al. (1998)	3	0.1791	-0.0083	0.3665
	Jumpponen and Trappe (1998)	1	-0.0331	-0.0823	0.0162
	Schulz and Boyle (2006)	1	**1.6568**	**1.6377**	**1.6759**
	Upson et al. (2009)	7	0.1329	-0.4178	0.6532
	Vohník et al. (2003)	3	-0.122	-0.3894	0.0305
	Vohník et al. (2005)	1	0	0	0
	Yu (2000)	1	0.1145	-0.0274	0.2564
Fungal family	*Incertae sedis*	15	-0.193	-0.5243	0.0374
	Helotiaceae	1	**0.0749**	**0.0175**	**0.1324**
	Vibrisseaceae	23	0.2604	-0.0009	0.5958
	Dermataceae	8	0.7652	-0.2562	1.3056
Fungal genus	*Meliniomyces*	1	**0.0749**	**0.0175**	**0.1324**
	Phialocephala	23	**0.2604**	**0.0021**	**0.5803**
	Leptodontidium	12	-0.2152	-0.5776	0.0358
	Mollisia	1	-0.4659	-1.2543	0.3225
	Oculimacula	1	0.2364	-0.4781	0.9509
	Tapesia	3	0.3805	-0.2664	1.0274

Table 6. Categorical non-parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal species	*Phialocephala fortinii*	23	**0.2604**	**0.0026**	**0.5931**
	Leptodontidium orchidicola	11	**-0.3257**	**-0.6973**	**-0.0409**
	Mollisia sp.	1	-0.4659	-1.2543	0.3225
	Oculimacula yallundae	1	0.2364	-0.4781	0.9509
	Tapesia sp.	3	0.3805	-0.2664	1.0274
Fungal strain	UAMH 8148	3	0.0515	-0.2012	0.2176
	UAMH 5422	2	-0.2207	-0.575	0.3129
	UAMH 8149	2	**-0.7874**	**-1.9367**	**-0.0718**
	UAMH 8151	2	-0.0361	-0.5432	0.2958
	UAMH 8152	2	**-0.2587**	**-0.5125**	**-0.0379**
	C2	1	**1.1409**	**0.1379**	**2.1439**
	SE24	5	0.2337	-0.0031	0.4569
	H4	1	-0.4659	-1.2543	0.3225
	I4	1	0.2364	-0.4781	0.9509
	C7	1	0.4532	-0.1255	1.0318
	I9	1	0.3079	-0.4072	1.0231
	CBS 554.86	1	-0.0012	-0.023	0.0205
	UAMH 8433	1	-0.2428	-0.5261	0.0405
	UAMH 9525	1	0.1145	-0.0274	0.2564
Growth habit	Tree	19	0.3348	-0.2294	0.7904
	Shrub	15	**-0.2249**	**-0.3512**	**-0.093**
	Graminoid	10	0.2641	-0.1781	0.7611
	Forb/herb	3	**0.2203**	**0.0925**	**0.4548**

Table 6. Categorical non-parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host group	Gymnosperm	18	0.3387	-0.2644	0.8397
	Dicot	18	-0.1007	-0.2767	0.0468
	Monocot	12	0.2131	-0.1032	0.5717
Host family	Pinaceae	18	0.3387	-0.2574	0.8333
	Ericaceae	5	-0.0945	-0.2976	0.0236
	Rosaceae	9	**-0.2698**	**-0.4236**	**-0.1049**
	Cyperaceae	1	**1.1409**	**0.1379**	**2.1439**
	Poaceae	8	0.1238	-0.3519	0.5514
	Asteraceae	1	**0.2638**	**0.1823**	**0.6402**
	Liliaceae	1	0.1145	-0.0274	0.2564
Host genus	*Pinus*	11	0.075	-0.0282	0.185
	Rhododendron	5	-0.0945	-0.2976	0.0236
	Dasiphora	4	**-0.233**	**-0.3664**	**-0.0324**
	Dryas	4	**-0.3066**	**-0.5498**	**-0.0276**
	Picea	4	-0.2321	-1.107	0.2828
	Carex	1	**1.1409**	**0.1379**	**2.1439**
	Larix	1	**1.6568**	**1.6377**	**1.6759**
	Deschampsia	7	0.1329	-0.4274	0.6593
	Asparagus	1	0.1145	-0.0274	0.2564
Host species	*Pinus sylvestris*	5	0.0224	-0.0965	0.1021
	Dasiphora fruticosa	4	**-0.233**	**-0.3664**	**-0.0417**
	Dryas octopetala	4	**-0.3066**	**-0.5498**	**-0.0212**
	Picea glauca	4	-0.2321	-1.107	0.2845
	Pinus contorta	5	0.1071	-0.0466	0.2718

Table 6. Categorical non-parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host species	*Larix decidua*	1	**1.6568**	**1.6377**	**1.6759**
	Deschampsia antarctica	7	0.1329	-0.4296	0.652
	Rhododendron sp.	5	-0.0945	-0.2976	0.0234
	Asparagus officinalis	1	0.1145	-0.0274	0.2564
Isolation from host	Yes	16	**0.632**	**0.1048**	**1.1622**
	No	33	-0.1128	-0.303	0.0511
Colonization of host	Yes	46	0.0885	-0.1567	0.3459
	No	2	0.5589	-0.1255	1.0318
Growth conditions	Sterile	17	0.1121	-0.0981	0.2599
	Growth Chamber	17	**0.5302**	**0.0788**	**0.9452**
	Greenhouse	14	**-0.2572**	**-0.5479**	**-0.0156**
Background sterilization	Sterilized	44	0.1038	-0.1569	0.3708
	Pasteurized	3	0.1791	-0.0083	0.3665
	No	1	-0.0331	-0.0823	0.0162
pH Stabilizer (detailed)	Vermiculite	11	0.0987	-0.0157	0.1571
	Expanded Clay Medium	1	**1.6568**	**1.6377**	**1.6759**
	No	35	-0.1055	-0.3138	0.0805
pH Stabilizer (binomial)	Yes	14	**0.5081**	**0.0726**	**0.9734**
	No	35	-0.1055	-0.3232	0.0768
Carbon (detailed)	Peat moss	27	**-0.181**	**-0.4031**	**-0.0062**
	Simple sugars	2	**1.4483**	**0.2397**	**1.6759**
	Protein and amino acids	3	**0.8321**	**0.4976**	**1.0274**
	Plant material	2	0.0519	-0.5261	0.1823
	No	9	0.0126	-0.3081	0.3508

Table 6. Categorical non-parametric root biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Carbon (binomial)	Yes	40	0.1164	-0.1472	0.4021
	No	9	0.0126	-0.3109	0.3487
Simple sugars	Yes	2	**1.4483**	**0.2397**	**1.6759**
	No	47	-0.0513	-0.2302	0.0901
Nitrogen	Yes	45	0.1023	-0.1473	0.3703
	No	4	0.1223	-0.0367	0.2841
Organic nitrogen	Yes	39	0.1112	-0.156	0.395
	No	10	0.058	-0.2365	0.3692
Peat moss	Yes	29	-0.1419	-0.358	0.0405
	No	20	**0.4798**	**0.0738**	**0.9155**
Proteins and amino acids	Yes	3	**0.8321**	**0.4976**	**1.0274**
	No	46	0.0812	-0.1535	0.3367
Other organic nitrogen	Yes	8	**0.641**	**0.123**	**1.2304**
	No	41	-0.106	-0.2899	0.0595
Inorganic nitrogen	Yes	17	**0.5242**	**0.0009**	**1.0306**
	No	32	-0.0883	-0.2819	0.0862
Ammonium	Yes	15	0.4993	-0.0669	1.004
	No	34	-0.0668	-0.2611	0.1021
Nitrate	Yes	5	**0.2441**	**0.0702**	**0.7826**
	No	44	0.0812	-0.1871	0.3622
Phosphorus	Yes	24	**0.4876**	**0.0982**	**0.8943**
	No	25	-0.1559	-0.3745	0.0298

Table 7. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant shoot biomass (with parametric variance) to the inoculation of a root endophyte of the Helotiales. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	N/A	N/A	N/A	N/A
Publication	9	302.0536	0	0.2818
Fungal family	3	27.9433	0	0.8416
Fungal genus	5	54.9901	0	0.7812
Fungal species	4	54.9819	0	0.7036
Fungal strain	9	75.1743	0	0.9438
Growth habit	3	104.2297	0	0.3162
Host group	2	69.3108	0	0.3548
Host family	5	141.2651	0	0.3728
Host genus	5	296.1137	0	0.0654
Host species	5	295.3092	0	0.0818
Isolation from host	1	66.0198	0	0.1392
Colonization of host	1	0.1752	0.67557	0.9502
System aeration	1	17.1306	0.00003	0.3808
Growth conditions	1	66.5913	0	0.1462
Initial sterilization	2	0.5438	0.76192	0.9944
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	2	260.1935	0	0.001
pH stabilizer (binomial)	1	89.0426	0	0.0822
Carbon (detailed)	3	182.0807	0	0.105
Carbon (binomial)	1	5.7734	0.01627	0.6606
Simple sugars	1	106.461	0	0.0346
Nitrogen	1	1.7626	0.1843	0.8474
Organic nitrogen	1	116.1363	0	0.035
Peat moss	1	107.7221	0	0.0444
Proteins and amino acids	1	73.3368	0	0.0798
Other organic nitrogen	1	144.9211	0	0.0126
Inorganic nitrogen	1	17.4497	0.00003	0.4496
Ammonium	1	19.1508	0.00001	0.4372
Nitrate	1	14.5168	0.00014	0.5278
Phosphorus	1	0.8658	0.35213	0.8698

