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# Effects of microbiome on conifer health and resistance to biotic and abiotic stress: A systematic review

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Marrian Tendai Rwizi

## ABSTRACT

The dynamics of plant-microbiome interactions under different stress conditions are important to understand in order to elucidate the mechanisms underlying forest decline and tree mortality. This study aims to evaluate the importance of ectomycorrhizal fungi in alleviating stress and enhancing defense in *Pinus* and *Picea* species. A meta-analysis was performed on primary research articles that assessed effects of ectomycorrhizal fungal on growth and resistance of these tree species. The stress factors studied were drought, pathogen infection, herbivory and pollutant stress. A PRISMA systematic review guideline was used in screening the articles from the two databases Web of Science and SCOPUS. The search produced a total of 1 806 articles, which were further screened by excluding review articles, book chapters, conference papers and other papers that did not include *Pinus* or *Picea* species and ectomycorrhizal fungi. A total of 118 articles were assessed and the statistical analysis was conducted as per factor (growth, survival, biotic and abiotic stress). Most of the published articles were on *Pinus* and a few on *Picea*. Overall, ectomycorrhizal fungi were found to enhance growth but had no effect on survival, though the results are more confined to *Pinus* species. Ectomycorrhizal fungi were not effective in alleviating abiotic and biotic stress. There was high heterogeneity among papers and publication bias in the analysis. As a result my analysis did not provide a concrete conclusion in endorsing ectomycorrhizal fungi as promoting conifer growth, survival and resistance to biotic and abiotic stress. Further research is needed on conifer- soil feedbacks in relation to ectomycorrhizal fungi. Moreover, there is need for conducting more experiments in the field to enable the life strategies of ectomycorrhizal fungi to be brought into sharper focus. This is important because conifer species are of high economic value through producing high quality timber and plays a crucial role in mitigating climate change.



Key words: Ectomycorrhizal fungi, *Pinus*, *Picea*, heterogeneity, publication bias, growth, survival, biotic and abiotic.

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## LIST OF ABBREVIATIONS

ECM- Ectomycorrhizal fungi,

AM- Arbuscular mycorrhizal fungi

REML- Random effects model

# 1. INTRODUCTION

Plants and their associated microbes have been interacting since the colonization of land by ancestral plants 450 million years ago. This assemblage of a plant host and its microbiome is called the holobiont (Baedke et al, 2020). Plant- microbiome relationships can be commensal or mutualistic, i.e. benefiting both partners (Bacon & White, 2016) (Van der Ent et al., 2009).

The microbiome includes organisms found below ground (in the rhizosphere) or above ground (phyllosphere). The rhizosphere is inhabited by a variety of microorganisms including bacteria, fungi, oomycetes, nematodes, protozoa and archaea. Mycorrhiza fungi are the most abundant members of the rhizosphere community with an estimated 80% plant association and have been found in over 200 000 plant species (Dastogeer et al., 2020). They play a major role in terrestrial ecosystems and are major drivers of carbon and nutrient cycles (van der Heijden et al., 2015). In the phyllosphere, microbes are very much affected by changes in temperature and moisture which may affect the plant. In addition to the rhizosphere and phyllosphere there is the endosphere. To colonize this internal compartment, microbiota must penetrate a plant's external boundary and overcome or hide from plant defenses (Bulgarelli et al., 2012). Arbuscular mycorrhizal fungi (AM) and other endophytic fungi are dominant colonizers of the endosphere (Dastogeer et al., 2020).

For trees to flourish they need Nitrogen, Phosphorus and water from soil, but the levels of these nutrients in soil are often too low to sustain tree growth and so the trees rely on ectomycorrhizal symbiosis to help them survive (Martin et al., 2016). Ectomycorrhizal fungi (ECM) can establish mutualistic symbiosis with a wide range of woody plants, including conifers and other gymnosperms, particularly in sites where nutrients are low and limiting (Read et al., 2004).They play a major role in temporal and boreal forests by providing soil nutrients and water in exchange of carbon, helping their host trees tolerating harsh environmental conditions (Policelli et al., 2020).

**Figure 1**: Mycorrhization of white bark seedlings with ectomycorrhizal fungi

Successful mycorrhizal colonization of white-bark (*Pinus albicaulis*) pine seedlings with a native *Suilloid* species in a greenhouse. White areas are ectomycorrhizal fungi which have colonized the roots (Lonergan, 2013).

Due to their large hyphal network in the soil (Figure1), ECM enhance the absorbing root surface of the plant host for mineral nutrients. In exchange, the plant host provides carbon to the mycorrhizal fungi(Smith, 2008). Additionally, ECM can be host- specific in response to the type of stress, affecting nutrient uptake, and leading to reduced plant growth (Taniguchi T, 2017).

Fluctuating environmental conditions can cause a plant to be attacked by pathogens and subsequent herbivore and or insect attack. In response to these attacks, plants have preformed and inducible defense mechanisms (Iqbal Zahra et al, 2021). Conifers such as Norway spruce can live for more than 500 to 600 years (Castagneri et al., 2013). One factor contributing to the longevity of conifers is their defensive strategies, the mechanisms they evolved against attack from insects and pathogens (Franceschi et al., 2005). In constitutive defense mechanisms, preformed barriers such as the cell wall, epidermal cuticle and the bark, protects the plant from attack and invasion. Preformed defenses can also be chemical defenses in which the tree produces anti-feedants, toxins, proteins and enzymes that are distributed in the bark and wood (Franceschi et al., 2005). Some proteins are specifically targeting certain microbes as shown in the antifungal activity of defensins (Thomma et al., 2002).

Inducible defense mechanisms increase the efficiency of the plant defense system and involve e.g. chemical defenses such as the release of secondary metabolites (phenolics, terpenoids and alkaloids) that can defend the tree against a wide range of pests or herbivore attack (Franceschi et al., 2005) and abiotic stresses such as drought, pollutants and salinity (Rodrigues et al., 2021). Plants respond to these stresses through different ways, for example they can escape from drought by adjusting their life cycle, decreasing the osmotic potential in their cells and upregulating antioxidant defenses. Molecular mechanisms include synthesis of stress proteins, and signalling stress detection (Athar et al., 2022). Several studies have documented the importance of mycorrhizal fungi in counteracting biotic stress in plants, including effects on pathogenic fungi such as *Fusarium*, *Rhizoctona*, *Verticillium*, *Thievalopsis*, *Aphanomyces*, *Phytophtora* and *Pythium* (Whipps, 2004), as well as nematodes from the genera *Heterodera*, *Meloidogyne*, *Pratylenchus* and *Radopholus* (Harrier & Watson, 2004).

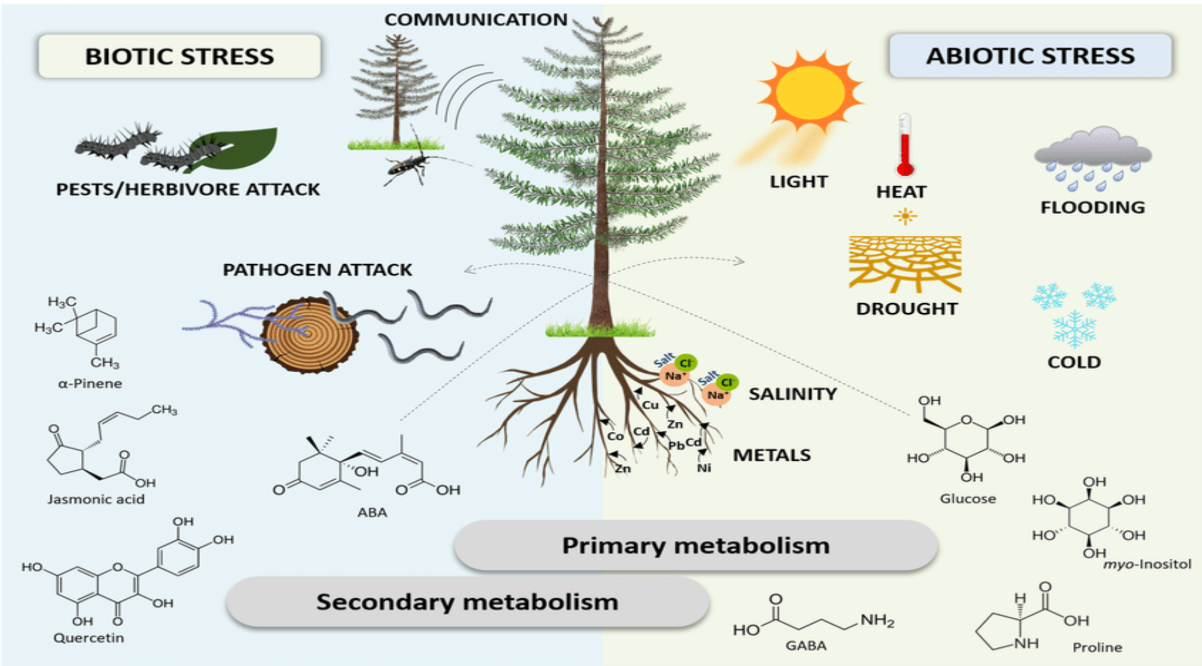



**Figure 2:** Chemical defense mechanisms of trees

Chemical defense mechanisms of trees by realising secondary metabolites in response to abiotic and biotic stress (Rodrigues et al., 2021).

During the past decades, individual studies have generated sufficient evidence on responses of plants to ectomycorrhizal associations that some conclusions can now be made about the nature of these associations. However, the published results are inconsistent to some extent. Some studies recorded positive effects of ectomycorrhizal fungi when administered to conifers(Kennedy et al., 2007) and others reported negative microbial responses(Herol et al., 2022) . However, there has been not enough quantitative synthesis that allows us to determine the effect of ectomycorrhizal fungi on conifer (*Pinus* or *Picea)* health, survival and defense. More systematic knowledge can be achieved through a meta-analysis, which is a method to summarise results of multiple independent studies, identifying conflicting published studies (Koricheva & Gurevitch, 2013), highlighting research gaps in data, and identifying common methodological problems (Lortie & Callaway, 2006).

### 1.1 AIM

Hitherto, most information on beneficial effects of mycorrhizal plant-fungal interactions has been gathered on arbuscular mycorrhizal fungi (AM) known to form symbiotic associations with many crop plants. Less attention has been given to ectomycorrhizal fungi (ECM) that are specific for symbioses with woody plants. There is thus a need for understanding the complex relationship between woody plants and their microbiota (particularly ectomycorrhizal fungi) in enhancing defense to biotic and abiotic stress. This need is especially pressing for forest trees such as the conifers which are crucial for future forest productivity and forest restoration.

### 1.2 OBJECTIVES

The main objective of this thesis is to evaluate to what extent ectomycorrhizal fungi in enhance growth and resistance to biotic and abiotic stress of conifers in the genera *Pinus* and *Picea*. I do this by conducting a meta-analysis of published primary research articles that have manipulated ectomycorrhizal fungi and other variables that has assessed its effect on growth and resistance to biotic and abiotic stress.

### 1.3 RESEARCH QUESTIONS

- Is there is scientific evidence that ectomycorrhizal fungi enhance plant growth, survival and defense to biotic and abiotic stress?
- Does the experiment location or growth condition affect the outcome of results?

## 2.0 METHOD

### 2.1 Literature search

The meta-analysis was performed in concordance with the PRISMA systematic review guidelines (BMJ, 2021) (Figure 3). A literature search was performed using the databases; Web of Science (https://www.webofscience.com/) and SCOPUS (https://www.scopus.com/). Terms used to search Web of Science were: ALL= (holobiont OR mi?crobiome OR ectomycorrhiz*) AND (spruce OR pine OR conifer OR gymnosperm) AND (health or resistance or growth or stress)). The search terms used in SCOPUS were: TITLE-ABS-KEY ((holobiont OR mi?crobiome OR ectomycorrhiz*) AND (spruce OR pine OR conifer OR gymnosperm) AND (health OR defense OR resistance OR growth OR stress)) AND (LIMIT-TO (DOCTYPE, “ar”)). Initially, the two searches identified 1 806. Abstracts and meta data for all articles were imported into Rayyan (https://www.rayyan.ai/), a web-tool to help researchers working on systematic reviews, so they could be individually reviewed. Each article was reviewed by two independent reviewers (me and one of my supervisors). Articles that did not deal with *Picea* or *Pinus*, ECM and/or the effects of ECM on conifer growth, survival, abiotic stress or biotic stress were excluded. Most articles that were published in the 1980s and 1990s were in accessible online, thus they were excluded for the meta-analysis.

Additionally, articles for which there was no online access, that were not written in English, or were not primary research articles were excluded. In the end, 118 articles were found suitable for meta-analysis. Of these 118 studies, only 112 articles had enough statistical data or other key information required to perform the meta-analysis (Figure 3).

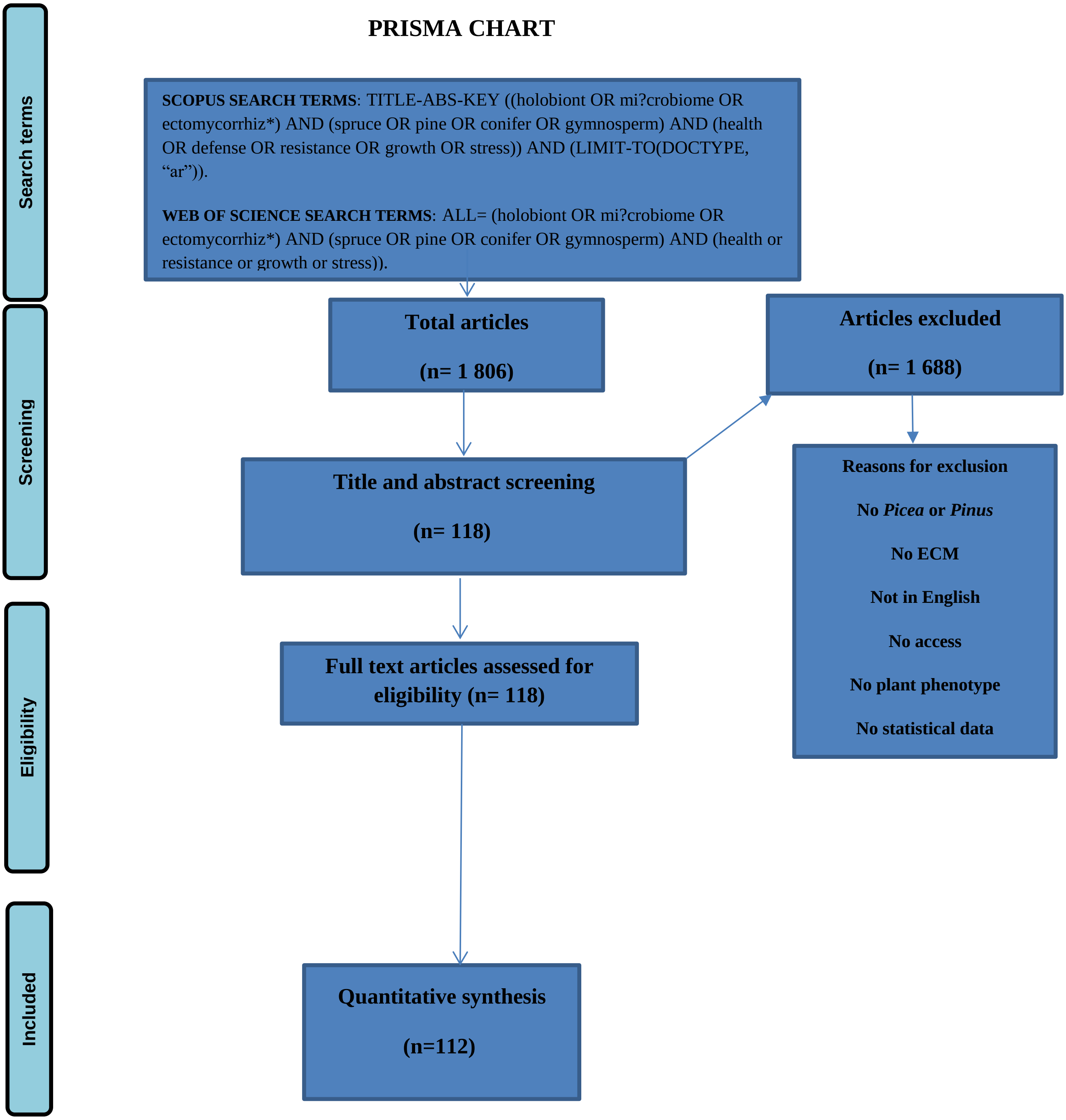



**Figure 3:** Prisma chart describing the screening process.

PRISMA chart describing the search protocol and screening process used to identify and select published research articles for this systematic review.

### 2.2 Data extraction

I read each of the 118 articles included in the meta-analysis and harvested data that could be used to calculate effect sizes (See Appendix E). The effect of ECM on tree growth, survival, biotic, and abiotic was investigated. The data parameters used in the study include seedling height, stem diameter, shoot length, and stem length, root length, survival and mortality (See Appendix B, C, D and A). For articles that did not provide data in the text, tables, or supplementary data files, Image J image analysis software (https://imagej.net/ij/) was used to derive data from figures. Mean and standard deviation or standard error values from data graphs were determined by measuring pixels and scaling these to the y-axis units. I also recorded additional factors that could influence the effect sizes. These possibly moderating factors were tree genus, tree age, ECM genus, soil type, and growth condition and stress type. Soil types were grouped into four categories: field, composite, sandy and media. Soil from the forest or field was categorised as field. Nursery soils, i.e. various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media. Studies that were conducted under controlled environments were coded as growth facility (greenhouse, glass house, lab, and nursery) and those which were carried out in the field were coded as field. Stress types were coded as heavy metals, pathogen infection, drought and insect attack.

### 2.3 Effect size standardisation and normalisation

Effect sizes were calculated following the method presented in the Hard- boiled synthesis protocols (Lajeunesse, 2016). Data extracted from the literature was normalised and calculated using the following formulae and steps:

1. The difference of **δ** between the means (X) of ECM treatment (T) and control was calculated:

$$\boldsymbol{\delta = X_T - X_C} \qquad \textbf{(1)}$$

(X$_T$ and X$_C$ are treatment and control means)

2. The homogenised variance (**σ**) of the means of treatment and control was calculated:

$$\boldsymbol{\sigma = \sqrt{}\ ((N_T\text{-}1)\ SD^2_{T+}\ (NC\text{-}1)\ SD^2_C / N_T - N_C} \qquad \textbf{(2)}$$

(N$_T$ and N$_C$ are treatment and control sample size)

3. I then standardised delta relative to sigma :-

$$\boldsymbol{\delta/\sigma} \textbf{ (delta/sigma)} \qquad (3)$$

4. and estimated data variance of effect size.

$$\mathbf{Var(\delta)=1/N_T+1/N_C+ \delta^2/2(N_T+ N_C)} \qquad (4)$$

5. performed bias correction:

$$\mathbf{J = 1\text{-}(3/4 \ x \ (4x \ (N_T+ N_C\text{-}2)\text{-}1))} \qquad (5)$$

**(J is the bias correction)**

6. Calculated delta (**δ)**

$$\boldsymbol{\delta = X_T\text{-}X_C/ \ \sigma \ x \ J} \qquad (6)$$

7. Calculated variance of the delta

$$\boldsymbol{\delta = \sqrt{}Var \ \delta \ {}^*j^2} \qquad (7)$$

8. And finally calculated effect size from Var δ.

$$\mathbf{Var \ (\delta) = 1/N_T + 1/N_C + \delta 2/2(N_T + N_C) \ x \ j2} \qquad (8)$$

**EFFECT SIZE**

$$\boldsymbol{(\delta) = X_T\text{-}X_C/ \ \sigma}$$

Data that were presented as proportions or percentages were converted to log response ratios (log RR) using the following formulae and steps:

1. Risk ratio (RR) was first calculated:

$$\mathbf{RR= P_{treatment}/P_{control}} \qquad (9)$$

**(P is the proportion)**

2. Response ratios were then transformed to log RR using the formulae:

$$\mathbf{RR = LN \ (RR)} \qquad (10)$$

3. and standard errors for log risk ratios were calculated.

$$\mathbf{SE \ log \ RR= (1/K_{T+}1/K_C - 1/N_T +1/N_C)} \qquad (11)$$

($N_T$ and $N_C$ are treatment and control sample size, and K is the number of events e.g., dead plants)

### 2.4 Data modelling and determination of pooled effect size

The overall effect of ECM fungi on their host was estimated using the METAFOR package by Viechtbauer (2010) in R (R version 4.2.3), by fitting a three level meta-analysis random effects model (Harrer et al., 2021). Level 1($\varepsilon$) were individual data points (effects) within studies. In level 2 **ζ(2)**, the individual data points that were clustered (K) by study. In level 3 **ζ(3),** the effect sizes from all studies were pooled into an overall estimated effect size (average). 2.

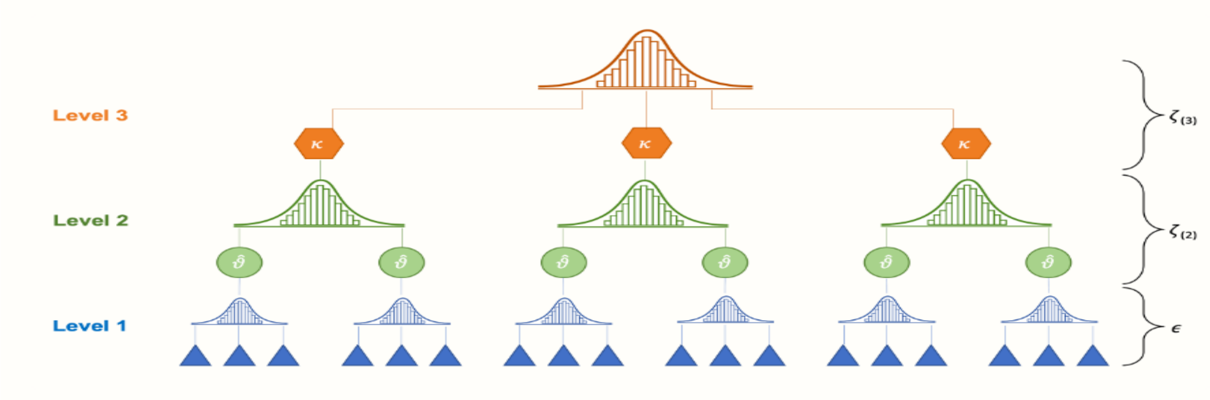



**Figure 4:** Three level meta-analysis model

Diagram of a three level meta-analysis model used in this study (Harrer et al., 2021). Level 1shows data points of individual studies and their effect sizes. Level 2 shows effect sizes of subgroup studies aggregated together where each study contributes only one effect size. Level 3 is the overall true pooled effect size from subgroups in level

The model equation used was:

$$\hat{\theta}_{ij}=\mu+\zeta_{(2)ij}+\zeta_{(3)j}+\epsilon_{ij}$$

Where $\hat{\theta}_{ij}$ is an estimate of the true effect size, **μ** is the true effect, **i** are some effect size nested in cluster which can be a subgroup **j** $\zeta_{(2)ij}$ and $\zeta_{(3)j}$ represent heterogeneity within clusters. The function used to run the model in R was:

```
full. Model <- rma.mv (yi = effect size,
                 V = var. d,
                 slab = author,
                 data =x,
                 random = ~ 1 | author/es.id,
                 test = "t",
                 method = "REML")
```

Where yi is the calculated individual effect size and V is the calculated variance delta. The author is representing individual studies (level 2) and es.id is representing individual effects (level 1).

The estimated pooled effect size was also transformed to a normal correlation to facilitate, easy interpretation of results using the function: **convert_z2r ()**.

Additional factors (moderators) such as soil type, growth condition, tree age, stress type and tree genus were assessed for their overall effects on the pooled effect size using the equation:

$$\hat{\theta}_{ij}=\theta+\beta x_i+\zeta_{(2)ij}+\zeta_{(3)j}+\epsilon_{ij}$$

Where **θ** is the intercept and **β** the regression weight of a predictor variable for instance soil type.

These factors were specified in **rma.mv ()**, using the mods argument. A three- level moderator model was used using the above equation:

```
mod. model <- rma.mv (yi = effect size, V = var. d,
                      slab = author,
                      data = data x,
                      random = ~ 1 | author/es.id,
                      test = "t",
                      method = "REML",
                      mods = ~ moderator x)
```

Where yi is the effect size and V is the variance delta.

### 2.5 Distribution of variance across levels

Higgin's and Thompson's $I^2$ statistic was used to quantify heterogeneity between study levels based on Cochran's Q. This is defined as the percentage of variability in the effect sizes in which the sampling error is not the cause. The formular for $I^2$ used is:

$$I^2=\frac{Q-(K-1)}{Q}$$

Where K is the total number of studies, and Q is the Cochran's Q, which is the weighted sum of squared differences between individual study effects and the pooled effect across studies, with the weights being those used in the pooling method (Higgins & Thompson, 2002).

**2.5 Bias detection**

The METAFOR package by Viechtbauer (2010) in R (R version 4.2.3) was used to create funnel plots to evaluate bias in the study and to determine the validity of the results, using the function: **funnel()**.

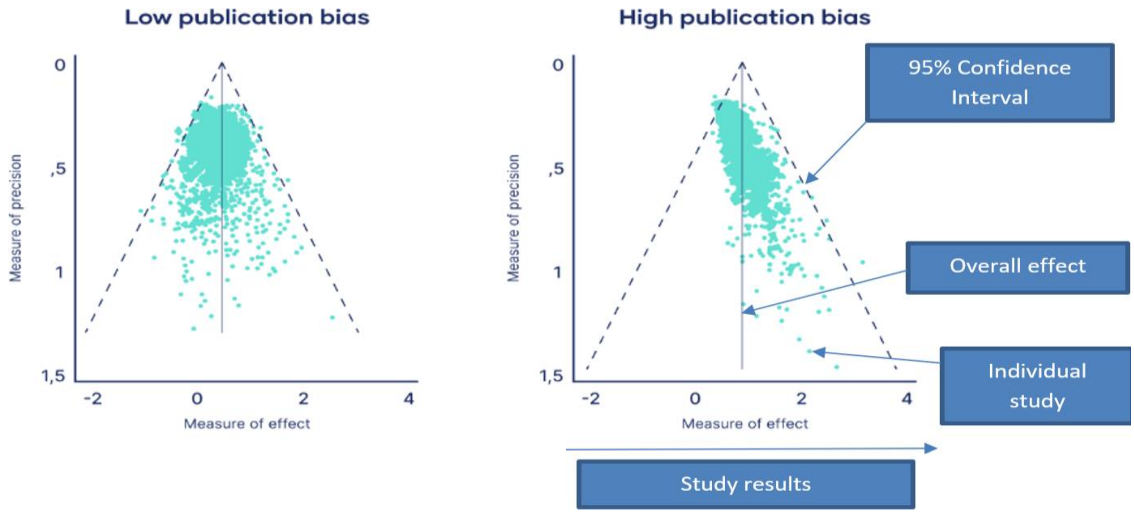



**Figure 5:** Diagram of a funnel plot

An example of a funnel plot modified from (https://www.scribbr.com/frequently-asked-questions/funnel-plot-publication-bias) Funnel plot showing publication bias of growth studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome (effect size). The outer dashed lines show 95% Confidence Interval limits. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical plot.

## 3.0 RESULTS

Out of 1806 searched articles, 118 articles were found suitable for meta-analysis but only 112 articles had enough data and other key information required to perform the meta-analysis.

### 3.1Effects of ECM on conifer tree growth

There are many articles on *Pinus* species compared to *Picea* species. The years with the most articles are 1998, 2004, 2005, 2007 and 2012, and all these years were dominated by *Pinus* species (Figure 6).

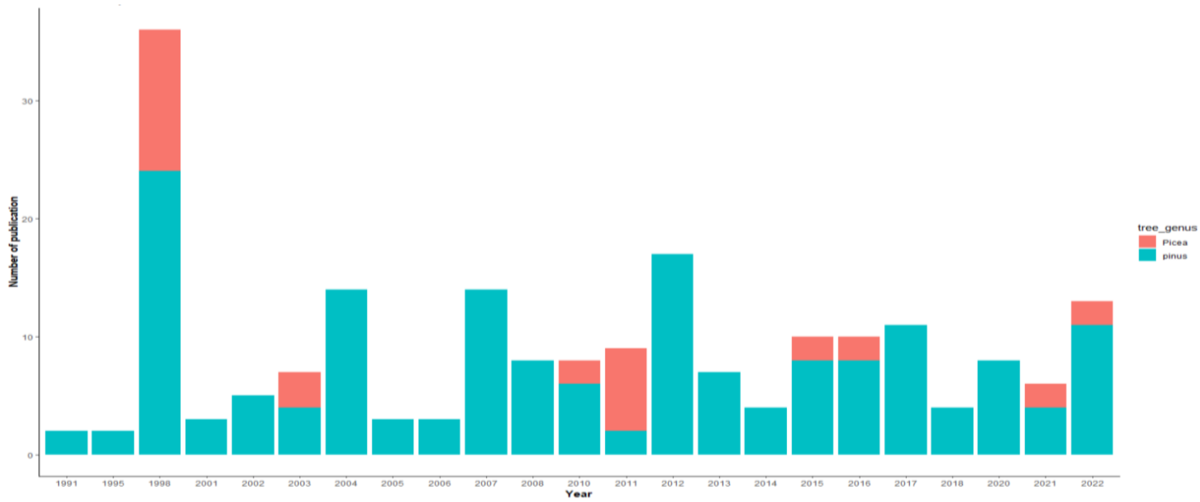



**Figure 6**: Number of publications on conifer tree growth

Publication year of articles included in the meta-analysis of ECM effect on Pinus and Picea growth.

Growth studies were mostly conducted in a growth facility, and much of the investigation was conducted on *Pinus* (Figure 7). There was a total of 32 studies conducted on *Picea* growth and 172 studies conducted on *Pinus* growth.

**Figure 7**: Growth conditions under which growth studies in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on Pinus and Picea growth were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to "growth facility" and those which were carried out in the field were allocated to "field".

The most common ECM genera used were *Suillus, Rhizopogon, Laccaria and Pisolithus*, though ECM was mostly tested on *Pinus* species (Figure 8).

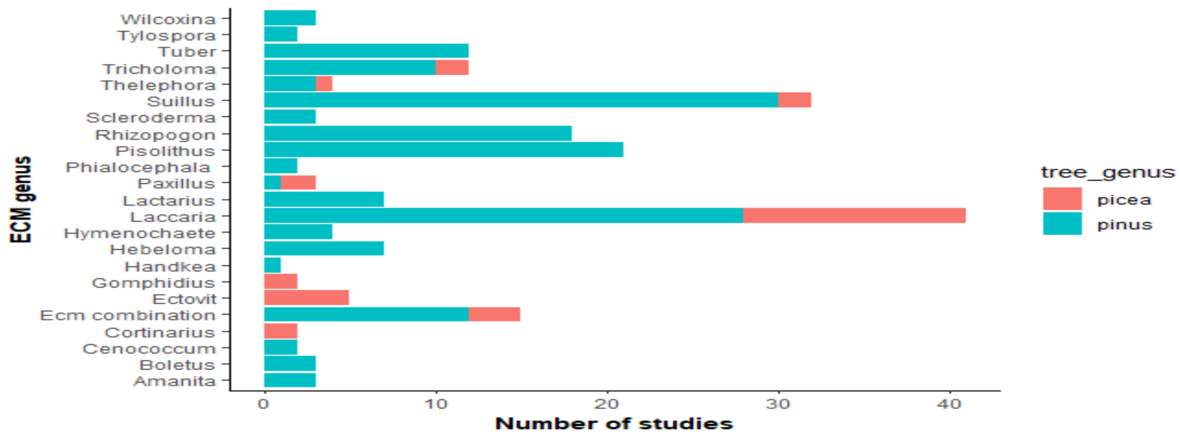



**Figure 8:** ECM genera which were used for growth studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* growth were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used. Ectovit is a mycorrhizal blend manufactured for commercial use.

The composite soil type was the most used on both *Picea* and *Pinus* species. Sandy was the least used soil type (Figure 8).