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 8. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant shoot biomass (with parametric variance) to the inoculation of a root endophyte of the Helotiales. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	N/A	N/A	N/A	N/A	N/A	N/A
Publication	25	290.751	0	34	592.8045	0
Fungal family	36	599.2638	0	39	627.207	0
Fungal genus	29	467.2215	0	34	522.2116	0
Fungal species	28	467.2044	0	32	522.1863	0
Fungal strain	15	229.3138	0	24	304.4881	0
Growth habit	36	522.9773	0	39	627.207	0
Host group	37	557.8962	0	39	627.207	0
Host family	32	459.4877	0	37	600.7527	0
Host genus	26	284.4521	0	31	580.5658	0
Host species	24	260.0415	0	29	555.3508	0
Isolation from host	38	561.1872	0	39	627.207	0
Colonization of host	36	581.4643	0	37	581.6395	0
System aeration	38	610.0765	0	39	627.207	0
Growth conditions	38	560.6158	0	39	627.207	0
Initial sterilization	37	626.6632	0	39	627.207	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	36	362.0178	0	38	622.2113	0
pH stabilizer (binomial)	38	538.1645	0	39	627.207	0
Carbon (detailed)	32	431.934	0	35	614.0147	0
Carbon (binomial)	38	621.4336	0	39	627.207	0
Simple sugars	38	520.7461	0	39	627.207	0
Nitrogen	38	625.4444	0	39	627.207	0
Organic nitrogen	38	511.0708	0	39	627.207	0
Peat moss	38	519.485	0	39	627.207	0
Proteins and amino acids	38	553.8703	0	39	627.207	0
Other organic nitrogen	38	482.2859	0	39	627.207	0
Inorganic nitrogen	38	609.7573	0	39	627.207	0
Ammonium	38	608.0563	0	39	627.207	0
Nitrate	38	612.6902	0	39	627.207	0
Phosphorus	38	626.3413	0	39	627.207	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 9. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric shoot biomass analyses of the Helotiales. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Publication	Alberton et al. (2010)	5	**0.0857**	**0.0202**	**0.1544**
	Haselwandter and Read (1982)	1	**0.3853**	**0.0213**	**1.3101**
	Jumpponen et al. (1998)	3	**0.2193**	**0.009**	**0.4262**
	Jumpponen and Trappe (1998)	1	**0.159**	**0.1343**	**0.1744**
	Perez-Naranjo (2010)	2	0.1209	-0.3392	0.2291
	Schulz and Boyle (2006)	1	**0.6484**	**0.6097**	**0.679**
	Upson et al. (2009)	7	0.2027	-0.2001	0.537
	Vohník et al. (2003)	3	-0.0423	-0.2217	0.0111
	Vohník et al. (2005)	1	**0.0219**	**0.0074**	**0.0364**
	Yu (2000)	1	0.0159	-0.0623	0.1101
Fungal family	*Incertae sedis*	6	**0.2496**	**0.0262**	**0.2677**
	Helotiaceae	1	**0.1889**	**0.1823**	**0.1974**
	Vibrisseaceae	21	**0.1846**	**0.0151**	**0.422**
	Dermataceae	8	0.3489	-0.0666	0.5807
Fungal genus	*Meliniomyces*	1	**0.1889**	**0.1823**	**0.1974**
	Phialocephala	21	**0.1846**	**0.0139**	**0.4227**
	Unidentified endophyte	2	0.1209	-0.3392	0.2291
	Mollisia	1	-0.1362	-0.5844	0.2573
	Oculimacula	1	0.5726	-0.2777	0.8243
	Tapesia	3	0.2602	-0.2394	0.6698
Fungal species	*Phialocephala fortinii*	21	**0.1846**	**0.0154**	**0.4217**
	Unidentified endophyte	2	0.1209	-0.3392	0.2291

Table 9. Categorical parametric shoot biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal species	*Mollisia* sp.	1	-0.1362	-0.5844	0.2573
	Oculimacula yallundae	1	0.5726	-0.2777	0.8243
	Tapesia sp.	3	0.2602	-0.2394	0.6698
Fungal strain	C2	1	**0.3853**	**0.0213**	**1.3101**
	SE24	5	**0.3267**	**0.1037**	**0.5286**
	AC1	2	0.1209	-0.3392	0.2291
	H4	1	-0.1362	-0.5844	0.2573
	I4	1	0.5726	-0.2777	0.8243
	C7	1	0.196	-0.1176	0.6454
	I9	1	0.3369	-0.54	0.6865
	CBS 554.86	1	0.0111	-0.0557	0.0151
	UAMH 8433	1	**-0.1917**	**-0.3498**	**-0.1707**
	UAMH 9525	1	0.0159	-0.0623	0.1101
Growth habit	Tree	15	**0.3364**	**0.0541**	**0.5119**
	Shrub	5	0.0123	-0.0768	0.0312
	Graminoid	13	0.1916	-0.0659	0.4377
	Forb/herb	3	**0.2712**	**0.0159**	**0.4396**
Host group	Gymnosperm	13	**0.4025**	**0.0754**	**0.5606**
	Dicot	9	0.2053	-0.0112	0.2577
	Monocot	15	0.1853	-0.0807	0.4083
Host family	Pinaceae	13	**0.4025**	**0.0683**	**0.5609**
	Ericaceae	5	0.0123	-0.0751	0.0304
	Cyperaceae	1	**0.3853**	**0.0213**	**1.3101**
	Poaceae	11	0.1814	-0.0963	0.4356

Table 9. Categorical parametric shoot biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host family	Asteraceae	1	**0.2739**	**0.2719**	**0.5949**
	Liliaceae	1	0.0159	-0.0623	0.1101
Host genus	*Pinus*	11	**0.0951**	**0.0378**	**0.1621**
	Rhododendron	5	0.0123	-0.0768	0.0311
	Carex	1	**0.3853**	**0.0213**	**1.3101**
	Larix	1	**0.6484**	**0.6097**	**0.679**
	Deschampsia	7	0.2027	-0.1778	0.5392
	Asparagus	1	0.0159	-0.0623	0.1101
Host species	*Pinus sylvestris*	5	**0.0857**	**0.0186**	**0.1533**
	Pinus contorta	5	**0.1747**	**0.1046**	**0.2765**
	Larix decidua	1	**0.6484**	**0.6097**	**0.679**
	Deschampsia antarctica	7	0.2027	-0.1831	0.5368
Host species	*Rhododendron* sp.	5	0.0123	-0.0735	0.031
	Asparagus officinalis	1	0.0159	-0.0623	0.1101
Isolation from host	Yes	18	**0.2815**	**0.1127**	**0.4392**
	No	20	**0.0802**	**0.0315**	**0.146**
Colonization of host	Yes	34	**0.2594**	**0.0969**	**0.3736**
	No	2	0.2354	-0.1176	0.6454
System aeration	Open	37	**0.2487**	**0.1008**	**0.3492**
	Closed	1	-0.0353	-0.1181	0.1907
Growth conditions	Sterile	18	**0.2005**	**0.0064**	**0.2599**
	Growth chamber	20	**0.3926**	**0.0923**	**0.5554**

Table 9. Categorical parametric shoot biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Initial sterilization	Sterilized	33	**0.2435**	**0.0908**	**0.346**
	Pasteurized	3	**0.2193**	**0.009**	**0.4262**
	No	1	**0.159**	**0.1343**	**0.1744**
pH stabilizer (detailed)	Vermiculite	11	**0.2412**	**0.0505**	**0.2646**
	Expanded clay medium	1	**0.6484**	**0.6097**	**0.679**
	No	24	0.0953	-0.0311	0.2683
pH stabilizer (binomial)	Yes	14	**0.3003**	**0.1059**	**0.4849**
	No	24	0.0953	-0.0321	0.2632
Carbon (detailed)	Peat moss	12	**0.0456**	**0.0148**	**0.0957**
	Simple sugars	3	**0.474**	**0.0417**	**0.6484**
	No	12	-0.063	-0.2865	0.1325
	Protein and amino acids	3	**0.5994**	**0.3814**	**0.7807**
	Plant material	2	0.2706	-0.3498	0.2719
Carbon (binomial)	Yes	26	**0.2721**	**0.1348**	**0.3981**
	No	12	-0.063	-0.2839	0.1283
Simple sugars	Yes	3	**0.474**	**0.0417**	**0.6484**
	No	35	**0.199**	**0.029**	**0.2571**
Nitrogen	Yes	34	**0.2442**	**0.0901**	**0.3462**
	No	4	0.1236	-0.017	0.2333
Organic nitrogen	Yes	24	**0.2785**	**0.1451**	**0.4188**
	No	14	-0.0674	-0.2528	0.1087
Peat moss	Yes	14	**0.0537**	**0.0205**	**0.1156**
	No	24	**0.2971**	**0.1364**	**0.4688**

Table 9. Categorical parametric shoot biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Proteins and amino acids	Yes	3	**0.5994**	**0.3814**	**0.7807**
	No	35	**0.2232**	**0.0233**	**0.3147**
Other organic nitrogen	Yes	8	**0.3336**	**0.2485**	**0.6473**
	No	30	0.0908	-0.0004	0.2044
Inorganic nitrogen	Yes	21	**0.2296**	**0.0179**	**0.3334**
	No	17	**0.3688**	**0.1335**	**0.5578**
Ammonium	Yes	19	**0.2285**	**0.0203**	**0.3267**
	No	19	**0.3699**	**0.1592**	**0.5556**
Nitrate	Yes	8	**0.216**	**0.0362**	**0.2645**
	No	30	**0.2944**	**0.0534**	**0.4561**
Phosphorus	Yes	28	**0.2442**	**0.093**	**0.345**
	No	10	**0.1827**	**0.0473**	**0.3279**

Table 10. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant total biomass (with parametric variance) to the inoculation of a root endophyte of the Helotiales. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	1.3919	0.23809	0.3024
Publication	6	21.4028	0.00155	0.1388
Fungal family	2	2.2838	0.31922	0.3324
Fungal genus	1	2.1118	0.14617	0.1934
Fungal species	N/A	N/A	N/A	N/A
Fungal strain	4	20.3761	0.00042	0.3702
Growth habit	3	20.0972	0.00016	0.0684
Host group	2	10.8476	0.00441	0.0248
Host family	3	20.0972	0.00016	0.0636
Host genus	3	20.0972	0.00016	0.0662
Host species	3	1.529	0.67559	0.5872
Isolation from host	1	0.0034	0.95357	0.9522
Colonization of host	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A
Growth conditions	1	0.9561	0.32817	0.3796
Initial sterilization	2	0.7516	0.68673	0.663
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	1	0.1348	0.71351	0.7452
pH stabilizer (binomial)	1	0.1348	0.71351	0.74
Carbon (detailed)	2	10.3815	0.00557	0.0632
Carbon (binomial)	1	8.6095	0.00334	0.0186
Simple sugars	N/A	N/A	N/A	N/A
Nitrogen	1	0.1303	0.71817	0.7126
Organic nitrogen	1	9.8939	0.00166	0.0034
Peat moss	1	6.0412	0.01398	0.0192
Proteins and amino acids	N/A	N/A	N/A	N/A
Other organic nitrogen	1	0.0037	0.95142	0.947
Inorganic nitrogen	1	0.3745	0.54056	0.5804
Ammonium	1	0.9561	0.32817	0.3882
Nitrate	1	0.0501	0.82289	0.8024
Phosphorus	1	0.0021	0.96366	0.9682