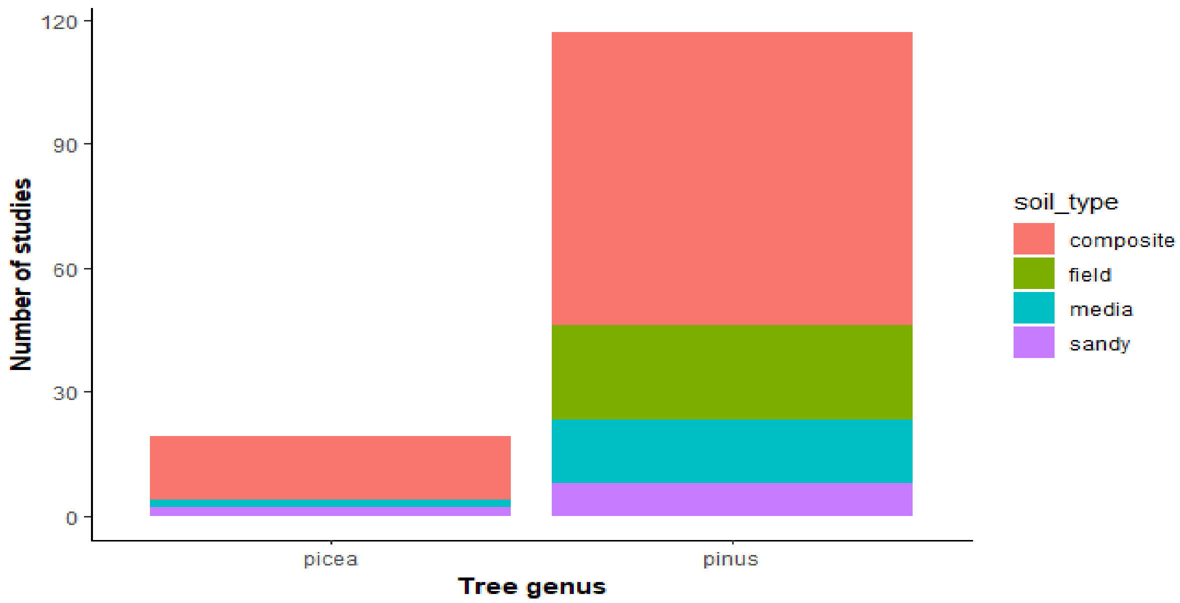


**Figure 8**: Soil type used on conifer tree growth studies.

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled estimated effect size based on the three -level meta -analysis model was 51 (95% CI: 1.73- 100; p=0.04). The large estimated pooled effect size indicates a very strong relationship between ectomycorrhizal fungi and tree growth. There was a high level of heterogeneity between individual studies and within studies. $I^2_{level\ 3}$(overall effect size) was 23.27% and $I^2_{level\ 2}$ (nested effect sizes from individual studies) was 76.73(Figure 10).

There is an indication of publication bias on tree growth factor because the plot is not symmetrical. Excessive number of studies do not fall within 95% confidence interval limit (Figure 9) and thus are statistically significant. Therefore, publications are biased although their studies are significant.

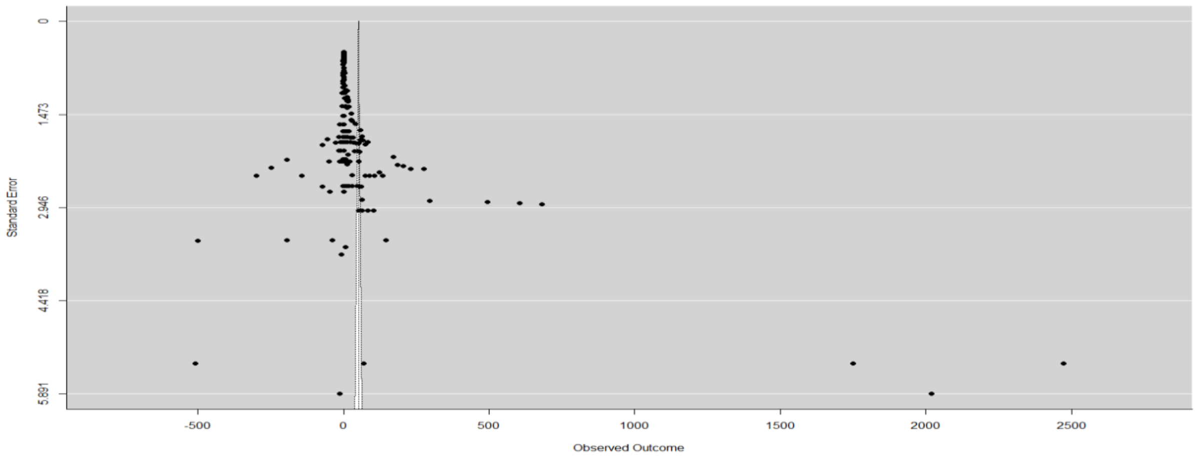


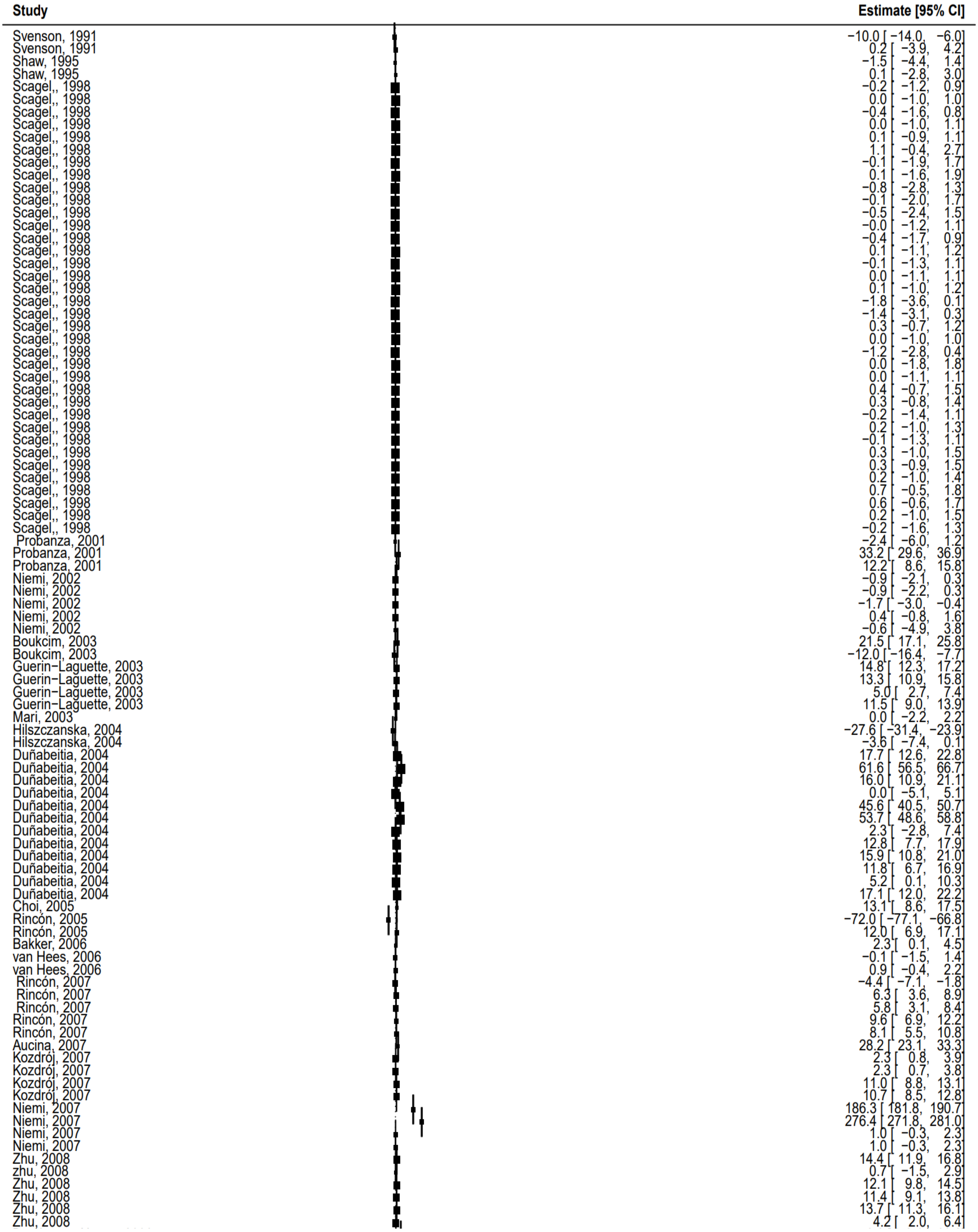

**Figure 9**: Funnel plot of publication bias of growth studies

Funnel plot showing publication bias of growth studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome (effect size). The outer dashed lines show the 95% Confidence Interval limit. The average effect size is shown by the dashed line in the middle. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted pollen.

The pooled estimated effects sizes of the moderators were huge indicating a positive moderating effect on the relationship between ectomycorrhizal fungi and conifer tree growth with no significance (P>0.05), except for soil type which had a p value of 0.03 (Table 1).

**Table 1**: Overview of estimated pooled effect sizes of growth factor moderators using a three level meta-analysis random effects model.

| Moderator | Estimate | Standard error | T value | Degrees of freedom | P value | Lower confidence interval | Higher confidence interval |
|---|---|---|---|---|---|---|---|
| ECM | 17.1264 | 166.6966 | 0.1027 | 180 | 0.9183 | -311.8045 | 346.0573 |
| Soil type | 74.3559 | 34.3555 | 2.1643 | 199 | 0.0316 | 6.6084 | 140 |
| Growth conditions | 44.2207 | 43. 3697 | 1.0196 | 202 | 0.309 | -41.2948 | 129.73 |
| Tree age | 31.227 | 32.1408 | 0.9716 | 202 | 0.3324 | -32.1475 | 94.6015 |
| Tree genus | 71.552 | 55.2014 | 1.2962 | 202 | 0.1964 | -32.2927 | 180.3971 |
| | | | | | | | |


Study
Estimate [95% CI]
Svenson, 1991 −10.0 [ −14.0, −6.0]
Svenson, 1991 0.2 [ −3.9, 4.2]
Shaw, 1995 −1.5 [ −4.4, 1.4]
Shaw, 1995 0.1 [ −2.8, 3.0]
Scagel,, 1998 −0.2 [ −1.2, 0.9]
Scagel,, 1998 0.0 [ −1.0, 1.0]
Scagel,, 1998 −0.4 [ −1.6, 0.8]
Scagel,, 1998 0.0 [ −1.0, 1.1]
Scagel,, 1998 0.1 [ −0.9, 1.1]
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Scagel,, 1998 −0.4 [ −1.7, 0.9]
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Scagel,, 1998 0.3 [ −0.7, 1.2]
Scagel,, 1998 0.0 [ −1.0, 1.0]
Scagel,, 1998 −1.2 [ −2.8, 0.4]
Scagel,, 1998 0.0 [ −1.8, 1.8]
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Scagel,, 1998 0.2 [ −1.0, 1.4]
Scagel,, 1998 0.7 [ −0.5, 1.8]
Scagel,, 1998 0.6 [ −0.6, 1.7]
Scagel,, 1998 0.2 [ −1.0, 1.5]
Scagel,, 1998 −0.2 [ −1.6, 1.3]
Probanza, 2001 −2.4 [ −6.0, 1.2]
Probanza, 2001 33.2 [ 29.6, 36.9]
Probanza, 2001 12.2 [ 8.6, 15.8]
Niemi, 2002 −0.9 [ −2.1, 0.3]
Niemi, 2002 −0.9 [ −2.2, 0.3]
Niemi, 2002 −1.7 [ −3.0, −0.4]
Niemi, 2002 0.4 [ −0.8, 1.6]
Niemi, 2002 −0.6 [ −4.9, 3.8]
Boukcim, 2003 21.5 [ 17.1, 25.8]
Boukcim, 2003 −12.0 [ −16.4, −7.7]
Guerin−Laguette, 2003 14.8 [ 12.3, 17.2]
Guerin−Laguette, 2003 13.3 [ 10.9, 15.8]
Guerin−Laguette, 2003 5.0 [ 2.7, 7.4]
Guerin−Laguette, 2003 11.5 [ 9.0, 13.9]
Mari, 2003 0.0 [ −2.2, 2.2]
Hilszczanska, 2004 −27.6 [ −31.4, −23.9]
Hilszczanska, 2004 −3.6 [ −7.4, 0.1]
Duñabeitia, 2004 17.7 [ 12.6, 22.8]
Duñabeitia, 2004 61.6 [ 56.5, 66.7]
Duñabeitia, 2004 16.0 [ 10.9, 21.1]
Duñabeitia, 2004 0.0 [ −5.1, 5.1]
Duñabeitia, 2004 45.6 [ 40.5, 50.7]
Duñabeitia, 2004 53.7 [ 48.6, 58.8]
Duñabeitia, 2004 2.3 [ −2.8, 7.4]
Duñabeitia, 2004 12.8 [ 7.7, 17.9]
Duñabeitia, 2004 15.9 [ 10.8, 21.0]
Duñabeitia, 2004 11.8 [ 6.7, 16.9]
Duñabeitia, 2004 5.2 [ 0.1, 10.3]
Duñabeitia, 2004 17.1 [ 12.0, 22.2]
Choi, 2005 13.1 [ 8.6, 17.5]
Rincón, 2005 −72.0 [ −77.1, −66.8]
Rincón, 2005 12.0 [ 6.9, 17.1]
Bakker, 2006 2.3 [ 0.1, 4.5]
van Hees, 2006 −0.1 [ −1.5, 1.4]
van Hees, 2006 0.9 [ −0.4, 2.2]
Rincón, 2007 −4.4 [ −7.1, −1.8]
Rincón, 2007 6.3 [ 3.6, 8.9]
Rincón, 2007 5.8 [ 3.1, 8.4]
Rincón, 2007 9.6 [ 6.9, 12.2]
Rincón, 2007 8.1 [ 5.5, 10.8]
Aucina, 2007 28.2 [ 23.1, 33.3]
Kozdrój, 2007 2.3 [ 0.8, 3.9]
Kozdrój, 2007 2.3 [ 0.7, 3.8]
Kozdrój, 2007 11.0 [ 8.8, 13.1]
Kozdrój, 2007 10.7 [ 8.5, 12.8]
Niemi, 2007 186.3 [ 181.8, 190.7]
Niemi, 2007 276.4 [ 271.8, 281.0]
Niemi, 2007 1.0 [ −0.3, 2.3]
Niemi, 2007 1.0 [ −0.3, 2.3]
Zhu, 2008 14.4 [ 11.9, 16.8]
zhu, 2008 0.7 [ −1.5, 2.9]
Zhu, 2008 12.1 [ 9.8, 14.5]
Zhu, 2008 11.4 [ 9.1, 13.8]
Zhu, 2008 13.7 [ 11.3, 16.1]
Zhu, 2008 4.2 [ 2.0, 6.4]