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 11. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant total biomass (with parametric variance) to the inoculation of a root endophyte of the Helotiales. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	20	57.4427	0.00002	21	58.8346	0.00002
Publication	15	37.4318	0.00109	21	58.8346	0.00002
Fungal family	19	56.5509	0.00001	21	58.8346	0.00002
Fungal genus	18	56.5249	0.00001	19	58.6367	0.00001
Fungal species	N/A	N/A	N/A	N/A	N/A	N/A
Fungal strain	8	30.3277	0.00018	12	50.7038	0
Growth habit	18	38.7375	0.00309	21	58.8346	0.00002
Host group	19	47.9871	0.00026	21	58.8346	0.00002
Host family	18	38.7375	0.00309	21	58.8346	0.00002
Host genus	18	38.7375	0.00309	21	58.8346	0.00002
Host species	16	11.4243	0.78257	19	12.9533	0.84095
Isolation from host	20	58.8313	0.00001	21	58.8346	0.00002
Colonization of host	N/A	N/A	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	20	57.8785	0.00002	21	58.8346	0.00002
Initial sterilization	19	58.083	0.00001	21	58.8346	0.00002
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	20	58.6998	0.00001	21	58.8346	0.00002
pH stabilizer (binomial)	20	58.6998	0.00001	21	58.8346	0.00002
Carbon (detailed)	17	46.5878	0.00014	19	56.9693	0.00001
Carbon (binomial)	20	50.2251	0.00021	21	58.8346	0.00002
Simple sugars	N/A	N/A	N/A	N/A	N/A	N/A
Nitrogen	20	58.7044	0.00001	21	58.8346	0.00002
Organic nitrogen	20	48.9408	0.00031	21	58.8346	0.00002
Peat moss	20	52.7934	0.00009	21	58.8346	0.00002
Proteins and amino acids	N/A	N/A	N/A	N/A	N/A	N/A
Other organic nitrogen	20	58.8309	0.00001	21	58.8346	0.00002
Inorganic nitrogen	20	58.4601	0.00001	21	58.8346	0.00002
Ammonium	20	57.8785	0.00002	21	58.8346	0.00002
Nitrate	20	58.7845	0.00001	21	58.8346	0.00002
Phosphorus	20	58.8326	0.00001	21	58.8346	0.00002

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 12. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric total biomass analyses of the Helotiales. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	15	**0.0509**	**0.0112**	**0.1296**
	Fresh weight	5	-0.0264	-0.1337	0.0299
Publication	Alberton et al. (2010)	5	0.0487	-0.0382	0.1116
	Haselwandter and Read (1982)	1	**0.6844**	**0.1006**	**1.7132**
	Jumpponen et al. (1998)	3	**0.1841**	**0.014**	**0.4074**
	Jumpponen and Trappe (1998)	1	**0.0774**	**0.0352**	**0.1009**
	Vohník et al. (2003)	3	**-0.0435**	**-0.2973**	**-0.0067**
	Vohník et al. (2005)	1	**0.0197**	**0.0066**	**0.0328**
	Yu (2000)	1	0.0511	-0.0455	0.1936
Fungal family	*Incertae sedis*	1	**0.0693**	**0.0578**	**0.08**
	Helotiaceae	1	**0.1094**	**0.0745**	**0.149**
	Vibrisseaceae	17	0.0248	-0.0228	0.0988
Fungal genus	*Meliniomyces*	1	**0.1094**	**0.0745**	**0.149**
	Phialocephala	17	0.0248	-0.0211	0.1018
Fungal strain	C2	1	**0.6844**	**0.1006**	**1.7132**
	SE24	4	**0.1138**	**0.0213**	**0.3148**
	CBS 554.86	1	-0.0106	-0.1862	0
	UAMH 8433	1	**-0.1254**	**-0.4425**	**-0.0866**
	UAMH 9525	1	0.0511	-0.0455	0.1936
Growth habit	Tree	11	0.0557	-0.0208	0.1131
	Shrub	5	0.009	-0.0606	0.0254
	Graminoid	1	**0.6844**	**0.1006**	**1.7132**

Table 12. Categorical parametric total biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Growth habit	Forb/herb	1	0.0511	-0.0455	0.1936
Host group	Gymnosperm	11	0.0557	-0.0202	0.1131
	Dicot	5	0.009	-0.0617	0.0254
	Monocot	3	0.3592	-0.0014	1.1165
Host family	Pinaceae	11	0.0557	-0.0203	0.1151
	Ericaceae	5	0.009	-0.0606	0.0254
	Cyperaceae	1	**0.6844**	**0.1006**	**1.7132**
	Liliaceae	1	0.0511	-0.0455	0.1936
Host genus	*Pinus*	11	0.0557	-0.0193	0.1136
	Rhododendron	5	0.009	-0.0617	0.0257
	Carex	1	**0.6844**	**0.1006**	**1.7132**
	Asparagus	1	0.0511	-0.0455	0.1936
Host species	*Pinus sylvestris*	5	0.0487	-0.0345	0.1108
	Pinus contorta	5	**0.1079**	**0.0438**	**0.2299**
	Rhododendron sp.	5	0.009	-0.0617	0.0257
	Asparagus officinalis	1	0.0511	-0.0455	0.1936
Isolation from host	Yes	5	0.0435	-0.0391	0.241
	No	15	**0.041**	**0.0048**	**0.0945**
Growth conditions	Sterile	7	0.0324	-0.0059	0.0791
	Growth chamber	13	0.0853	-0.0182	0.3401
Initial sterilization	Sterilized	15	0.0387	-0.0008	0.096
	Pasteurized	3	**0.1841**	**0.014**	**0.4074**
	No	1	**0.0774**	**0.0352**	**0.1009**

Table 12. Categorical parametric total biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
pH stabilizer (detailed)	Vermiculite	9	0.0512	-0.0216	0.1053
	No	11	0.0356	-0.0056	0.2014
pH stabilizer (binomial)	Yes	9	0.0512	-0.0228	0.1059
	No	11	0.0356	-0.0063	0.1794
Carbon (detailed)	Peat moss	12	0.029	-0.0072	0.067
	Plant material	1	**-0.2973**	**-0.4425**	**-0.1862**
	No	4	0.331	-0.0072	1.0261
Carbon (binomial)	Yes	16	0.029	-0.0063	0.0681
	No	4	0.331	-0.0072	1.0261
Nitrogen	Yes	17	**0.0408**	**0.0031**	**0.0999**
	No	3	0.0876	-0.0519	0.3384
Organic nitrogen	Yes	15	0.0275	-0.0089	0.0654
	No	5	**0.3402**	**0.0166**	**0.9685**
Peat moss	Yes	13	0.0298	-0.0065	0.0671
	No	7	0.2589	-0.063	0.7883
Other organic nitrogen	Yes	3	0.0308	-0.2973	0.4074
	No	17	**0.0422**	**0.0045**	**0.1007**
Inorganic nitrogen	Yes	9	**0.0477**	**0.0058**	**0.126**
	No	11	0.013	-0.0415	0.0865

Table 12. Categorical parametric total biomass analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Ammonium	Yes	7	0.0324	-0.0066	0.0778
	No	13	0.0853	-0.0146	0.3262
Nitrate	Yes	3	**0.0469**	**0.0115**	**0.6844**
	No	17	0.0375	-0.0238	0.0891
Phosphorus	Yes	12	**0.0423**	**0.0023**	**0.1039**
	No	8	0.0385	-0.0706	0.124

Table 13. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of nitrogen concentration (with parametric variance) to the inoculation of a root endophyte of the Helotiales. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	2	4.3548	0.11333	0.5234
Publication	4	4.4743	0.34561	0.879
Fungal family	3	9.0452	0.0287	0.4398
Fungal genus	4	6.1313	0.18956	0.7896
Fungal species	3	5.6296	0.13109	0.7262
Fungal strain	4	18.9501	0.0008	0.5538
Growth habit	2	3.8366	0.14686	0.5586
Host group	2	5.0073	0.08179	0.4686
Host family	2	3.8366	0.14686	0.5664
Host genus	2	3.8366	0.14686	0.5716
Host species	3	4.1287	0.2479	0.7674
Isolation from host	1	0.1012	0.75044	0.8566
Colonization of host	1	13.235	0.00027	0.0494
System aeration	N/A	N/A	N/A	N/A
Growth conditions	1	0.699	0.40313	0.6214
Initial sterilization	2	0.3487	0.84001	0.9572
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	1	0.5807	0.44606	0.6738
pH stabilizer (binomial)	1	0.5807	0.44606	0.6738
Carbon (detailed)	1	2.3226	0.12751	0.4014
Carbon (binomial)	1	2.1084	0.1465	0.3978
Simple sugars	N/A	N/A	N/A	N/A
Nitrogen	1	0.7637	0.38218	0.6626
Organic nitrogen	1	15.67	0.00008	0.0208
Peat moss	1	3.9699	0.04632	0.2396
Proteins and amino acids	1	13.4466	0.00025	0.0378
Other organic nitrogen	1	0.1043	0.74669	0.8772
Inorganic nitrogen	1	6.7107	0.00958	0.1274
Ammonium	1	6.7107	0.00958	0.1238
Nitrate	1	2.1028	0.14703	0.4238
Phosphorus	1	0.699	0.40313	0.6384