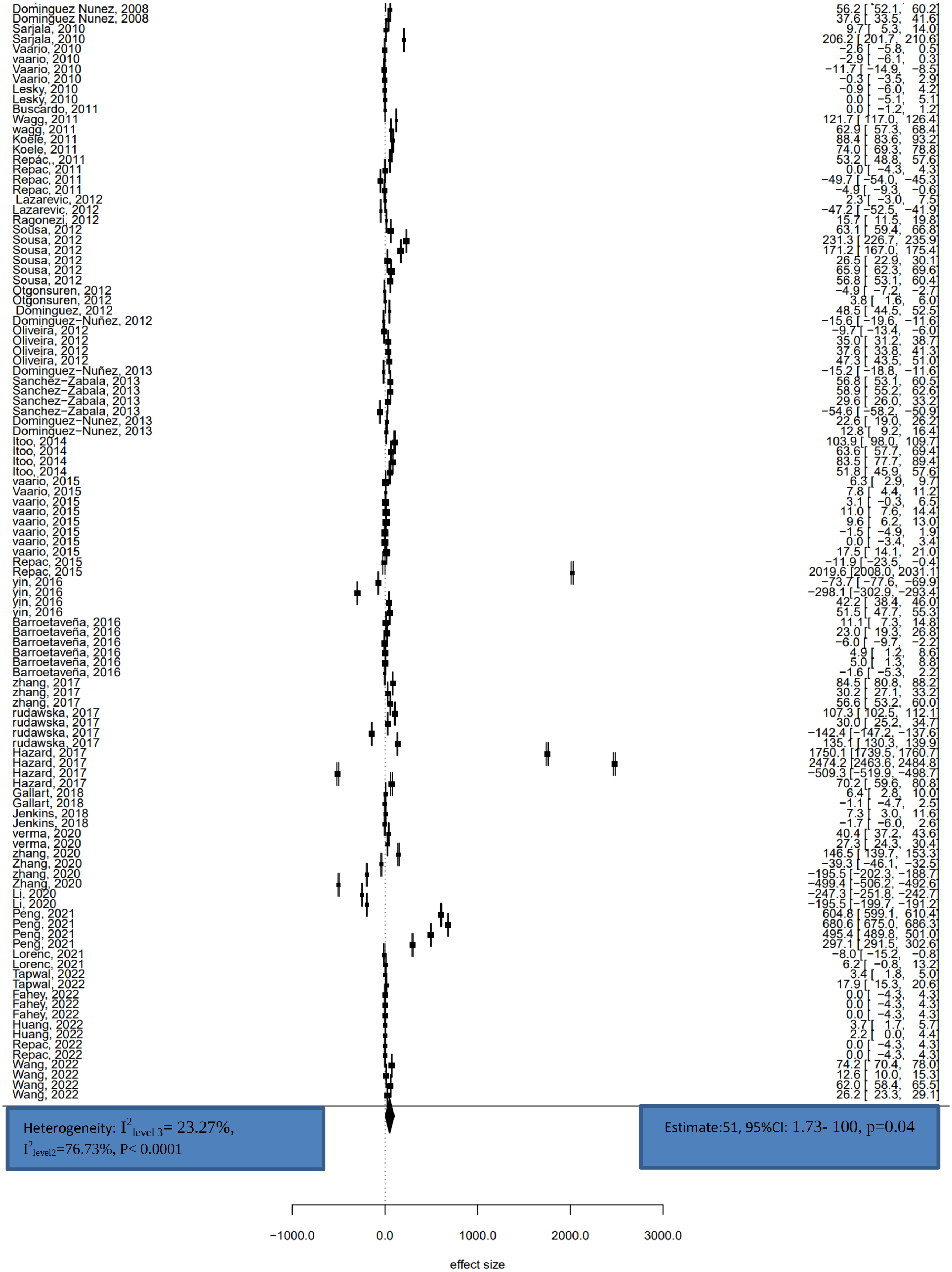
Dominguez Nunez, 2008 56.2 [ 52.1, 60.2]
Dominguez Nunez, 2008 37.6 [ 33.5, 41.6]
Sarjala, 2010 9.7 [ 5.3, 14.0]
Sarjala, 2010 206.2 [ 201.7, 210.6]
Vaario, 2010 −2.6 [ −5.8, 0.5]
vaario, 2010 −2.9 [ −6.1, 0.3]
Vaario, 2010 −11.7 [ −14.9, −8.5]
Vaario, 2010 −0.3 [ −3.5, 2.9]
Lesky, 2010 −0.9 [ −6.0, 4.2]
Lesky, 2010 0.0 [ −5.1, 5.1]
Buscardo, 2011 0.0 [ −1.2, 1.2]
Wagg, 2011 121.7 [ 117.0, 126.4]
wagg, 2011 62.9 [ 57.3, 68.4]
Koele, 2011 88.4 [ 83.6, 93.2]
Koele, 2011 74.0 [ 69.3, 78.8]
Repác,, 2011 53.2 [ 48.8, 57.6]
Repac, 2011 0.0 [ −4.3, 4.3]
Repac, 2011 −49.7 [ −54.0, −45.3]
Repac, 2011 −4.9 [ −9.3, −0.6]
Lazarevic, 2012 2.3 [ −3.0, 7.5]
Lazarevic, 2012 −47.2 [ −52.5, −41.9]
Ragonezi, 2012 15.7 [ 11.5, 19.8]
Sousa, 2012 63.1 [ 59.4, 66.8]
Sousa, 2012 231.3 [ 226.7, 235.9]
Sousa, 2012 171.2 [ 167.0, 175.4]
Sousa, 2012 26.5 [ 22.9, 30.1]
Sousa, 2012 65.9 [ 62.3, 69.6]
Sousa, 2012 56.8 [ 53.1, 60.4]
Otgonsuren, 2012 −4.9 [ −7.2, −2.7]
Otgonsuren, 2012 3.8 [ 1.6, 6.0]
Dominguez, 2012 48.5 [ 44.5, 52.5]
Dominguez−Nuñez, 2012 −15.6 [ −19.6, −11.6]
Oliveira, 2012 −9.7 [ −13.4, −6.0]
Oliveira, 2012 35.0 [ 31.2, 38.7]
Oliveira, 2012 37.6 [ 33.8, 41.3]
Oliveira, 2012 47.3 [ 43.5, 51.0]
Dominguez−Nuñez, 2013 −15.2 [ −18.8, −11.6]
Sanchez−Zabala, 2013 56.8 [ 53.1, 60.5]
Sanchez−Zabala, 2013 58.9 [ 55.2, 62.6]
Sanchez−Zabala, 2013 29.6 [ 26.0, 33.2]
Sanchez−Zabala, 2013 −54.6 [ −58.2, −50.9]
Dominguez−Nunez, 2013 22.6 [ 19.0, 26.2]
Dominguez−Nunez, 2013 12.8 [ 9.2, 16.4]
Itoo, 2014 103.9 [ 98.0, 109.7]
Itoo, 2014 63.6 [ 57.7, 69.4]
Itoo, 2014 83.5 [ 77.7, 89.4]
Itoo, 2014 51.8 [ 45.9, 57.6]
vaario, 2015 6.3 [ 2.9, 9.7]
Vaario, 2015 7.8 [ 4.4, 11.2]
vaario, 2015 3.1 [ −0.3, 6.5]
vaario, 2015 11.0 [ 7.6, 14.4]
vaario, 2015 9.6 [ 6.2, 13.0]
vaario, 2015 −1.5 [ −4.9, 1.9]
vaario, 2015 0.0 [ −3.4, 3.4]
vaario, 2015 17.5 [ 14.1, 21.0]
Repac, 2015 −11.9 [ −23.5, −0.4]
Repac, 2015 2019.6 [2008.0, 2031.1]
yin, 2016 −73.7 [ −77.6, −69.9]
yin, 2016 −298.1 [−302.9, −293.4]
yin, 2016 42.2 [ 38.4, 46.0]
yin, 2016 51.5 [ 47.7, 55.3]
Barroetaveña, 2016 11.1 [ 7.3, 14.8]
Barroetaveña, 2016 23.0 [ 19.3, 26.8]
Barroetaveña, 2016 −6.0 [ −9.7, −2.2]
Barroetaveña, 2016 4.9 [ 1.2, 8.6]
Barroetaveña, 2016 5.0 [ 1.3, 8.8]
Barroetaveña, 2016 −1.6 [ −5.3, 2.2]
zhang, 2017 84.5 [ 80.8, 88.2]
zhang, 2017 30.2 [ 27.1, 33.2]
zhang, 2017 56.6 [ 53.2, 60.0]
rudawska, 2017 107.3 [ 102.5, 112.1]
rudawska, 2017 30.0 [ 25.2, 34.7]
rudawska, 2017 −142.4 [−147.2, −137.6]
rudawska, 2017 135.1 [ 130.3, 139.9]
Hazard, 2017 1750.1 [1739.5, 1760.7]
Hazard, 2017 2474.2 [2463.6, 2484.8]
Hazard, 2017 −509.3 [−519.9, −498.7]
Hazard, 2017 70.2 [ 59.6, 80.8]
Gallart, 2018 6.4 [ 2.8, 10.0]
Gallart, 2018 −1.1 [ −4.7, 2.5]
Jenkins, 2018 7.3 [ 3.0, 11.6]
Jenkins, 2018 −1.7 [ −6.0, 2.6]
verma, 2020 40.4 [ 37.2, 43.6]
verma, 2020 27.3 [ 24.3, 30.4]
zhang, 2020 146.5 [ 139.7, 153.3]
Zhang, 2020 −39.3 [ −46.1, −32.5]
zhang, 2020 −195.5 [−202.3, −188.7]
Zhang, 2020 −499.4 [−506.2, −492.6]
Li, 2020 −247.3 [−251.8, −242.7]
Li, 2020 −195.5 [−199.7, −191.2]
Peng, 2021 604.8 [ 599.1, 610.4]
Peng, 2021 680.6 [ 675.0, 686.3]
Peng, 2021 495.4 [ 489.8, 501.0]
Peng, 2021 297.1 [ 291.5, 302.6]
Lorenc, 2021 −8.0 [ −15.2, −0.8]
Lorenc, 2021 6.2 [ −0.8, 13.2]
Tapwal, 2022 3.4 [ 1.8, 5.0]
Tapwal, 2022 17.9 [ 15.3, 20.6]
Fahey, 2022 0.0 [ −4.3, 4.3]
Fahey, 2022 0.0 [ −4.3, 4.3]
Fahey, 2022 0.0 [ −4.3, 4.3]
Huang, 2022 3.7 [ 1.7, 5.7]
Huang, 2022 2.2 [ 0.0, 4.4]
Repac, 2022 0.0 [ −4.3, 4.3]
Repac, 2022 0.0 [ −4.3, 4.3]
Wang, 2022 74.2 [ 70.4, 78.0]
Wang, 2022 12.6 [ 10.0, 15.3]
Wang, 2022 62.0 [ 58.4, 65.5]
Wang, 2022 26.2 [ 23.3, 29.1]
Heterogeneity: $I^2_{level\ 3}$= 23.27%, $I^2_{level2}$=76.73%, P< 0.0001
Estimate:51, 95%CI: 1.73- 100, p=0.04
−1000.0
0.0
1000.0
2000.0
3000.0
effect size

**Figure 9**: Forest plot of the overall effects of ECM on growth

Forest plot of the overall effects of Ectomycorrhizal fungi on *Pinus* and *Picea* growth. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall effect of the study.

### 3.2 Effect of ECM on conifer resistance to abiotic stress

In contrary to *Pinus* species, from the year 1991 to 2022, there are scanty recorded studies of *Picea* species (only recorded three times). The total number of articles was high in 2004, 2007 and 2012, followed by a substantial decrease in 2005 and later.

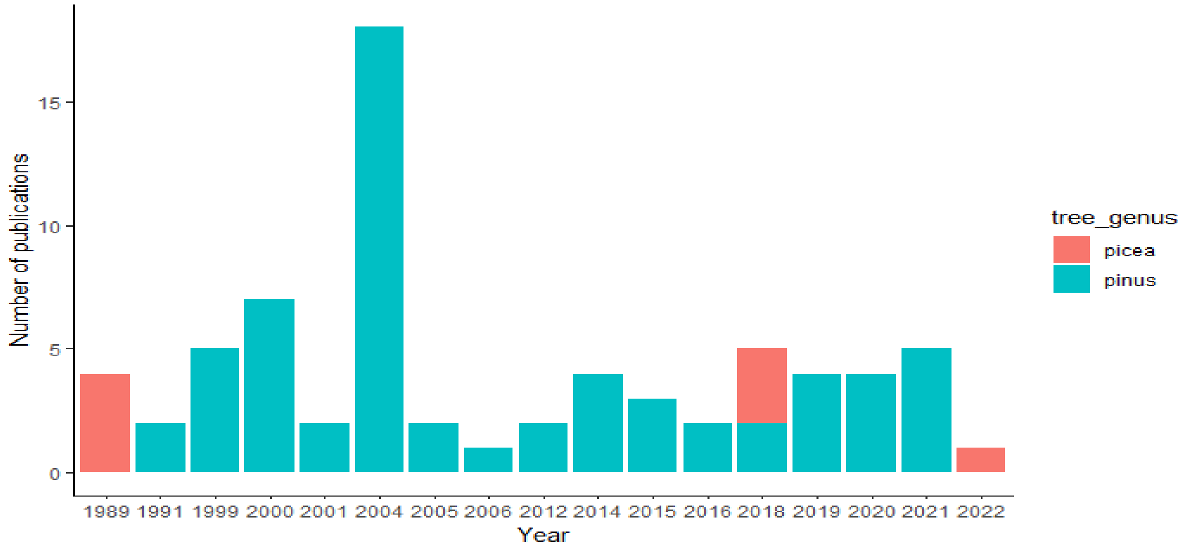


**Figure 9**: Number of publications on conifer resistance to abiotic stress

Publication year of articles included in the meta-analysis of ECM effect on *Pinus* and *Picea* on abiotic stress.

Growth studies were mostly conducted in a growth facility, and much of the investigation was conducted on *Pinus*. No field studies were conducted on *Picea* (Figure 9).

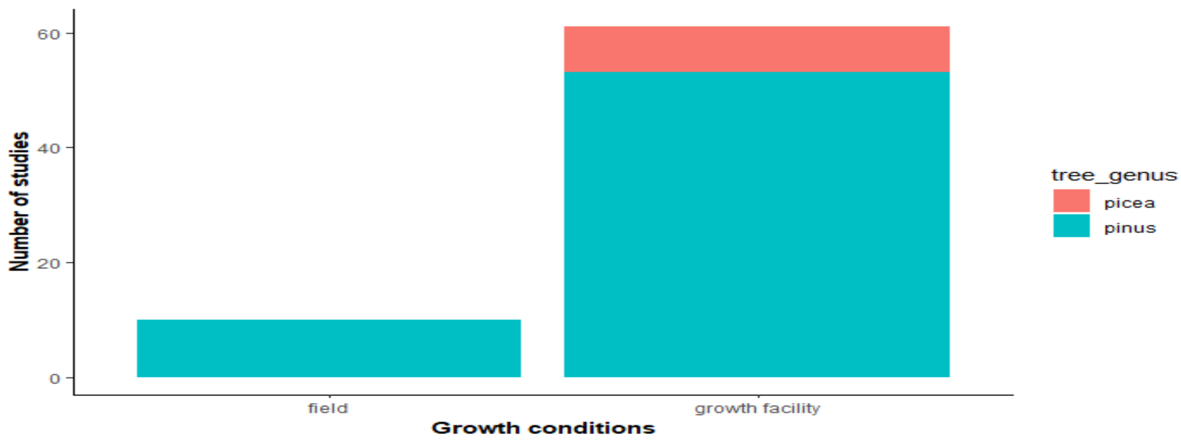

**Figure 10:** Growth conditions under which studies on abiotic stress in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on abiotic stress were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to "growth facility" and those which were carried out in the field were allocated to "field".

The most common ECM genera used were members of the genus *Suillus* or a combination of different ectomycorrhizal fungi. The most tested tree species were in the genus *Pinus*. (Figure 10).

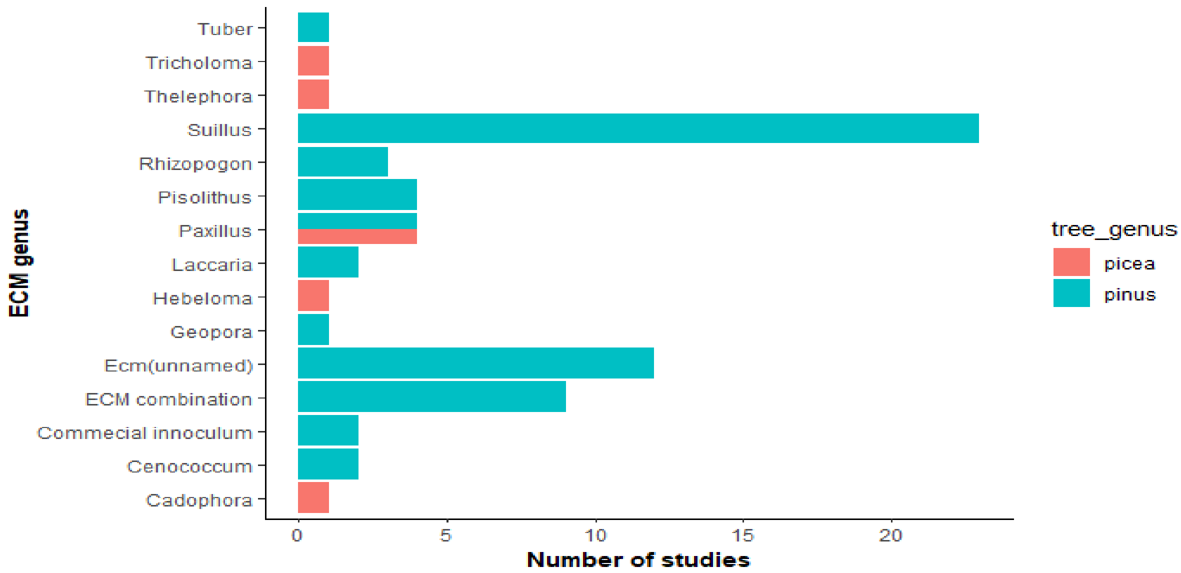


**Figure 11**: ECM genera which were used for growth studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on abiotic stress were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used.