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 14. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant nitrogen concentration (with parametric variance) to the inoculation of a root endophyte of the Helotiales. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	20	67.2819	0	22	71.6367	0
Publication	17	62.6293	0	21	67.1035	0
Fungal family	19	62.5915	0	22	71.6367	0
Fungal genus	16	58.4249	0	20	64.5562	0
Fungal species	15	58.2168	0	18	63.8464	0
Fungal strain	9	38.8664	0.00001	13	57.8166	0
Growth habit	19	63.2669	0	21	67.1035	0
Host group	20	66.6294	0	22	71.6367	0
Host family	19	63.2669	0	21	67.1035	0
Host genus	19	63.2669	0	21	67.1035	0
Host species	18	62.9748	0	21	67.1035	0
Isolation from host	21	71.5355	0	22	71.6367	0
Colonization of host	20	58.0322	0.00001	21	71.2672	0
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	21	70.9377	0	22	71.6367	0
Initial sterilization	20	71.288	0	22	71.6367	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	21	71.056	0	22	71.6367	0
pH stabilizer (binomial)	21	71.056	0	22	71.6367	0
Carbon (detailed)	18	63.1842	0	19	65.5068	0
Carbon (binomial)	21	69.5283	0	22	71.6367	0
Simple sugars	N/A	N/A	N/A	N/A	N/A	N/A
Nitrogen	21	70.873	0	22	71.6367	0
Organic nitrogen	21	55.9667	0.00005	22	71.6367	0
Peat moss	21	67.6667	0	22	71.6367	0
Proteins and amino acids	21	58.1901	0.00002	22	71.6367	0
Other organic nitrogen	21	71.5323	0	22	71.6367	0
Inorganic nitrogen	21	64.926	0	22	71.6367	0
Ammonium	21	64.926	0	22	71.6367	0
Nitrate	21	69.5339	0	22	71.6367	0
Phosphorus	21	70.9377	0	22	71.6367	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 15. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric nitrogen concentration analyses of the Helotiales. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Shoot nitrogen concentration	13	**0.1286**	**0.0377**	**0.2154**
	Plant nitrogen concentration	6	0.0668	-0.0652	0.1341
	Foliar nitrogen concentration	1	**0.0694**	**0.0606**	**0.0773**
Publication	Alberton et al. (2010)	5	**0.1167**	**0.0399**	**0.2011**
	Jumpponen et al. (1998)	3	0.0991	-0.0386	0.1526
	Jumpponen and Trappe (1998)	1	0.0295	-0.0481	0.0531
	Upson et al. (2009)	7	0.1465	-0.0758	0.2911
	Vohník et al. (2005)	1	**0.0694**	**0.0606**	**0.0773**
Fungal family	*Incertae sedis*	1	**0.1879**	**0.0901**	**0.2595**
	Helotiaceae	1	**0.1149**	**0.0993**	**0.1421**
	Vibrisseaceae	10	**0.0645**	**0.0169**	**0.1001**
	Dermataceae	7	0.1465	-0.0704	0.2926
Fungal genus	*Meliniomyces*	1	**0.1149**	**0.0993**	**0.1421**
	Phialocephala	10	**0.0645**	**0.0174**	**0.0993**
	Mollisia	1	0.2042	-0.0705	0.2892
	Oculimacula	1	0.1562	-0.0383	0.2427
	Tapesia	3	0.1138	-0.2453	0.3666
Fungal species	*Phialocephala fortinii*	10	**0.0645**	**0.0186**	**0.0998**
	Mollisia sp.	1	0.2042	-0.0705	0.2892
	Oculimacula yallundae	1	0.1562	-0.0383	0.2427
	Tapesia sp.	3	0.1138	-0.2453	0.3666

Table 15. Categorical parametric nitrogen concentration analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Fungal strain	SE24	5	0.0695	-0.0658	0.1391
	H4	1	0.2042	-0.0705	0.2892
	I4	1	0.1562	-0.0383	0.2427
	C7	1	**-0.107**	**-0.2326**	**-0.0561**
	I9	1	0.2732	-0.257	0.4268
Growth habit	Tree	11	**0.1073**	**0.0438**	**0.1637**
	Shrub	1	**0.0694**	**0.0606**	**0.0773**
	Graminoid	7	0.1465	-0.0697	0.289
Host group	Gymnosperm	11	**0.1073**	**0.0434**	**0.1637**
	Dicot	2	0.0611	-0.1227	0.0773
	Monocot	7	0.1465	-0.0762	0.2872
Host family	Pinaceae	11	**0.1073**	**0.0448**	**0.1635**
	Ericaceae	1	**0.0694**	**0.0606**	**0.0773**
	Poaceae	7	0.1465	-0.078	0.2937
Host genus	*Pinus*	11	**0.1073**	**0.0433**	**0.1634**
	Rhododendron	1	**0.0694**	**0.0606**	**0.0773**
	Deschampsia	7	0.1465	-0.0761	0.2883
Host species	*Pinus sylvestris*	5	**0.1167**	**0.0376**	**0.2011**
	Pinus contorta	5	0.0915	-0.0263	0.1428
	Deschampsia antarctica	7	0.1465	-0.0778	0.2911
	Rhododendron sp.	1	**0.0694**	**0.0606**	**0.0773**
Isolation from host	Yes	11	**0.0886**	**0.0081**	**0.1997**
	No	10	**0.0976**	**0.0509**	**0.156**

Table 15. Categorical parametric nitrogen concentration analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Colonization of host	Yes	18	**0.1141**	**0.0612**	**0.1872**
	No	2	**-0.1124**	**-0.2326**	**-0.0561**
Growth conditions	Sterile	15	**0.0986**	**0.0526**	**0.168**
	Growth chamber	6	0.0668	-0.0652	0.1329
Initial sterilization	Sterilized	16	**0.0937**	**0.0468**	**0.158**
	Pasteurized	3	0.0991	-0.0386	0.1526
	No	1	0.0295	-0.0481	0.0531
pH stabilizer (detailed)	Vermiculite	7	**0.1114**	**0.0378**	**0.19**
	No	14	**0.0869**	**0.0299**	**0.1601**
pH stabilizer (binomial)	Yes	7	**0.1114**	**0.0372**	**0.1905**
	No	14	**0.0869**	**0.0296**	**0.1572**
Carbon (detailed)	Peat moss	10	**0.0806**	**0.0482**	**0.1323**
	Protein and amino acids	3	**-0.1523**	**-0.2453**	**-0.0543**
	No	4	**0.2368**	**0.0187**	**0.3757**
Carbon (binomial)	Yes	17	**0.0726**	**0.0311**	**0.1114**
	No	4	**0.2368**	**0.0187**	**0.3757**
Nitrogen	Yes	20	**0.0896**	**0.0447**	**0.15**
	No	1	0.134	-0.1265	0.1495
Organic nitrogen	Yes	16	**0.0648**	**0.0177**	**0.1027**
	No	5	**0.203**	**0.0744**	**0.3337**
Peat moss	Yes	12	**0.0771**	**0.042**	**0.1197**
	No	9	0.1423	-0.017	0.2599
Proteins and amino acids	Yes	3	**-0.1523**	**-0.2453**	**-0.0543**
	No	18	**0.1043**	**0.0656**	**0.1646**

Table 15. Categorical parametric nitrogen concentration analyses of the Helotiales (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Other organic nitrogen	Yes	2	0.1062	-0.1227	0.1701
	No	19	**0.0918**	**0.0471**	**0.1533**
Inorganic nitrogen	Yes	11	**0.1122**	**0.07**	**0.2012**
	No	10	0.0219	-0.1124	0.1015
Ammonium	Yes	11	**0.1122**	**0.0699**	**0.1985**
	No	10	0.0219	-0.1155	0.0995
Nitrate	Yes	1	**0.0694**	**0.0606**	**0.0773**
	No	20	**0.1109**	**0.0378**	**0.1803**
Phosphorus	Yes	15	**0.0986**	**0.0543**	**0.1704**
	No	6	0.0668	-0.0652	0.1327

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APPENDIX 4

DETAILED RESULTS FOR THE META-ANALYSIS:

P. fortiniii s.l.

Table 1. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant root biomass (with parametric variance) to the inoculation of *Phialocephala fortinii sensu lato*. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	0.9893	0.31991	0.935
Publication	6	9.9432	0.12706	0.294
Fungal strain	4	6.9638	0.13781	0.655
Growth habit	3	53.5255	0	0.61
Host group	2	58.4833	0	0.452
Host family	3	76.9909	0	0.484
Host genus	3	8.4993	0.03674	0.112
Host species	3	2.0928	0.55336	0.35
Isolation from host	1	21.6592	0	0.481
Colonization of host	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A
Growth conditions	1	74.2796	0	0.151
Initial sterilization	2	4.6124	0.09964	0.854
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	1	2.4254	0.11938	0.285
pH stabilizer (binomial)	1	37.932	0	0.372
Carbon (detailed)	3	113.8121	0	0.29
Carbon (binomial)	1	0.003	0.95606	0.991
Simple sugars	1	99.4846	0	0.103
Nitrogen	1	0.9366	0.33315	0.826
Organic nitrogen	1	0.0189	0.89066	0.986
Peat moss	1	90.1182	0	0.065
Proteins and amino acids	N/A	N/A	N/A	N/A
Other organic nitrogen	1	106.0287	0	0.077
Inorganic nitrogen	1	4.2677	0.03884	0.882
Ammonium	1	2.0733	0.14989	0.866
Nitrate	1	38.8015	0	0.252
Phosphorus	1	1.6501	0.19895	0.96

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 2. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant root biomass (with parametric variance) to the inoculation of *Phialocephala fortinii* s.l. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	18	332.7641	0	19	333.7535	0
Publication	11	23.8511	0.01338	17	33.7943	0.00892
Fungal strain	9	27.9895	0.00096	13	34.9533	0.00086
Growth habit	17	280.3344	0	20	333.8599	0
Host group	18	275.3767	0	20	333.8599	0
Host family	15	251.662	0	18	328.6529	0
Host genus	14	25.295	0.03176	17	33.7943	0.00892
Host species	12	6.4449	0.89202	15	8.5377	0.90042
Isolation from host	19	312.2007	0	20	333.8599	0
Colonization of host	N/A	N/A	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	19	259.5804	0	20	333.8599	0
Initial sterilization	18	329.2475	0	20	333.8599	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	17	44.4344	0.0003	18	46.8598	0.00022
pH stabilizer (binomial)	19	295.9279	0	20	333.8599	0
Carbon (detailed)	14	214.6982	0	17	328.5103	0
Carbon (binomial)	19	333.8569	0	20	333.8599	0
Simple sugars	19	234.3753	0	20	333.8599	0
Nitrogen	19	332.9233	0	20	333.8599	0
Organic nitrogen	19	333.841	0	20	333.8599	0
Peat moss	19	243.7417	0	20	333.8599	0
Proteins and amino acids	N/A	N/A	N/A	N/A	N/A	N/A
Other organic nitrogen	19	227.8312	0	20	333.8599	0
Inorganic nitrogen	19	329.5922	0	20	333.8599	0
Ammonium	19	331.7866	0	20	333.8599	0
Nitrate	19	295.0584	0	20	333.8599	0
Phosphorus	19	332.2099	0	20	333.8599	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 3. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric root biomass analyses of *Phialocephala fortinii* s.l. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	12	0.2742	-0.0477	0.902
	Fresh weight	6	0.1806	-0.0551	0.442
Publication	Alberton et al. (2010)	1	-0.1275	-0.2615	0.0766
	Haselwandter and Read (1982)	1	**0.4909**	**0.1379**	**2.1439**
	Jumpponen et al. (1998)	3	0.1307	-0.0467	0.3719
	Jumpponen and Trappe (1998)	1	-0.0204	-0.0823	0.0162
	Vohník et al. (2003)	3	-0.0174	-0.2719	0.0326
	Vohník et al. (2005)	1	0	0	0
	Yu (2000)	1	0.108	-0.0274	0.2564
Fungal strain	C2	1	**0.4909**	**0.1379**	**2.1439**
	SE24	5	0.3022	-0.0379	0.5544
	CBS 554.86	1	0.0153	-0.023	0.0205
	UAMH 8433	1	-0.0751	-0.5261	0.0405
	UAMH 9525	1	0.108	-0.0274	0.2564
Growth habit	Tree	9	0.4219	-0.1153	1.1072
	Shrub	5	-0.0024	-0.0369	0.0098
	Graminoid	1	**0.4909**	**0.1379**	**2.1439**
	Forb/herb	2	0.3875	-0.0274	0.6402
Host group	Gymnosperm	8	0.6233	-0.1632	1.2998
	Dicot	7	0.119	-0.0056	0.2516
	Monocot	3	**0.2986**	**0.0388**	**1.0588**

Table 3. Categorical parametric root biomass analyses of *P. fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host family	Pinaceae	8	0.6233	-0.1601	1.315
	Ericaceae	5	-0.0024	-0.0558	0.0092
	Cyperaceae	1	**0.4909**	**0.1379**	**2.1439**
	Liliaceae	1	0.108	-0.0274	0.2564
Host genus	*Pinus*	7	-0.066	-0.2004	0.0828
	Rhododendron	5	-0.0024	-0.0504	0.0098
	Carex	1	**0.4909**	**0.1379**	**2.1439**
	Asparagus	1	0.108	-0.0274	0.2564
Host species	*Pinus sylvestris*	1	-0.1275	-0.2615	0.0766
	Pinus contorta	5	0.0254	-0.0429	0.1567
	Rhododendron sp.	5	-0.0024	-0.0505	0.0098
	Asparagus officinalis	1	0.108	-0.0274	0.2564
Isolation from host	Yes	5	0.4157	-0.0918	1.3563
	No	14	0.1463	-0.0006	0.2437
Growth conditions	Sterile	3	-0.0269	-0.1359	0.028
	Growth chamber	16	**0.4672**	**0.0987**	**1.0843**
Initial sterilization	Sterilized	14	0.2696	-0.0029	0.7144
	Pasteurized	3	0.1307	-0.0395	0.3719
	No	1	-0.0204	-0.0823	0.0162
pH stabilizer (detailed)	Vermiculite	5	-0.0618	-0.1889	0.0897
	No	12	**0.0669**	**0.005**	**0.3788**
pH stabilizer (binomial)	Yes	7	0.4175	-0.1015	1.1712
	No	12	**0.0669**	**0.005**	**0.338**
Carbon (detailed)	Peat moss	8	-0.0197	-0.1009	0.0258

Table 3. Categorical parametric root biomass analyses of *P. fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Carbon (detailed)	Simple sugars	1	**0.6183**	**0.2397**	**1.6759**
	Plant material	1	**-0.2719**	**-0.5261**	**-0.023**
	No	4	**0.2612**	**0.0183**	**0.8076**
Carbon (binomial)	Yes	15	0.2543	-0.0078	0.7002
	No	4	**0.2612**	**0.0173**	**0.8711**
Simple sugars	No	18	0.0342	-0.0401	0.1821
	Yes	1	**0.6183**	**0.2397**	**1.6759**
Nitrogen	Yes	16	0.2597	-0.0048	0.6619
	No	3	0.1055	-0.0509	0.2931
Organic nitrogen	Yes	14	0.2537	-0.0168	0.6541
	No	5	**0.2704**	**0.0383**	**0.8585**
Peat moss	Yes	10	0.0144	-0.0671	0.1548
	No	9	**0.5569**	**0.1257**	**1.4572**
Other organic nitrogen	Yes	6	**0.599**	**0.2112**	**1.5716**
	No	13	0.0065	-0.0573	0.0929
Inorganic nitrogen	Yes	7	0.281	-0.0214	0.8529
	No	12	0.1241	-0.0223	0.3251
Ammonium	Yes	5	0.2746	-0.0407	0.8322
	No	14	**0.1709**	**0.0214**	**0.3713**
Nitrate	Yes	4	**0.1226**	**0.004**	**0.2774**
	No	15	0.4914	-0.0846	1.0836
Phosphorus	Yes	10	0.2674	-0.0044	0.7412
	No	9	0.1507	-0.07	0.4024

Table 4. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant root biomass (with non-parametric variance) to the inoculation of *Phialocephala fortinii* s.l. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	2.6596	0.10293	0.506
Publication	7	6.0901	0.52926	0.0912
Fungal strain	5	6.4733	0.26285	0.0994
Growth habit	3	11.8185	0.00803	0.2786
Host group	2	6.7117	0.03488	0.4536
Host family	4	12.3739	0.01478	0.389
Host genus	3	5.4558	0.14131	0.0212
Host species	3	0.8391	0.8401	0.425
Isolation from host	1	19.7604	0.00001	0.005
Colonization of host	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A
Growth conditions	2	3.9217	0.14074	0.4704
Initial sterilization	2	1.1769	0.55518	0.7356
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	1	0.1611	0.68815	0.6012
pH stabilizer (binomial)	1	5.4069	0.02006	0.2596
Carbon (detailed)	3	29.0296	0	0.0296
Carbon (binomial)	1	0.0143	0.90496	0.9478
Simple sugars	1	24.8744	0	0.0258
Nitrogen	1	0.5172	0.47203	0.6726
Organic nitrogen	1	0.0034	0.95319	0.977
Peat moss	1	5.9862	0.01442	0.2202
Proteins and amino acids	N/A	N/A	N/A	N/A
Other organic nitrogen	1	9.787	0.00176	0.0904
Inorganic nitrogen	1	14.8729	0.00012	0.0154
Ammonium	1	10.9091	0.00096	0.081
Nitrate	1	0.1799	0.67143	0.8284
Phosphorus	1	8.8755	0.00289	0.072

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 5. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant root biomass (with non-parametric variance) to the inoculation of *Phialocephala fortinii* s.l. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	21	46.3174	0.00116	22	48.977	0.0008
Publication	13	8.2559	0.82654	20	14.346	0.81253
Fungal strain	12	9.5516	0.65523	17	16.0249	0.52207
Growth habit	20	37.1607	0.01119	23	48.9792	0
Host group	21	42.2675	0.00389	23	48.9792	0.00892
Host family	17	35.6211	0.00515	21	47.9951	0.00086
Host genus	14	7.2523	0.92455	17	12.7081	0.75549
Host species	12	3.0297	0.99533	15	3.8688	0.99814
Isolation from host	22	29.2189	0.13872	23	48.9792	0.00125
Colonization of host	N/A	N/A	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	21	45.0575	0.0017	23	48.9792	0.00125
Initial sterilization	21	47.8023	0.00073	23	48.9792	0.00125
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	20	16.2758	0.69937	21	16.4369	0.74462
pH stabilizer (binomial)	22	43.5724	0.00401	23	48.9792	0.00125
Carbon (detailed)	17	18.7623	0.34235	20	47.7919	0.00045
Carbon (binomial)	22	48.965	0.00081	23	48.9792	0.00125
Simple sugars	22	24.1048	0.34176	23	48.9792	0.00125
Nitrogen	22	48.462	0.00094	23	48.9792	0.00125
Organic nitrogen	22	48.9758	0.00081	23	48.9792	0.00125
Peat moss	22	42.993	0.00473	23	48.9792	0.00125
Proteins and amino acids	N/A	N/A	N/A	N/A	N/A	N/A
Other organic nitrogen	22	39.1922	0.01341	23	48.9792	0.00125
Inorganic nitrogen	22	34.1063	0.04792	23	48.9792	0.00125
Ammonium	22	38.0701	0.01799	23	48.9792	0.00125
Nitrate	22	48.7993	0.00085	23	48.9792	0.00125
Phosphorus	22	40.1037	0.01051	23	48.9792	0.00125

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 6. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the non-parametric root biomass analyses of *Phialocephala fortinii* s.l. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Publication	Dry weight	15	0.3627	-0.0161	0.8229
	Fresh weight	6	0.0649	-0.1641	0.3044
Measurement type	Alberton et al. (2010)	1	-0.0925	-0.2615	0.0766
	Fernando and Currah (1996)	2	0.0167	-0.3248	0.2053
	Haselwandter and Read (1982)	1	**1.1409**	**0.1379**	**2.1439**
	Jumpponen et al. (1998)	3	0.1791	-0.0083	0.3665
	Jumpponen and Trappe (1998)	1	-0.0331	-0.0823	0.0162
	Vohník et al. (2003)	3	-0.122	-0.3894	0.0305
	Vohník et al. (2005)	1	0	0	0
	Yu (2000)	1	0.1145	-0.0274	0.2564
Fungal strain	UAMH 8148	3	0.0515	-0.2012	0.2176
	C2	1	**1.1409**	**0.1379**	**2.1439**
	SE24	5	0.2337	-0.0031	0.4616
	CBS 554.86	1	-0.0012	-0.023	0.0205
	UAMH 8433	1	-0.2428	-0.5261	0.0405
	UAMH 9525	1	0.1145	-0.0274	0.2564
Growth habit	Tree	10	**0.468**	**0.0247**	**0.9577**
	Shrub	7	-0.0883	-0.2564	0.0731
	Graminoid	1	**1.1409**	**0.1379**	**2.1439**
	Forb/herb	2	0.2734	-0.0274	0.6402
Host group	Gymnosperm	9	**0.4874**	**0.0125**	**1.0269**
	Dicot	9	0.0171	-0.1824	0.217

Table 6. Categorical non-parametric root biomass analyses of *P. fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host group	Monocot	3	**0.3305**	**0.0074**	**1.1409**
Host family	Pinaceae	9	**0.4874**	**0.0064**	**1.0162**
	Ericaceae	5	-0.0945	-0.2976	0.0233
	Rosaceae	1	-0.0776	-0.3248	0.1696
	Cyperaceae	1	**1.1409**	**0.1379**	**2.1439**
	Liliaceae	1	0.1145	-0.0274	0.2564
Host genus	*Pinus*	7	0.0734	-0.0644	0.2249
	Rhododendron	5	-0.0945	-0.2976	0.0219
	Carex	1	**1.1409**	**0.1379**	**2.1439**
	Asparagus	1	0.1145	-0.0274	0.2564
Host species	*Pinus sylvestris*	1	-0.0925	-0.2615	0.0766
	Pinus contorta	5	0.1071	-0.0385	0.2671
	Rhododendron sp.	5	-0.0945	-0.2976	0.0236
	Asparagus officinalis	1	0.1145	-0.0274	0.2564
Isolation from host	Yes	5	1.0108	-0.0584	1.5384
	No	17	0.0702	-0.0556	0.1936
Growth conditions	Sterile	3	-0.0427	-0.1883	0.0552
	Growth chamber	16	**0.3672**	**0.0212**	**0.7699**
	Greenhouse	2	0.0167	-0.3248	0.2053
Initial sterilization	Sterilized	17	0.3018	-0.0283	0.7134
	Pasteurized	3	0.1791	-0.0083	0.3665
	No	1	-0.0331	-0.0823	0.0162
pH stabilizer (detailed)	Vermiculite	5	0.0269	-0.0936	0.1458
	No	15	0.1107	-0.0595	0.3129