Soil types: composite, field and sandy were used on both *Pinus* and *Picea* and media soil type was not used on both tree species. The number of studies performed using these three soil types were almost equal on *Pinus* species and on Picea species as well (Figure 12).

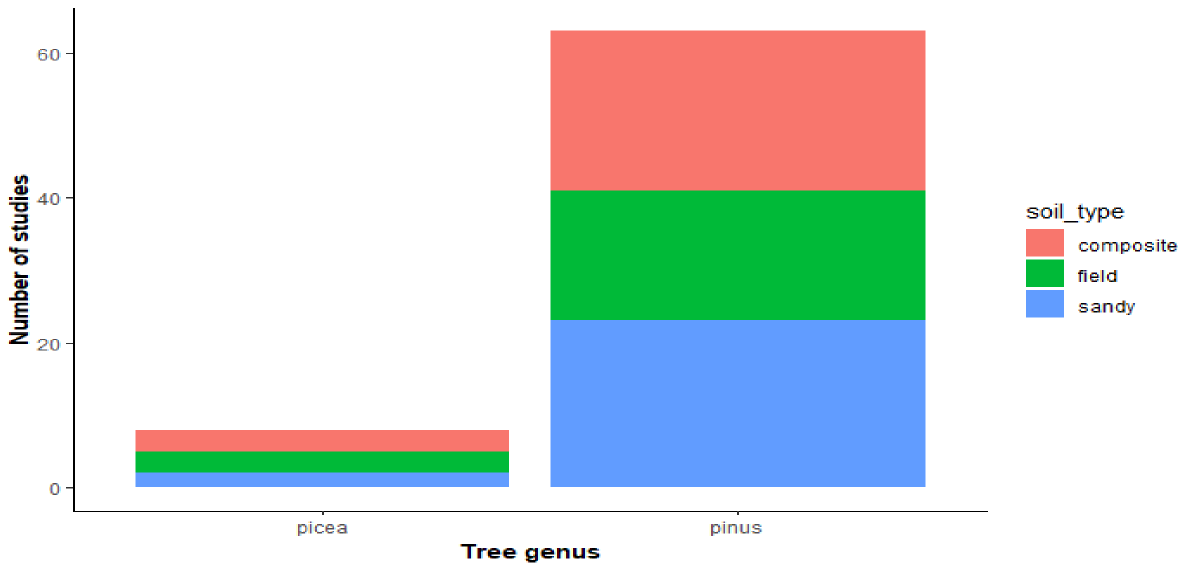


**Figure 12:** Soil type used on conifer resistance to abiotic stress studies.

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled effect size based on the three- level meta -analysis model was 0.0014 (95% CI: -0.02- 0.02; p=0, 9), indicating a very small effect of ectomycorrhizal fungi on abiotic stress. There is low level of heterogeneity in the abiotic factor.$I^2_{level\ 3}$ (overall effect size) was 0% and $I^2_{level\ 1}$(individual effects) was 100%, meaning variability in effect size estimates is due to sampling error within studies. (Figure 12).

There is an indication of publication bias because small studies that favours ectomycorrhizal fungi are missing at the lower right hand-side of the plot vice versa (the plot is not symmetrical) or small negative studies at the bottom left do not balance small positive studies at the bottom right. However almost all studies are not significant as only 2 studies were significant.

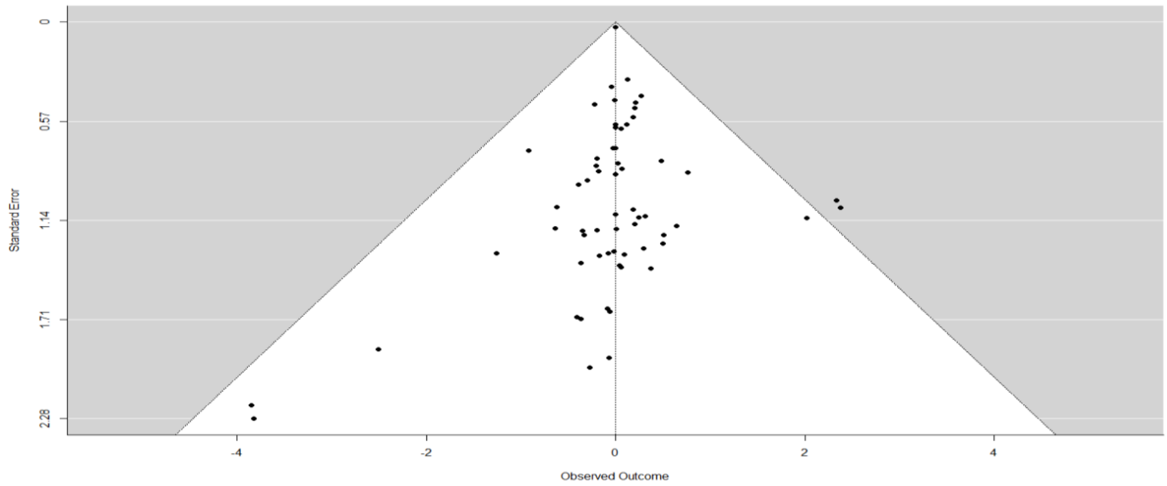


**Figure 13:** Funnel plot showing publication bias on abiotic stress studies.

Funnel plot showing publication bias of abiotic stress studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome. The outer dashed lines show the 95%Confidence Interval limit. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted funnel.

The pooled estimated effects sizes of the moderators were dispersed around zero meaning ectomycorrhizal fungi did not enhance conifer resistance to abiotic stress (Table 2). They had no significant moderating effect (P > 0.05) on the relationship between ectomycorrhizal fungi and conifer resistance to abiotic stress.

**Table 2**: Overview of estimated pooled effect sizes of abiotic factor moderators using a three level meta-analysis random effects model.

| Moderator | Estimate | Standard error | T value | Degrees of freedom | P value | Lower confidence interval | Higher confidence interval |
|---|---|---|---|---|---|---|---|
| ECM | 0.001 | 0.5904 | 0.0017 | 56 | 0.9987 | -1.1818 | 1.1838 |
| Soil type | 0.079 | 0.1356 | 0.5829 | 68 | 0.5619 | -0.1915 | 0.3496 |
| Growth conditions | 0.136 | 0.3183 | 0.4272 | 69 | 0.6705 | -0.499 | 0.7709 |
| Tree age | 0.0057 | 0.0375 | 0.152 | 69 | 0.8796 | -0.0691 | 0.0805 |
| Tree genus | 0.0047 | 0.2939 | -0.0159 | 69 | 0.9874 | -0.5816 | 0.5909 |
| Stress type | -0.527 | 0.2597 | -0.2029 | 68 | 0.8398 | -0.5709 | 0.4655 |

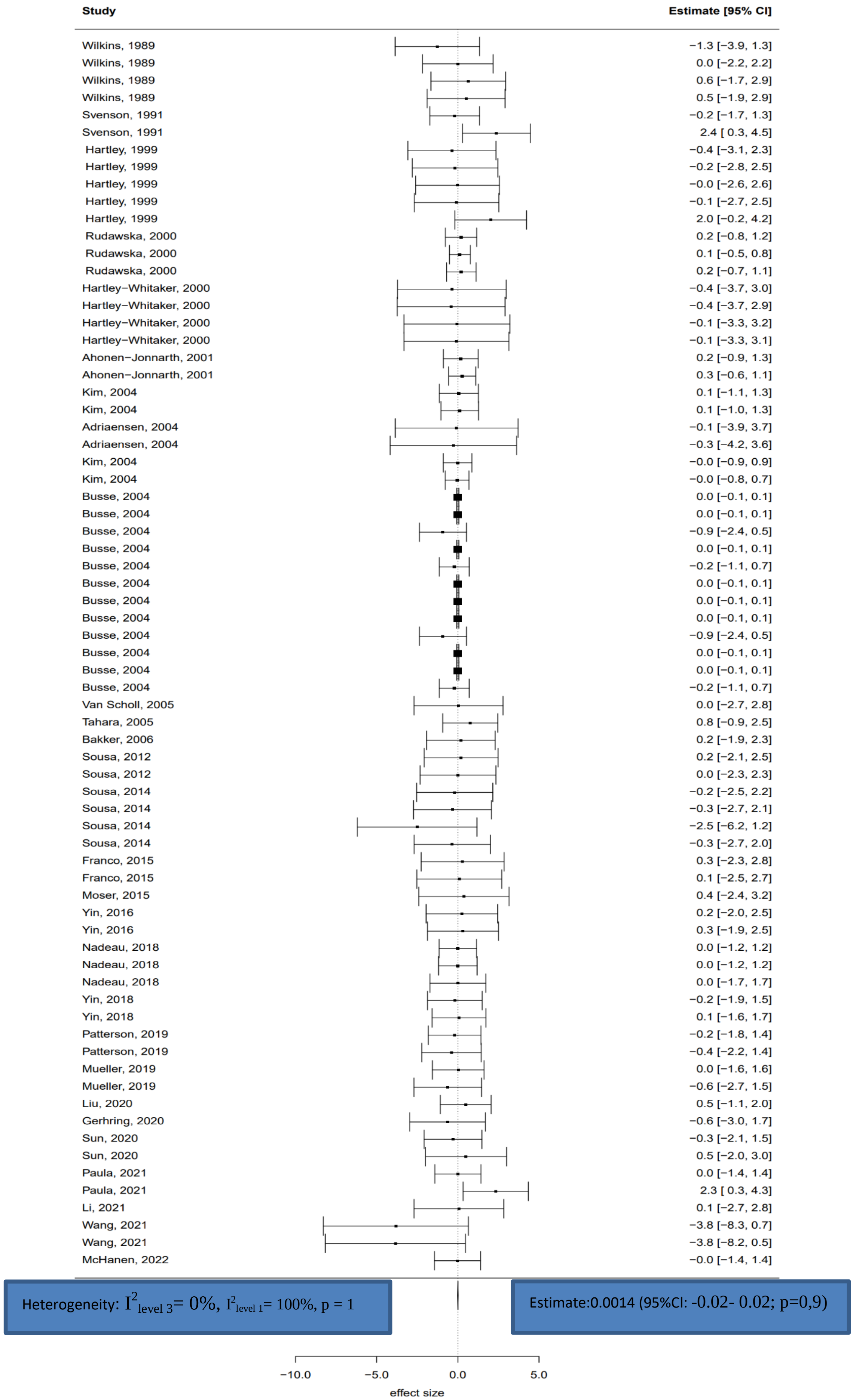
Study
Estimate [95% CI]
Wilkins, 1989 −1.3 [−3.9, 1.3]
Wilkins, 1989 0.0 [−2.2, 2.2]
Wilkins, 1989 0.6 [−1.7, 2.9]
Wilkins, 1989 0.5 [−1.9, 2.9]
Svenson, 1991 −0.2 [−1.7, 1.3]
Svenson, 1991 2.4 [ 0.3, 4.5]
Hartley, 1999 −0.4 [−3.1, 2.3]
Hartley, 1999 −0.2 [−2.8, 2.5]
Hartley, 1999 −0.0 [−2.6, 2.6]
Hartley, 1999 −0.1 [−2.7, 2.5]
Hartley, 1999 2.0 [−0.2, 4.2]
Rudawska, 2000 0.2 [−0.8, 1.2]
Rudawska, 2000 0.1 [−0.5, 0.8]
Rudawska, 2000 0.2 [−0.7, 1.1]
Hartley−Whitaker, 2000 −0.4 [−3.7, 3.0]
Hartley−Whitaker, 2000 −0.4 [−3.7, 2.9]
Hartley−Whitaker, 2000 −0.1 [−3.3, 3.2]
Hartley−Whitaker, 2000 −0.1 [−3.3, 3.1]
Ahonen−Jonnarth, 2001 0.2 [−0.9, 1.3]
Ahonen−Jonnarth, 2001 0.3 [−0.6, 1.1]
Kim, 2004 0.1 [−1.1, 1.3]
Kim, 2004 0.1 [−1.0, 1.3]
Adriaensen, 2004 −0.1 [−3.9, 3.7]
Adriaensen, 2004 −0.3 [−4.2, 3.6]
Kim, 2004 −0.0 [−0.9, 0.9]
Kim, 2004 −0.0 [−0.8, 0.7]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.9 [−2.4, 0.5]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.2 [−1.1, 0.7]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.9 [−2.4, 0.5]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.2 [−1.1, 0.7]
Van Scholl, 2005 0.0 [−2.7, 2.8]
Tahara, 2005 0.8 [−0.9, 2.5]
Bakker, 2006 0.2 [−1.9, 2.3]
Sousa, 2012 0.2 [−2.1, 2.5]
Sousa, 2012 0.0 [−2.3, 2.3]
Sousa, 2014 −0.2 [−2.5, 2.2]
Sousa, 2014 −0.3 [−2.7, 2.1]
Sousa, 2014 −2.5 [−6.2, 1.2]
Sousa, 2014 −0.3 [−2.7, 2.0]
Franco, 2015 0.3 [−2.3, 2.8]
Franco, 2015 0.1 [−2.5, 2.7]
Moser, 2015 0.4 [−2.4, 3.2]
Yin, 2016 0.2 [−2.0, 2.5]
Yin, 2016 0.3 [−1.9, 2.5]
Nadeau, 2018 0.0 [−1.2, 1.2]
Nadeau, 2018 0.0 [−1.2, 1.2]
Nadeau, 2018 0.0 [−1.7, 1.7]
Yin, 2018 −0.2 [−1.9, 1.5]
Yin, 2018 0.1 [−1.6, 1.7]
Patterson, 2019 −0.2 [−1.8, 1.4]
Patterson, 2019 −0.4 [−2.2, 1.4]
Mueller, 2019 0.0 [−1.6, 1.6]
Mueller, 2019 −0.6 [−2.7, 1.5]
Liu, 2020 0.5 [−1.1, 2.0]
Gerhring, 2020 −0.6 [−3.0, 1.7]
Sun, 2020 −0.3 [−2.1, 1.5]
Sun, 2020 0.5 [−2.0, 3.0]
Paula, 2021 0.0 [−1.4, 1.4]
Paula, 2021 2.3 [ 0.3, 4.3]
Li, 2021 0.1 [−2.7, 2.8]
Wang, 2021 −3.8 [−8.3, 0.7]
Wang, 2021 −3.8 [−8.2, 0.5]
McHanen, 2022 −0.0 [−1.4, 1.4]
Heterogeneity: $I^2_{level\ 3}$= 0%, $I^2_{level\ 1}$= 100%, p = 1
Estimate:0.0014 (95%CI: -0.02- 0.02; p=0,9)
−10.0
−5.0
0.0
5.0
effect size

**Figure 14:** Forest plot of the overall effects of ECM on conifer resistance to abiotic stress

Forest plot of the overall effects of ectomycorrhizal fungi on *Pinus* or *Picea* to abiotic stress. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall effect of the study.

### 3.3 Effects of ECM on conifer tree Survival

There are more published articles on *Pinus* compared to *Picea*. Publications for *Picea* were high in 2005 and 2011 followed by a sharp decrease in 2014. There were no *Picea* publications between 2014 to 2020 (Figure 13).