Table 6. Categorical non-parametric root biomass analyses of *P, fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
pH stabilizer (binomial)	Yes	7	0.5212	-0.0327	1.1173
	No	15	0.1107	-0.0669	0.3036
Carbon (detailed)	Peat moss	11	0.0062	-0.114	0.106
	Simple sugars	1	**1.3075**	**0.2397**	**1.6759**
	Plant material	1	**-0.2746**	**-0.5261**	**-0.023**
	No	4	0.2382	-0.0467	0.9403
Carbon (binomial)	Yes	18	0.265	-0.0379	0.651
	No	4	0.2382	-0.0467	0.9403
Simple sugars	Yes	1	**1.3075**	**0.2397**	**1.6759**
	No	21	0.0888	-0.0401	0.2336
Nitrogen	Yes	19	0.2889	-0.0241	0.6887
	No	3	0.1294	-0.0615	0.3243
Organic nitrogen	Yes	17	0.2578	-0.0516	0.6718
	No	5	**0.2701**	**0.0146**	**0.8134**
Peat moss	Yes	13	0.078	-0.058	0.2193
	No	9	0.4974	-0.0538	1.0563
Other organic nitrogen	Yes	6	0.627	-0.0547	1.2194
	No	16	0.0676	-0.0504	0.2132
Inorganic nitrogen	Yes	7	**0.8082**	**0.0051**	**1.3736**
	No	15	0.0643	-0.0743	0.1995
Ammonium	Yes	5	0.7673	-0.0687	1.3649
	No	17	0.105	-0.0433	0.2668

Table 6. Categorical non-parametric root biomass analyses of *P, fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Nitrate	Yes	4	**0.3601**	**0.0172**	**1.1029**
	No	18	0.2474	-0.0373	0.6184
Phosphorus	Yes	10	**0.5677**	**0.0473**	**1.0948**
	No	12	0.0518	-0.1151	0.2214

Table 7. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant shoot biomass (with parametric variance) to the inoculation of *Phialocephala fortinii* s.l. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	N/A	N/A	N/A	N/A
Publication	6	12.1179	0.05939	0.3732
Fungal strain	4	16.2424	0.00271	0.4198
Growth habit	3	76.1503	0	0.4986
Host group	2	127.1859	0	0.1812
Host family	3	125.4051	0	0.3632
Host genus	3	9.8311	0.02006	0.138
Host species	3	2.4982	0.47561	0.085
Isolation from host	1	38.2432	0	0.4232
Colonization of host	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A
Growth conditions	1	102.6378	0	0.1268
Initial sterilization	2	0.0809	0.96038	0.998
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	1	0.1826	0.66912	0.7234
pH stabilizer (binomial)	1	88.5161	0	0.1434
Carbon (detailed)	3	105.6667	0	0.4094
Carbon (binomial)	1	0.1397	0.70859	0.9704
Simple sugars	1	95.1211	0	0.1086
Nitrogen	1	0.9725	0.32405	0.8858
Organic nitrogen	1	6.5725	0.01036	0.854
Peat moss	1	91.9649	0	0.1166
Proteins and amino acids	N/A	N/A	N/A	N/A
Other organic nitrogen	1	148.381	0	0.035
Inorganic nitrogen	1	5.6399	0.01756	0.9326
Ammonium	1	2.2531	0.13335	0.9348
Nitrate	1	51.5841	0	0.2298
Phosphorus	1	0.004	0.94977	0.9988

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 8. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant shoot biomass (with parametric variance) to the inoculation of *Phialocephala fortinii* s.l. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	N/A	N/A	N/A	N/A	N/A	N/A
Publication	11	28.1637	0.00306	17	40.2817	0.00118
Fungal strain	9	29.129	0.00062	13	45.3714	0.00002
Growth habit	18	188.3064	0	21	264.4567	0
Host group	19	137.2708	0	21	264.4567	0
Host family	15	116.7039	0	18	242.109	0
Host genus	14	30.4506	0.00661	17	40.2817	0.00118
Host species	12	5.2617	0.94866	15	7.7599	0.93305
Isolation from host	20	226.2135	0	21	264.4567	0
Colonization of host	N/A	N/A	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	20	161.8189	0	21	264.4567	0
Initial sterilization	19	264.3759	0	21	264.4567	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	18	53.5704	0.00002	19	53.7531	0.00004
pH stabilizer (binomial)	20	175.9406	0	21	264.4567	0
Carbon (detailed)	15	152.6561	0	18	258.3228	0
Carbon (binomial)	20	264.317	0	21	264.4567	0
Simple sugars	20	169.3356	0	21	264.4567	0
Nitrogen	20	263.4842	0	21	264.4567	0
Organic nitrogen	20	257.8842	0	21	264.4567	0
Peat moss	20	172.4918	0	21	264.4567	0
Proteins and amino acids	N/A	N/A	N/A	N/A	N/A	N/A
Other organic nitrogen	20	116.0757	0	21	264.4567	0
Inorganic nitrogen	20	258.8168	0	21	264.4567	0
Ammonium	20	262.2036	0	21	264.4567	0
Nitrate	20	212.8726	0	21	264.4567	0
Phosphorus	20	264.4527	0	21	264.4567	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 9. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric shoot biomass analyses of *Phialocephala fortinii* s.l. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Publication	Alberton et al. (2010)	1	0.0313	-0.0183	0.087
	Haselwandter and Read (1982)	1	**0.3853**	**0.0213**	**1.3101**
	Jumpponen et al. (1998)	3	**0.2193**	**0.009**	**0.4262**
	Jumpponen and Trappe (1998)	1	**0.159**	**0.1343**	**0.1744**
	Vohník et al. (2003)	3	-0.0423	-0.2217	0.0111
	Vohník et al. (2005)	1	**0.0219**	**0.0074**	**0.0364**
	Yu (2000)	1	0.0159	-0.0623	0.1101
Fungal strain	C2	1	**0.3853**	**0.0213**	**1.3101**
	SE24	5	**0.3267**	**0.1064**	**0.5342**
	CBS 554.86	1	0.0111	-0.0557	0.0151
	UAMH 8433	1	**-0.1917**	**-0.3498**	**-0.1707**
	UAMH 9525	1	0.0159	-0.0623	0.1101
Growth habit	Tree	10	0.3306	-0.0157	0.5686
	Shrub	5	0.0123	-0.0735	0.031
	Graminoid	1	**0.3853**	**0.0213**	**1.3101**
	Forb/herb	2	0.2305	-0.0623	0.5949
Host group	Gymnosperm	8	**0.466**	**0.0279**	**0.6399**
	Dicot	8	0.0293	-0.0321	0.0879
	Monocot	3	0.2271	-0.0249	0.863
Host family	Pinaceae	8	**0.466**	**0.0257**	**0.6407**
	Ericaceae	5	0.0123	-0.0735	0.031
	Cyperaceae	1	**0.3853**	**0.0213**	**1.3101**

Table 9. Categorical parametric shoot biomass analyses of *P. fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host family	Cyperaceae	1	**0.3853**	**0.0213**	**1.3101**
	Liliaceae	1	0.0159	-0.0623	0.1101
Host genus	*Pinus*	7	**0.0715**	**0.0094**	**0.1918**
	Rhododendron	5	0.0123	-0.0768	0.0312
	Carex	1	**0.3853**	**0.0213**	**1.3101**
	Asparagus	1	0.0159	-0.0623	0.1101
Host species	*Pinus sylvestris*	1	0.0313	-0.0183	0.087
	Pinus contorta	5	**0.1747**	**0.1024**	**0.2886**
	Rhododendron sp.	5	0.0123	-0.0831	0.031
	Asparagus officinalis	1	0.0159	-0.0623	0.1101
Isolated from host	Yes	6	0.2815	-0.0156	0.5754
	No	14	**0.0549**	**0.0022**	**0.1511**
Septic conditions	Sterile	4	0.0095	-0.0453	0.0395
	Growth Chamber	16	**0.3771**	**0.0564**	**0.5928**
Initial sterilization	Sterilized	15	**0.1849**	**0.0071**	**0.4299**
	Pasteurized	3	**0.2193**	**0.009**	**0.4262**
	No	1	**0.159**	**0.1343**	**0.1744**
pH stabilizer (detailed)	Vermiculite	5	0.0539	-0.0055	0.1274
	No	13	0.0298	-0.0252	0.1418
pH stabilizer (binomial)	Yes	7	**0.3724**	**0.0328**	**0.5885**
	No	13	0.0298	-0.0251	0.1327
Carbon (detailed)	Peat moss	8	0.0235	-0.0043	0.0551
	Simple sugars	2	0.4118	-0.1181	0.679

Table 9. Categorical parametric shoot biomass analyses of *P. fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Carbon (detailed)	Plant material	1	**-0.1813**	**-0.3498**	**-0.0557**
	No	4	0.217	-0.0265	0.8191
Carbon (binomial)	Yes	16	**0.1832**	**0.0065**	**0.4266**
	No	4	0.217	-0.0265	0.7473
Simple sugars	Yes	2	0.4118	-0.1181	0.679
	No	18	**0.0471**	**0.0132**	**0.1379**
Nitrogen	Yes	17	**0.1872**	**0.0118**	**0.4282**
	No	3	0.0631	-0.0628	0.2874
Organic nitrogen	Yes	14	**0.1998**	**0.0213**	**0.4574**
	No	6	0.0424	-0.092	0.5483
Peat moss	Yes	10	**0.0348**	**0.0066**	**0.0967**
	No	10	0.3863	-0.0345	0.6321
Other organic nitrogen	Yes	6	**0.4892**	**0.1088**	**0.6708**
	No	14	0.0246	-0.0182	0.0854
Inorganic nitrogen	Yes	8	**0.2011**	**0.0097**	**0.4713**
	No	12	0.0724	-0.0289	0.235
Ammonium	Yes	6	0.1961	-0.003	0.4618
	No	14	**0.1202**	**0.0001**	**0.3337**
Nitrate	Yes	4	**0.0584**	**0.0173**	**0.2008**
	No	16	0.3189	-0.0286	0.5459
Phosphorus	Yes	11	**0.1849**	**0.0042**	**0.4284**
	No	9	**0.18**	**0.0082**	**0.3659**

Table 10. Among-study heterogeneity (Q_M= Q for the model) of the factors used in the categorical analyses on the response of plant total biomass (with parametric variance) to the inoculation of *Phialocephala fortinii* s.l. Refer to Table 1 in Appendix 2 for more details.