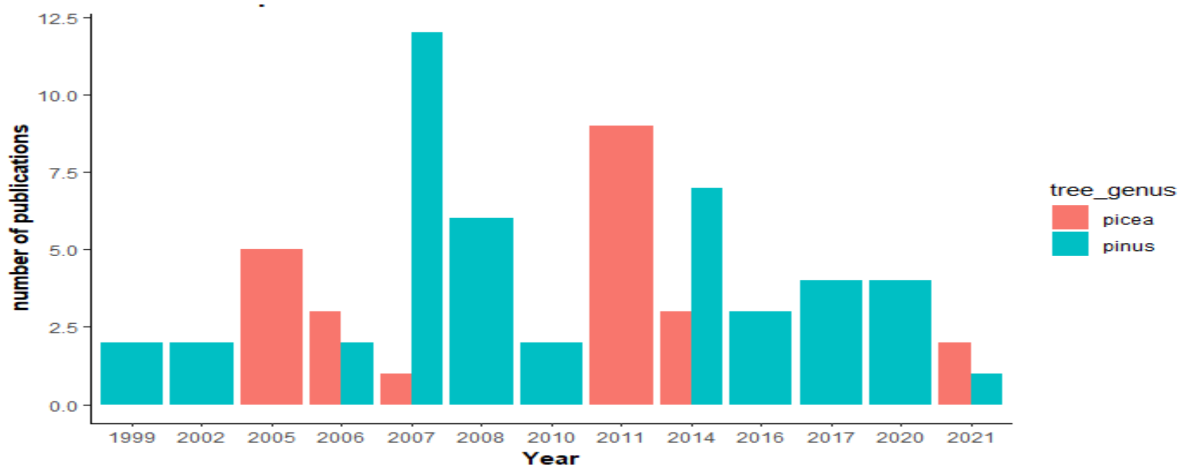


**Figure 15:** Number of publications on conifer survival.

Publication year of articles included in the meta-analysis of ECM effect on *Pinus* and *Picea* survival.

Most studies were conducted in the field and a significant number of *Picea* species were tested in the field (Figure 14).

**Figure 16:** Growth conditions under which studies on conifer survival in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on *Pinus* and *Picea* survival were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to "growth facility" and those which were carried out in the field were allocated to "field".

The most common ECM genera used were *Suillus*, *ECM combination* and *Pisolithus*. ECM was mostly tested on *Pinus* species (Figure 15).

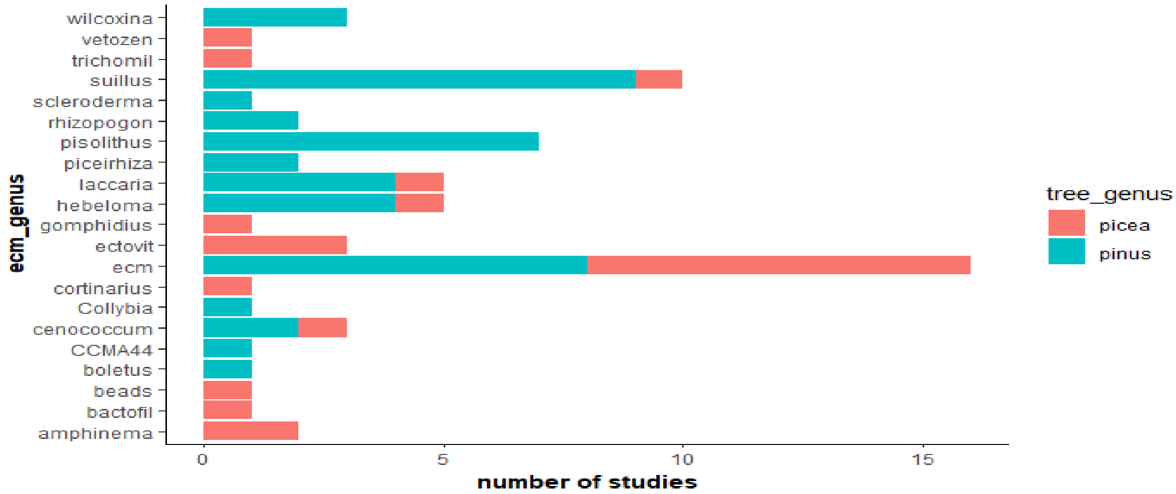


**Figure 17:** ECM genera which were used for growth studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on survival were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used.

All the four soil types were used on *Pinus* species and three soil types excluding media were used on *Picea* species. The most used soil type on *Pinus* species was the field soil. Both field and composite soil types were mostly used on *Picea* species.

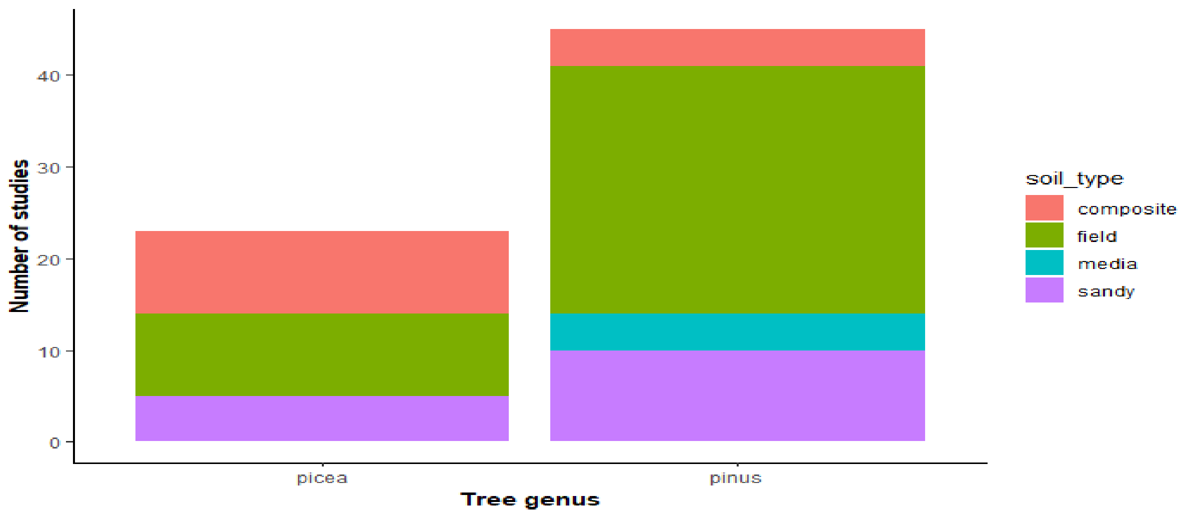

**Figure 18:**Soil type used on conifer tree survival studies.

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled estimated effect size based on the three-level meta -analysis model was 0.09 (95% CI: 0.25- 0.44; p = 1) meaning that ectomycorrhizal fungi had a negative effect on conifer survival. There is high heterogeneity in the study, $I^2_{\text{level 3}}$ (overall effect size) was 34.27% and $I^2_{\text{level 2}}$ (nested effect sizes from individual studies) was 64.61% (Figure 17).

There is an indication of publication bias because the graph is asymmetrical. Small studies that do not favour and that favours ectomycorrhizal fungi are missing at the lower right hand and left hand of the plot. Most studies are not significant, and a few significant studies are outside the triangle.

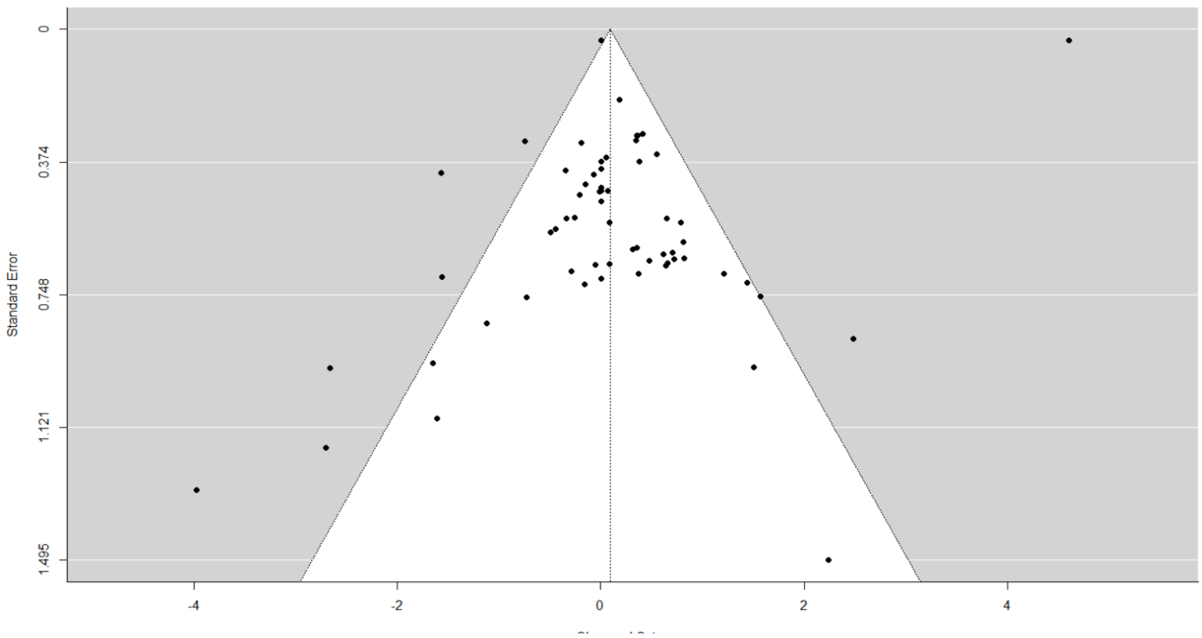


**Figure 19:** Funnel plot showing publication bias of survival studies.

Funnel plot showing publication bias of studies on survival. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome (effect size). The outer dashed lines show the 95% confidence interval. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted funnel.

The pooled estimated effects sizes of the moderators were dispersed around zero meaning ectomycorrhizal fungi did not enhance and conifer tree survival (Table 3). They had no significant moderating effect (P>0.05) on the relationship between ectomycorrhizal fungi and conifer survival.

**Table 3**: Overview of estimated pooled effect sizes of survival factor moderators using a three level meta-analysis random effects model.

| **Moderator** | **Estimate** | **Standard error** | **T value** | **Degrees of freedom** | **P value** | **Lower confidence interval** | **Higher confidence interval** |
|---|---|---|---|---|---|---|---|
| ECM | 0.001 | 0.6831 | 0.0015 | 47 | 0.9988 | -1.3732 | 1.3752 |
| Soil type | -0.0876 | 0.4044 | -0.2165 | 63 | 0.8293 | -0.8957 | 0.7206 |
| Growth conditions | 0.0654 | 0.219 | -0.2986 | 66 | 0.7662 | -0.3719 | 0.5027 |
| Tree age | 0.2698 | 0.3117 | 0.8657 | 66 | 0.3898 | -0.3525 | 0.8921 |
| Tree genus | 0.1403 | 0.3002 | 0.4672 | 66 | 0.6419 | -0.4592 | 0.7397 |

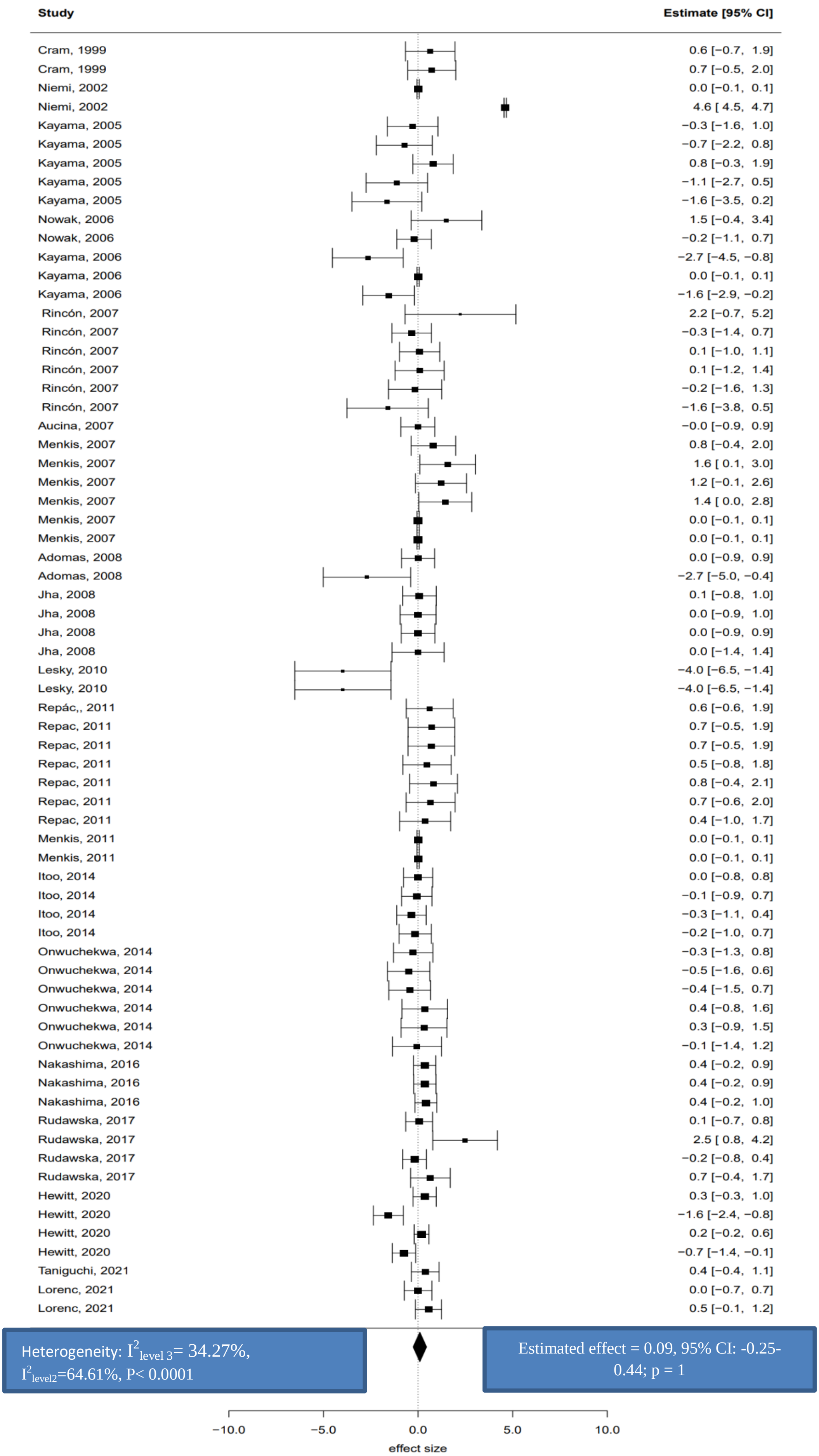
Study
Estimate [95% CI]
Cram, 1999 0.6 [−0.7, 1.9]
Cram, 1999 0.7 [−0.5, 2.0]
Niemi, 2002 0.0 [−0.1, 0.1]
Niemi, 2002 4.6 [ 4.5, 4.7]
Kayama, 2005 −0.3 [−1.6, 1.0]
Kayama, 2005 −0.7 [−2.2, 0.8]
Kayama, 2005 0.8 [−0.3, 1.9]
Kayama, 2005 −1.1 [−2.7, 0.5]
Kayama, 2005 −1.6 [−3.5, 0.2]
Nowak, 2006 1.5 [−0.4, 3.4]
Nowak, 2006 −0.2 [−1.1, 0.7]
Kayama, 2006 −2.7 [−4.5, −0.8]
Kayama, 2006 0.0 [−0.1, 0.1]
Kayama, 2006 −1.6 [−2.9, −0.2]
Rincón, 2007 2.2 [−0.7, 5.2]
Rincón, 2007 −0.3 [−1.4, 0.7]
Rincón, 2007 0.1 [−1.0, 1.1]
Rincón, 2007 0.1 [−1.2, 1.4]
Rincón, 2007 −0.2 [−1.6, 1.3]
Rincón, 2007 −1.6 [−3.8, 0.5]
Aucina, 2007 −0.0 [−0.9, 0.9]
Menkis, 2007 0.8 [−0.4, 2.0]
Menkis, 2007 1.6 [ 0.1, 3.0]
Menkis, 2007 1.2 [−0.1, 2.6]
Menkis, 2007 1.4 [ 0.0, 2.8]
Menkis, 2007 0.0 [−0.1, 0.1]
Menkis, 2007 0.0 [−0.1, 0.1]
Adomas, 2008 0.0 [−0.9, 0.9]
Adomas, 2008 −2.7 [−5.0, −0.4]
Jha, 2008 0.1 [−0.8, 1.0]
Jha, 2008 0.0 [−0.9, 1.0]
Jha, 2008 0.0 [−0.9, 0.9]
Jha, 2008 0.0 [−1.4, 1.4]
Lesky, 2010 −4.0 [−6.5, −1.4]
Lesky, 2010 −4.0 [−6.5, −1.4]
Repác,, 2011 0.6 [−0.6, 1.9]
Repac, 2011 0.7 [−0.5, 1.9]
Repac, 2011 0.7 [−0.5, 1.9]
Repac, 2011 0.5 [−0.8, 1.8]
Repac, 2011 0.8 [−0.4, 2.1]
Repac, 2011 0.7 [−0.6, 2.0]
Repac, 2011 0.4 [−1.0, 1.7]
Menkis, 2011 0.0 [−0.1, 0.1]
Menkis, 2011 0.0 [−0.1, 0.1]
Itoo, 2014 0.0 [−0.8, 0.8]
Itoo, 2014 −0.1 [−0.9, 0.7]
Itoo, 2014 −0.3 [−1.1, 0.4]
Itoo, 2014 −0.2 [−1.0, 0.7]
Onwuchekwa, 2014 −0.3 [−1.3, 0.8]
Onwuchekwa, 2014 −0.5 [−1.6, 0.6]
Onwuchekwa, 2014 −0.4 [−1.5, 0.7]
Onwuchekwa, 2014 0.4 [−0.8, 1.6]
Onwuchekwa, 2014 0.3 [−0.9, 1.5]
Onwuchekwa, 2014 −0.1 [−1.4, 1.2]
Nakashima, 2016 0.4 [−0.2, 0.9]
Nakashima, 2016 0.4 [−0.2, 0.9]
Nakashima, 2016 0.4 [−0.2, 1.0]
Rudawska, 2017 0.1 [−0.7, 0.8]
Rudawska, 2017 2.5 [ 0.8, 4.2]
Rudawska, 2017 −0.2 [−0.8, 0.4]
Rudawska, 2017 0.7 [−0.4, 1.7]
Hewitt, 2020 0.3 [−0.3, 1.0]
Hewitt, 2020 −1.6 [−2.4, −0.8]
Hewitt, 2020 0.2 [−0.2, 0.6]
Hewitt, 2020 −0.7 [−1.4, −0.1]
Taniguchi, 2021 0.4 [−0.4, 1.1]
Lorenc, 2021 0.0 [−0.7, 0.7]
Lorenc, 2021 0.5 [−0.1, 1.2]
Heterogeneity: $I^2_{level\ 3}$= 34.27%, $I^2_{level2}$=64.61%, P< 0.0001
Estimated effect = 0.09, 95% CI: -0.25-0.44; p = 1
−10.0
−5.0
0.0
5.0
10.0
effect size

**Figure 20:** Forest plot of the overall effects of ECM on conifer survival

Forest plot of the overall effects of ectomycorrhizal fungi on *Pinus* or *Picea* survival. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall effect of the study.

### 3.4 Effects of ECM on conifer resistance to biotic stress

There were very few publications on *Picea* species between 1993 and 2022. Only three articles were published (2010, 2018 and 2021), (Figure 20).

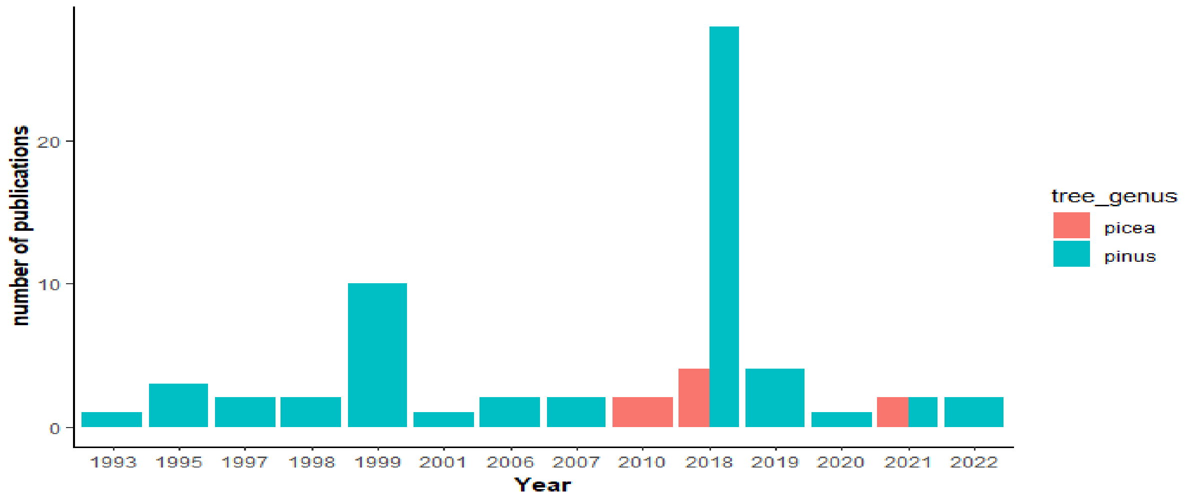


**Figure 21:** Number of publications on conifer resistance to biotic stress

Publication year of articles included in the meta-analysis of ECM effect on *Pinus* and *Picea* on biotic stress.

Most studies were conducted in a growth facility with *Pinus* accounting to more than half of the studies. Minute studies were conducted in the field on both tree species.

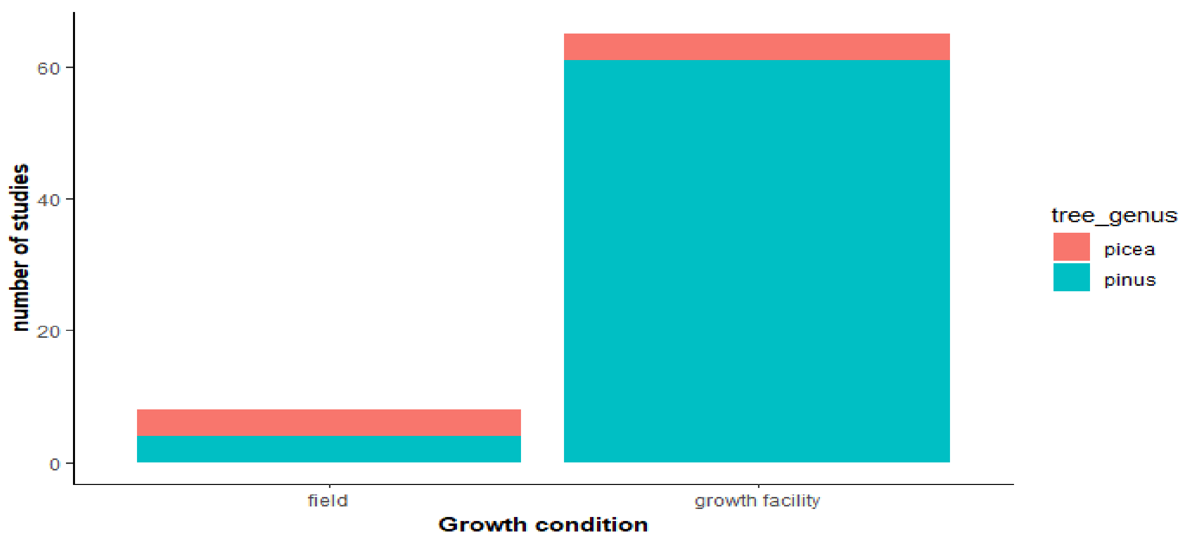

**Figure 22:** Growth conditions under which studies on conifer biotic stress studies in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on biotic stress were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to "growth facility" and those which were carried out in the field were allocated to "field". (*Pinus* is represented by blue and *Picea* by pink).

The most used ECM were the *Rhizopogon*, *Lactarius*, *Suillus*, *Paxillus* and ECM combination, but they were only experimented *Pinus*. There were very few studies on Picea species (Figure 20).

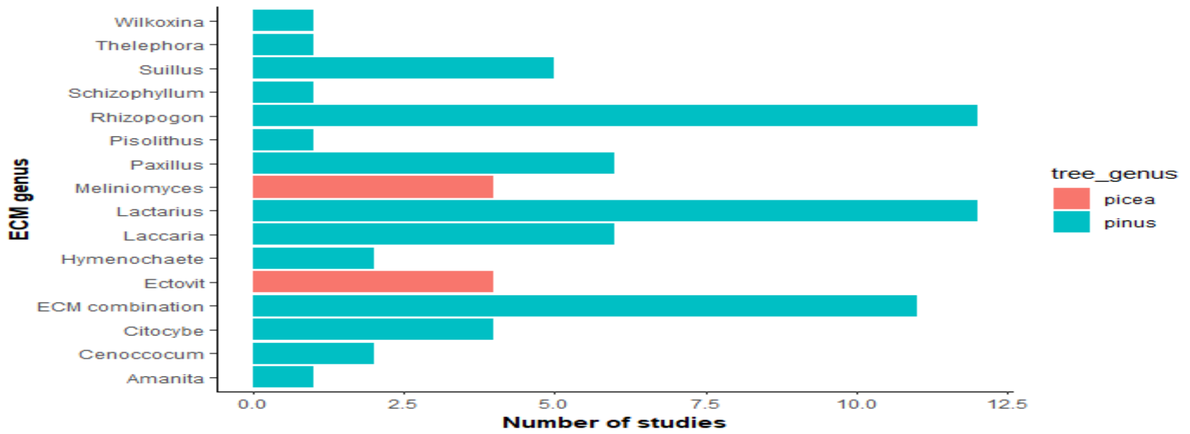


**Figure 23:** ECM genera which were used for biotic studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on biotic stress were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used.

The most common used soil type on *Pinus* species was the composite followed by the field soil type. Both composite and field soil types were equally used on *Picea* species.

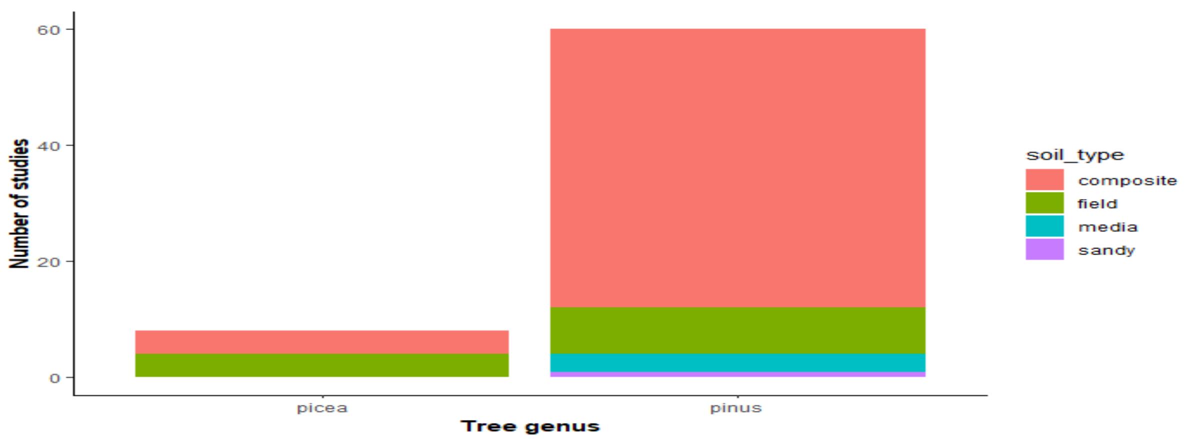

**Figure 24:** Soil type used on conifer resistance to biotic stress studies

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled estimated effect size based on the level three meta -analysis model was (-0.1), (95% CI: -0.8- 0.69; p = 1) meaning ectomycorrhizal fungi did not improve tree resistance to biotic stress. There is high heterogeneity in the biotic factor study. $I^2_{level\ 3}$ (overall effect size) was 5.5% and $I^2_{level\ 2}$ (nested effect sizes from individual studies) was 90.34% (Figure 22).

The pooled estimated effects sizes of the moderators were below zero indicating a very weak relationship on biotic stress (Table 4). They had no significant moderating effect (P>0.05) on the relationship between ectomycorrhizal fungi and conifer resistance to biotic stress, though growth conditions, tree age and soil type had positive effects.

**Table 4**: Overview of estimated pooled effect sizes of biotic factor moderators using a three level meta-analysis random effects model.

| Moderator | Estimate | Standard error | T value | Degrees of freedom | P value | Lower confidence interval | Higher confidence interval |
|---|---|---|---|---|---|---|---|
| ECM | -2.078 | 0.6831 | 0.0015 | 56 | 0.4721 | -7.6393 | 3.6873 |
| Soil type | -0.1581 | 0.4044 | -0.2165 | 63 | 0.8697 | -2.0.762 | 1.7599 |
| Growth conditions | 0.8807 | 0.219 | -0.2986 | 71 | 0.3722 | -2.8363 | 1.0749 |
| Tree age | 0.9474 | 0.3117 | 0.8657 | 57 | 0.7386 | -4.7106 | 6.6054 |
| Stress type | 7.7104 | 5.4015 | 1.4275 | 37 | 0.1618 | -3.2341 | 18.6549 |

There is an indication of publication bias because the graph looks asymmetrical. There is only one small study that does not favour ectomycorrhizal fungi at the lower bottom left of the funnel (missing small studies). Most studies are however not significant.

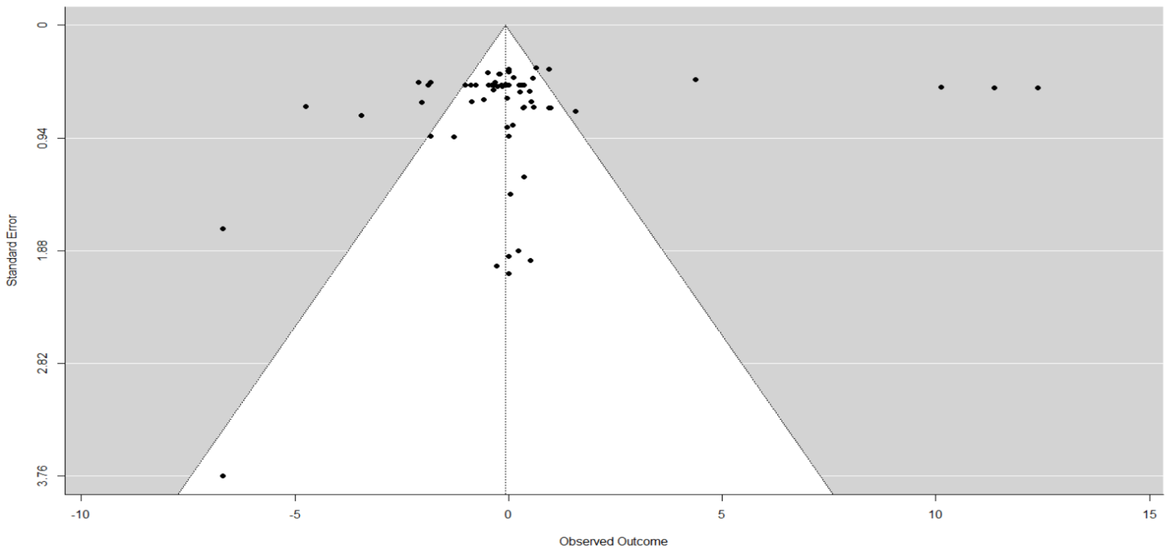


**Figure 25:** Funnel plot showing publication bias of biotic studies.

Funnel plot showing publication bias of biotic studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome. The outer dashed lines shows the 95% confidence interval limit. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted funnel.