Factor	df	Q_M	p	p (rand)
Measurement type	1	0.813	0.36723	0.4072
Publication	6	23.2076	0.00073	0.2652
Fungal strain	4	20.3761	0.00042	0.3662
Growth habit	3	20.2213	0.00015	0.1042
Host group	2	10.9717	0.00415	0.0534
Host family	3	20.2213	0.00015	0.1048
Host genus	3	20.2213	0.00015	0.1064
Host species	3	2.171	0.53768	0.3136
Isolation from host	1	0.4526	0.50111	0.4912
Colonization of host	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A
Growth conditions	1	2.0193	0.15531	0.2448
Initial sterilization	2	1.0601	0.58859	0.5386
Agar	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	1	0.725	0.39449	0.4302
pH stabilizer (binomial)	1	0.725	0.39449	0.4352
Carbon (detailed)	2	11.4255	0.0033	0.0788
Carbon (binomial)	1	9.8152	0.00173	0.0264
Simple sugars	N/A	N/A	N/A	N/A
Nitrogen	1	0.2501	0.617	0.5436
Organic nitrogen	1	11.2535	0.00079	0.0056
Peat moss	1	7.1745	0.00739	0.0068
Proteins and amino acids	N/A	N/A	N/A	N/A
Other organic nitrogen	1	0.0011	0.97384	0.9708
Inorganic nitrogen	1	0.0657	0.79776	0.7808
Ammonium	1	2.0193	0.15531	0.2484
Nitrate	1	1.4883	0.22248	0.2796
Phosphorus	1	0.0316	0.85897	0.8636

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 11. Within-study heterogeneity (Q_W) and total heterogeneity (Q_T) of the factors used in the categorical analyses on the response of plant total biomass (with parametric variance) to the inoculation of *Phialocephala fortinii* s.l. See Table 1 in Appendix 2 for more details.

Factor	df	Q_W	p	df	Q_T	p
Measurement type	16	55.2208	0	17	56.0338	0
Publication	11	32.8262	0.00056	17	56.0338	0
Fungal strain	8	30.3277	0.00018	12	50.7038	0
Growth habit	14	35.8125	0.00111	17	56.0338	0
Host group	15	45.0621	0.00007	17	56.0338	0
Host family	14	35.8125	0.00111	17	56.0338	0
Host genus	14	35.8125	0.00111	17	56.0338	0
Host species	12	6.8186	0.86936	15	8.9897	0.87806
Isolation from host	16	55.5812	0	17	56.0338	0
Colonization of host	N/A	N/A	N/A	N/A	N/A	N/A
System aeration	N/A	N/A	N/A	N/A	N/A	N/A
Growth conditions	16	54.0145	0.00001	17	56.0338	0
Initial sterilization	15	54.9737	0	17	56.0338	0
Agar	N/A	N/A	N/A	N/A	N/A	N/A
pH stabilizer (detailed)	16	55.3087	0	17	56.0338	0
pH stabilizer (binomial)	16	55.3087	0	17	56.0338	0
Carbon (detailed)	13	42.5633	0.00005	15	53.9889	0
Carbon (binomial)	16	46.2186	0.00009	17	56.0338	0
Simple sugars	N/A	N/A	N/A	N/A	N/A	N/A
Nitrogen	16	55.7837	0	17	56.0338	0
Organic nitrogen	16	44.7803	0.00015	17	56.0338	0
Peat moss	16	48.8593	0.00003	17	56.0338	0
Proteins and amino acids	N/A	N/A	N/A	N/A	N/A	N/A
Other organic nitrogen	16	56.0327	0	17	56.0338	0
Inorganic nitrogen	16	55.9681	0	17	56.0338	0
Ammonium	16	54.0145	0.00001	17	56.0338	0
Nitrate	16	54.5455	0	17	56.0338	0
Phosphorus	16	56.0022	0	17	56.0338	0

N/A: Not available. There were not enough studies in all categories to proceed with the analysis.

Table 12. Natural log (ln) of effect size values with bootstrapped 95% confidence intervals (BS CI) of the individual categories for each factor of the parametric total biomass analyses of *Phialocephala fortinii* s.l. Effect sizes in bold are significant. See Table 7 in Chapter 2 for significant factors. Degrees of freedom (df) = number of studies -1.

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Measurement type	Dry weight	11	0.034	-0.0161	0.1574
	Fresh weight	5	-0.0264	-0.1246	0.0357
Publication	Alberton et al. (2010)	1	-0.0551	-0.1335	0.0465
	Haselwandter and Read (1982)	1	**0.6844**	**0.1006**	**1.7132**
	Jumpponen et al. (1998)	3	**0.1841**	**0.014**	**0.4074**
	Jumpponen and Trappe (1998)	1	**0.0774**	**0.0352**	**0.1009**
	Vohník et al. (2003)	3	**-0.0435**	**-0.2973**	**-0.0067**
	Vohník et al. (2005)	1	**0.0197**	**0.0066**	**0.0328**
	Yu (2000)	1	0.0511	-0.0455	0.1936
Fungal strain	C2	1	**0.6844**	**0.1006**	**1.7132**
	SE24	4	**0.1138**	**0.0213**	**0.3148**
	CBS 554.86	1	-0.0106	-0.1862	0
	UAMH 8433	1	**-0.1254**	**-0.4425**	**-0.0866**
	UAMH 9525	1	0.0511	-0.0455	0.1936
Growth habit	Tree	7	-0.0055	-0.0888	0.1295
	Shrub	5	0.009	-0.0617	0.0254
	Graminoid	1	**0.6844**	**0.1006**	**1.7132**
	Forb/herb	1	0.0511	-0.0455	0.1936
Host group	Gymnosperm	7	-0.0055	-0.0915	0.1356
	Dicot	5	0.009	-0.0617	0.0254
	Monocot	3	0.3592	-0.0014	1.1165

Table 12. Categorical parametric total biomass analyses of *P. fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Host family	Pinaceae	7	-0.0055	-0.0964	0.1299
	Ericaceae	5	0.009	-0.0617	0.0252
	Cyperaceae	1	**0.6844**	**0.1006**	**1.7132**
	Liliaceae	1	0.0511	-0.0455	0.1936
Host genus	*Pinus*	7	-0.0055	-0.0932	0.1313
	Rhododendron	5	0.009	-0.0617	0.0249
	Carex	1	**0.6844**	**0.1006**	**1.7132**
	Asparagus	1	0.0511	-0.0455	0.1936
Host species	*Pinus sylvestris*	1	-0.0551	-0.1335	0.0465
	Pinus contorta	5	**0.1079**	**0.0428**	**0.2515**
	Rhododendron sp.	5	0.009	-0.0617	0.0254
	Asparagus officinalis	1	0.0511	-0.0455	0.1936
Isolation from host	Yes	4	0.0417	-0.0598	0.3351
	No	12	0.0092	-0.0254	0.063
Growth conditions	Sterile	3	0.0054	-0.0558	0.0351
	Growth chamber	13	0.0853	-0.0157	0.318
Initial sterilization	Sterilized	11	0.0191	-0.0378	0.0962
	Pasteurized	3	**0.1841**	**0.014**	**0.4074**
	No	1	**0.0774**	**0.0352**	**0.1009**
pH stabilizer (detailed)	Vermiculite	5	-0.0141	-0.0973	0.0917
	No	11	0.0356	-0.0057	0.1891
pH stabilizer (binomial)	Yes	5	-0.0141	-0.0977	0.091
	No	11	0.0356	-0.007	0.2049

Table 12. Categorical parametric total biomass analyses of *P. fortinii* s.l. (continued from previous page).

Factor	Category	df	ln Effect size	-95% BS CI	+95% BS CI
Carbon (detailed)	Peat	8	0.0057	-0.0446	0.033
	Plant material	1	**-0.2973**	**-0.4425**	**-0.1862**
	No	4	0.331	-0.0072	1.0261
Carbon (binomial)	Yes	12	0.0061	-0.0468	0.035
	No	4	0.331	-0.0072	1.0261
Nitrogen	Yes	13	0.0224	-0.0284	0.0971
	No	3	0.0876	-0.0519	0.3384
Organic nitrogen	Yes	11	0.004	-0.0531	0.03
	No	5	**0.3402**	**0.0172**	**0.9702**
Peat moss	Yes	9	0.0069	-0.04	0.0355
	No	7	0.2589	-0.0662	0.8152
Other organic nitrogen	Yes	3	0.0308	-0.2973	0.4074
	No	13	0.0247	-0.023	0.0966
Inorganic nitrogen	Yes	5	0.028	-0.0307	0.17
	No	11	0.013	-0.0416	0.0887
Ammonium	Yes	3	0.0054	-0.0558	0.0351
	No	13	0.0853	-0.0179	0.3178
Nitrate	Yes	3	**0.0469**	**0.0115**	**0.6844**
	No	13	-0.0143	-0.0774	0.0583
Phosphorus	Yes	8	0.0234	-0.0292	0.1066
	No	8	0.0385	-0.0722	0.1259

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APPENDIX 5

EXPERIMENT ON THE EFFECTS OF FUNGAL METABOLITES ON THE GROWTH OF *B. papyrifera* WHILE THE SEEDLINGS WERE SIMULTANEOUSLY INOCULATED WITH AN ENDOPHYTE

APPENDIX 5: SIMULTANEOUS INOCULATION

Methods

Ten endophytes were selected for simultaneous growth with *B. papyrifera* seedlings. This experiment was conducted three different times with different sets of root endophytes, which were grouped by their growth rates; these are: (1) the fastest growing, *Phialocephala fortinii*, *P. sphaeroides* and *Cryptosporiopsis ericae*, (2) the intermediate, Dermataceae I, *Chaetosphaeria* sp. and *Meliniomyces variabilis* and (3) the slowest growing, *Meliniomyces* sp., *Meliniomyces vraolstadiae*, Hyaloscyphaceae sp. I and Helotiaceae sp. III. *B. papyrifera* seeds were surface sterilized in 15% hydrogen peroxide for 30 minutes, rinsed in sterile distilled water at least 5 times and placed in Petri dishes with water agar (15g agar per liter of dH_2O) under sterile conditions. The Petri dishes were sealed with parafilm and placed in a growth chamber with a 16 hour light ($200\mu Mol \cdot m^{-2} \cdot s^{-1}$)-8 hour dark cycle at a constant 20°C. Humidity in the growth chambers was set at 80%, but varied between 30% and 65%. This was not an issue for the set of fastest growing fungi, which were tested first. During this relatively short period, humidity remained above 50%. For the other two sets however, the humidity remained between 30% and 50% and caused desiccation in some replicates.

Seven to 12 days after surface sterilization (the number of days depending on the endophyte set), 16 seedlings per treatment (208 total) were transferred to Petri dishes containing buffered agar in the following fashion (Figure 1): under sterile conditions, a cut perpendicular to the diameter of a Petri dish was made in the agar; this cut was made 1.5cm from the edge of the Petri dish for the fastest growing fungi and 1.0cm for the

other two sets (1.5cm was unnecessarily large).The smaller piece of agar was discarded and a small groove was melted in the agar on the surface perpendicular to the bottom of the dish (the newly exposed surface) at the center of the cut. A *Betula* seed was then placed in the groove with the radicle in the agar and the plate sealed with parafilm and placed upright in the growth chamber under the above conditions. The agar medium was prepared by adding 15g agar, 10g dextrose, 0.5g $MgSO_4 \cdot 7H_2O$, 1g KH_2PO_4, 0.2g $CaCl_2$ and 0.8g $(NH_4)_2SO_4$ per liter of dH_2O and buffered with 50mM 2-(N-morpholino)ethanesulfonic acid (MES) titrated at pH 6.0. Once ready, the media was autoclaved and 24mL was poured per Petri dish under sterile conditions using an automatic pipettor. The initial pH was 5.7.

Once most of the seedlings had reached the top of the Petri dish (between 31 and 34 days), they were processed for endophyte inoculation. Seedlings varied greatly in size and were consequently assigned to one of 3 size classes (small, medium or large) prior to inoculation with fungal endophytes. Seedlings of each size class were then randomly assigned to each treatment. Under sterile conditions, two pieces of agar on both sides of the plant were removed, a slot was made in the Petri dish above the seedling (slightly larger than shoot width) and the agar was lifted up and the leaves and shoot were moved to the outside of the Petri dish, with the shoot in the newly made slot and the roots still inside. Then, an autoclaved 47mm 0.2μm Whatman® nuclepore polycarbonate filter was placed on top of the roots. For the fastest growing fungi, a 5mm mycelial plug was then placed in the center of the nuclepore filter. For the average and slowest growing fungi, a

1.5cm in diameter disk of buffered agar was placed in the center of the filter before the mycelial plug. This agar disk was half the thickness of the media in the Petri dish. This was achieved by pouring 12mL into a Petri dish using an automatic pipettor instead of 24mL. The agar disks were used to promote the growth of slower fungi and also increase the density of the colony on top of the filter. An autoclaved polycarbonate filter, and a 1.5cm agar disk when appropriate, was placed on top of the roots of the control treatments. An agar plug was applied in this case, however, as it would fall off if there was no mycelium to keep it attached to the substrate. Once inoculation was complete, the Petri dishes were sealed with parafilm, ensuring that no open spaces were found between the shoot and the slot. They were then brought to the growth chambers and laid flat for two days before placing them upright. This prevented mycelial plugs from falling off the filters.

When at least one of the endophytes neared the edge of the filter, which was after 21, 36 and 38 days for the fastest, intermediate and slowest growing fungi respectively, the Petri dishes were removed from the growth chamber so the seedlings could be scanned and weighed. First, the filter with the endophyte was discarded. Then, plants were carefully removed from the agar, using 90°C dH_20 for melting excess agar stuck to the roots when necessary. Plants were then scanned on an HP Scanjet 4370 scanner at 600 dots per inch. These images were analyzed for root length, shoot length and number of root tips using WinRHIZO (2009). After scanning, plants were dried and total, shoot and root weight was measured. Differences between control and experimental means were

assessed via two-way ANOVA using SPSS. The two factors were treatment and plant size class. All data except shoot length were log transformed to obtain an approximately normal distribution.

Results

Few significant differences in growth responses were detected in the simultaneous growth experiment (Table 1). None of the seedlings grown with *Chaetosphaeria sp.* survived the duration of the experiment. *Meliniomyces* sp. had a considerably smaller total and shoot biomass than the control. *Meliniomyces* sp., Hyaloscyphaceae sp. I and Helotiaceae sp. III had significantly smaller root length than the control. Moreover, many more control seedlings survived until collection compared to those inoculated with these same endophytes. In particular, only 3 out of 15 seedlings inoculated with *Meliniomyces* sp. survived until collection. These effects may be due to low ambient humidity in the growth chambers, which was a particular problem during the experiements involving this group of endophytes.

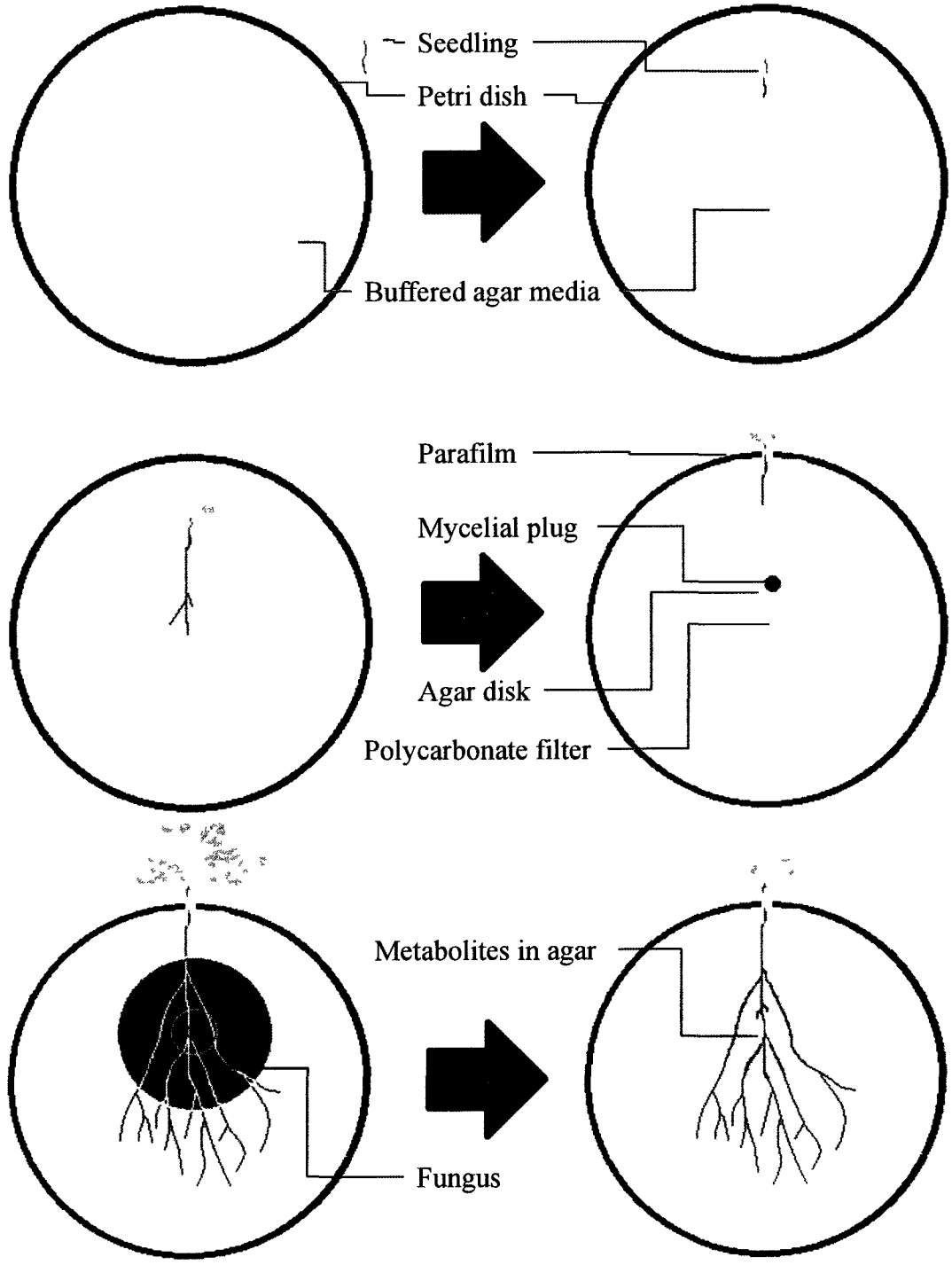

Figure 1. Diagram indicating the different steps in testing the effects of fungal metabolites on plant growth when a *B. papyrifera* seedling and a fungus are grown simultaneously on buffered agar media, but physically separated by a polycarbonate filter.

Table 1. Total, shoot and root dry weight, shoot and root length and number of tips of *B. papyrifera* seedlings inoculated simultaneously with an endophytic root fungus. Significant values at $p<0.05$ are in bold with groups from Tukey test.

	n	Total weight (mg)		Shoot weight (mg)		Root weight (mg)		Shoot length (cm)		Root length (cm)		Number of tips	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group 1													
Control	10	16.8	11.3	11.5	7.3	5.3	4.3	0.631	0.131	32.11	26.49	19.6	16.7
Cryptosporiopsis ericae	9	14.7	11.4	10.1	8.1	4.6	3.8	0.744	0.131	27.61	23.85	16.1	16.1
Phialocephala fortinii	11	23.2	20.8	17.6	16.6	5.6	4.7	0.622	0.147	38.84	25.88	23.6	17.9
Phialocephala sphaeroides	14	12.6	9.1	8.5	5.8	4.1	3.4	0.529	0.103	34.27	27.00	19.2	11.6
Group 2													
Control	8	12.1	6.0	9.8	5.5	2.3	0.9	0.727	0.102	24.01	11.34	15.4	5.4
Meliniomyces variabilis	2	7.3	5.4	5.2	3.5	2.1	2.0	0.946	0.099	22.90	11.08	22.0	2.8
Dermateaceae I	7	9.9	4.4	7.9	3.4	2.0	1.0	0.877	0.171	26.79	13.00	18.6	11.4
Group 3													
Control	14	**11.8^{b}**	**7.2**	**8.7^{b}**	**5.7**	3.2	1.9	0.805	0.151	**37.86^{b}**	**19.46**	22.7	11.7
Meliniomyces sp.	3	**3.0^{a}**	**0.4**	**1.8^{a}**	**0.5**	1.2	0.2	0.754	0.125	**15.30^{a}**	**6.82**	12.7	7.2
Meliniomyces vraolstadiae	7	**6.8^{a,b}**	**5.3**	**4.4^{a,b}**	**3.4**	2.4	2.0	0.676	0.279	**18.73^{a}**	**15.29**	16.9	12.7
Helotiaceae sp. III	11	**8.8^{b}**	**4.1**	**6.2^{b}**	**3.3**	2.5	1.2	0.760	0.085	**25.95^{a,b}**	**14.21**	22.5	12.8
Hyaloscyphaceae sp. I	8	**7.1^{a,b}**	**3.9**	**5.5^{b}**	**2.8**	1.7	1.2	0.675	0.163	**19.01^{a}**	**12.52**	12.8	6.9