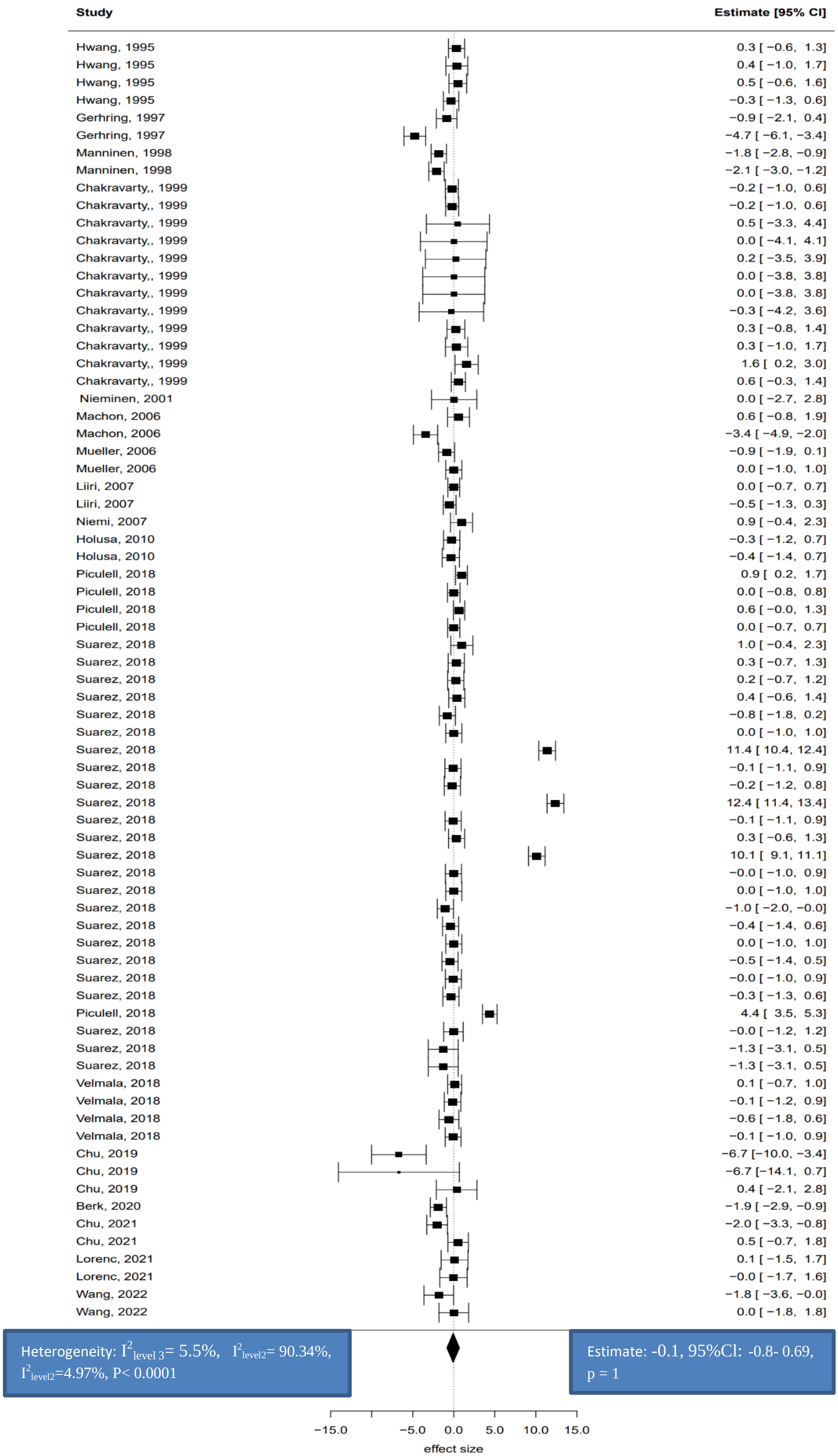
Study
Estimate [95% CI]
Hwang, 1995 0.3 [ −0.6, 1.3]
Hwang, 1995 0.4 [ −1.0, 1.7]
Hwang, 1995 0.5 [ −0.6, 1.6]
Hwang, 1995 −0.3 [ −1.3, 0.6]
Gerhring, 1997 −0.9 [ −2.1, 0.4]
Gerhring, 1997 −4.7 [ −6.1, −3.4]
Manninen, 1998 −1.8 [ −2.8, −0.9]
Manninen, 1998 −2.1 [ −3.0, −1.2]
Chakravarty,, 1999 −0.2 [ −1.0, 0.6]
Chakravarty,, 1999 −0.2 [ −1.0, 0.6]
Chakravarty,, 1999 0.5 [ −3.3, 4.4]
Chakravarty,, 1999 0.0 [ −4.1, 4.1]
Chakravarty,, 1999 0.2 [ −3.5, 3.9]
Chakravarty,, 1999 0.0 [ −3.8, 3.8]
Chakravarty,, 1999 0.0 [ −3.8, 3.8]
Chakravarty,, 1999 −0.3 [ −4.2, 3.6]
Chakravarty,, 1999 0.3 [ −0.8, 1.4]
Chakravarty,, 1999 0.3 [ −1.0, 1.7]
Chakravarty,, 1999 1.6 [ 0.2, 3.0]
Chakravarty,, 1999 0.6 [ −0.3, 1.4]
Nieminen, 2001 0.0 [ −2.7, 2.8]
Machon, 2006 0.6 [ −0.8, 1.9]
Machon, 2006 −3.4 [ −4.9, −2.0]
Mueller, 2006 −0.9 [ −1.9, 0.1]
Mueller, 2006 0.0 [ −1.0, 1.0]
Liiri, 2007 0.0 [ −0.7, 0.7]
Liiri, 2007 −0.5 [ −1.3, 0.3]
Niemi, 2007 0.9 [ −0.4, 2.3]
Holusa, 2010 −0.3 [ −1.2, 0.7]
Holusa, 2010 −0.4 [ −1.4, 0.7]
Piculell, 2018 0.9 [ 0.2, 1.7]
Piculell, 2018 0.0 [ −0.8, 0.8]
Piculell, 2018 0.6 [ −0.0, 1.3]
Piculell, 2018 0.0 [ −0.7, 0.7]
Suarez, 2018 1.0 [ −0.4, 2.3]
Suarez, 2018 0.3 [ −0.7, 1.3]
Suarez, 2018 0.2 [ −0.7, 1.2]
Suarez, 2018 0.4 [ −0.6, 1.4]
Suarez, 2018 −0.8 [ −1.8, 0.2]
Suarez, 2018 0.0 [ −1.0, 1.0]
Suarez, 2018 11.4 [ 10.4, 12.4]
Suarez, 2018 −0.1 [ −1.1, 0.9]
Suarez, 2018 −0.2 [ −1.2, 0.8]
Suarez, 2018 12.4 [ 11.4, 13.4]
Suarez, 2018 −0.1 [ −1.1, 0.9]
Suarez, 2018 0.3 [ −0.6, 1.3]
Suarez, 2018 10.1 [ 9.1, 11.1]
Suarez, 2018 −0.0 [ −1.0, 0.9]
Suarez, 2018 0.0 [ −1.0, 1.0]
Suarez, 2018 −1.0 [ −2.0, −0.0]
Suarez, 2018 −0.4 [ −1.4, 0.6]
Suarez, 2018 0.0 [ −1.0, 1.0]
Suarez, 2018 −0.5 [ −1.4, 0.5]
Suarez, 2018 −0.0 [ −1.0, 0.9]
Suarez, 2018 −0.3 [ −1.3, 0.6]
Piculell, 2018 4.4 [ 3.5, 5.3]
Suarez, 2018 −0.0 [ −1.2, 1.2]
Suarez, 2018 −1.3 [ −3.1, 0.5]
Suarez, 2018 −1.3 [ −3.1, 0.5]
Velmala, 2018 0.1 [ −0.7, 1.0]
Velmala, 2018 −0.1 [ −1.2, 0.9]
Velmala, 2018 −0.6 [ −1.8, 0.6]
Velmala, 2018 −0.1 [ −1.0, 0.9]
Chu, 2019 −6.7 [−10.0, −3.4]
Chu, 2019 −6.7 [−14.1, 0.7]
Chu, 2019 0.4 [ −2.1, 2.8]
Berk, 2020 −1.9 [ −2.9, −0.9]
Chu, 2021 −2.0 [ −3.3, −0.8]
Chu, 2021 0.5 [ −0.7, 1.8]
Lorenc, 2021 0.1 [ −1.5, 1.7]
Lorenc, 2021 −0.0 [ −1.7, 1.6]
Wang, 2022 −1.8 [ −3.6, −0.0]
Wang, 2022 0.0 [ −1.8, 1.8]
Heterogeneity: $I^2_{level\ 3}$= 5.5%, $I^2_{level2}$= 90.34%, $I^2_{level2}$=4.97%, P< 0.0001
Estimate: -0.1, 95%CI: -0.8- 0.69, p = 1
−15.0
−5.0
0.0
5.0
10.0
15.0
effect size

**Figure 17:**

Forest plot of the overall effects of ectomycorrhizal fungi on *Pinus* or *Picea* to biotic stress. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall pooled effect size of the studies.

## 4.0 DISCUSSION

In this study a meta- analysis of the effects of ectomycorrhizal fungi in enhancing conifer (*Pinus* and *Picea*) growth, survival and resistance to biotic and abiotic stress was conducted. I found that there was a large body of literature on this topic (1806 publications). Statistical data was recorded for articles which measured morphological characteristics such as seedling height, root length and stem diameter. This is because plant height is closely related to the life span, seed mass and time to maturity(Moles et al., 2009), and linked to the yield potential(Tilly et al., 2014). Stem diameter has been considered to be the best predictor of field survival and growth (Haase, 2008) and root length very important because it controls water and nutrient uptake. Other parameters recorded were growth rate, survival, mortality and disease incidence. Several articles which were published in the 1980s and 1990s were in accessible, thus were excluded for the meta-analysis. The reason may be because they had not been digitalised during that time.

A meta-analysis outcome can be affected by publication and other forms of selection biases, and funnel plots are usually used to quantify and detect such biases (Tang & Liu, 2000). A symmetrical funnel indicates absence of bias, and an asymmetrical funnel indicates bias(Sterne & Harbord, 2004), (Figure 5). There were huge volume of studies on growth which may have caused the width of the confidence intervals to decrease(Higgins, 2011). There is an indication of publication bias in this study which is indicated by the asymmetry of funnel plots(Sterne & Harbord, 2004). However asymmetrical shape of the funnel plots may also be as a result of other biases such as non- inclusion of articles that were not accessible but relevant, language (only studies written in English was included), method of selection or small study effects. Additional, negative studies have a small chance on publication in English language journals, although the regularity has not always been observed(Thornton & Lee, 2000). The bias can also be as a result of citation as studies with positive results are cited more. As a result, they are easily identified and incorporated in databases (Eyding et al., 2010). Karst et al. (2023) also gave evidence of citation bias on mycorrhizal networks in forests and this has affected a clear understanding of mycorrhizal structure and function.

This analysis is also characterised by high heterogeneity which made it difficult to interpret the results. Higgins and Thompson (2002) argue that heterogeneity is inevitable and any level of heterogeneity is acceptable provided that the studies included were appropriate and the data was handled properly. In this analysis, I used the widely accepted heterogeneity statistic $I^{2.}$ However it should be noted that this statistic may overestimate the heterogeneity when the sample size of the study is small. (von Hippel, 2015). Heterogeneity between studies may also produce asymmetrical funnel plots. The plot assumes that the spread of effect sizes is as a result of heterogeneity, but this does not necessarily indicate that the effects are insignificant. Additional, when dealing with larger studies more investment is needed and there is a chance of the methodology being more rigorous. This can also contribute to asymmetry in the funnel plots (Page et al., 2020). Thus, all conclusions made in this thesis should be considered with these biases in mind.

Lack of correct identification of mycorrhiza may also contribute to inaccurate results in that species may have been incorrectly designated in databases. This is supported by Fruleux et al. (2022) who argues that there may be putative diagnosis errors such as reported ectomycorrhizal fungi which will be otherwise Arbuscular mycorrhizal fungi. Improving sequencing technologies that produce more longer sequence reads and more accurate base calling may help to identify mycorrhiza and resolve these inaccuracies.

In this study, most of the experiments were conducted in growth facilities except for survival studies where field experiments dominated. This limited transfer of methods to the field was highlighted as critical regardless of publication bias by Khokon and Meier (2023). The criticality comes in the sense that the field encompasses the widest ecosystem where mycorrhizal traits could be studied without moderating environmental conditions. Lack of consistency in the results of this study was also as a result of lack of more published articles on the relationship of ECM with *Picea* or *Pinus*. The whole study was also dominated by the use of *Suillus* species as the ectomycorrhizal inoculant. A total of 8.2% of ectomycorrhizal fungi papers in the past 40 years have concerned *Suillus* which is known to exhibit a high degree of specificity to conifers(Dahlberg & Finlay, 1999). Interestingly Zhang et al. (2022) study on host shift speciation of *Suillus* and the Pinaceae did not identify any cospeciation patterns between *Suillus* and the sub genera Pinacea and their history together is seen to be discordant.

The initial research question of this meta-analysis was to know if there is evidence of ectomycorrhizal fungi in enhancing conifer growth and survival and if it improves their resistance to biotic and abiotic stress. Ectomycorrhizal fungi were however found to enhance growth but no significant effect was found on enhancing conifer survival and resistance to biotic and abiotic stress. The evidence of ectomycorrhizal fungi in enhancing growth is supported in a meta-analysis by Alberton et al. (2014) where ECM was found to increase growth of *Pinus species*. However, data from only 6 studies were collected for this meta-analysis. A meta-analysis by Gan et al. (2021) provided some quantitative evidence of the rhizosphere in influencing below ground carbon and nutrient cycling in forest ecosystems which in turn improves growth.

In this study, ectomycorrhizal fungi were however found to have no relationship on tree resistance to abiotic stress. A review by Lehto and Zwiazek (2011) suggested that mycorrhizal structure may impede water movement to the plant due to fine root architecture or the hydrophobicity of the cell wall. This may heavily affect the plant's water absorption efficiency and can get worse during drought stress. Defrenne et al. (2019) research revealed a distinct root structure from seedlings planted in a nursery compared to seedlings regenerated in the field. This architectural difference was thought to lack of ectomycorrhizal partners, which may in turn affect a plant's response to abiotic stress, survival and growth.

Karst et al. (2008) used a meta -analysis to quantitatively evaluate the role of biotic and abiotic factors on host growth and responses to ectomycorrhizal associations on *Pinus* and *Picea*. Overall, in their analysis the host biomass increased in response to ectomycorrhizal inoculation, but the results were distorted by publication bias and methodological issues thus, distorted the spectrum on which they evaluated the host responses to ectomycorrhizal inoculation. This also supports this meta-analysis.

In this study ectomycorrhizal fungi had no effect on survival. This is revealed in Quoreshi et al. (2008), where conifer survival rate of the inoculated seedlings was not significant from the control whose seedlings were naturally colonised by the resident fungi. Nevertheless, ectomycorrhizal fungi helped the conifers to alleviate biotic stress against pathogens and insects. A meta-analysis by Holden and Treseder (2013), showed an increase of fungal abundance following an insect infestation and pathogen induced mortality in a boreal forest.

Howbeit, fungal abundance does not imply the effectiveness of ectomycorrhizal fungi to the host plant (Wagg et al., 2011).

In this study moderators such as soil type, growth condition and tree age were tested to determine their influence on the relationship between conifer growth, survival and resistance to biotic and abiotic stress and ectomycorrhizal fungi. All the moderators They had no significant moderating effect on the relationship between ectomycorrhizal fungi and conifer tree resistance to biotic stress, survival and growth, except for soil type as whole. Therefore, the study cannot determine which soil type contributed the most because they did not have a significant effect when analysed individually but had a significant effect when analysed as a whole.

## 5.0 CONCLUSION

The interaction between ectomycorrhizal fungi and their conifer host is very complex. Thus it is difficult to capture all the factors that influence the relationship within a study. In this study, publication bias and study heterogeneity made it difficult to interpret the effects of ectomycorrhizal fungi on *Pinus* and *Picea* growth, survival and resistance to biotic and abiotic stress. Therefore, the analysis did not provide concrete conclusions. However, the results of the analysis emphasize the importance of ectomycorrhizal fungi on conifer growth. The majority of the studies were conducted in growth facilities while very few were conducted in the field. There is need to conduct more experiments in the field to better understand the role of ectomycorrhizal fungi in conifer health and success. Also negative results must be published and a platform for this scenario must be created. I also urge researchers to report publication biases in their results. Therefore, there is still too sparse knowledge to provide recommendations on how ectomycorrhizal fungi can be used in forest management.

## REFERENCES


Alberton, O., Aguiar, D., Gimenes, R., Gimenes, R. & Carrenho, R. (2014). Meta-analysis for responses of eucalyptus and pine inoculated with ectomycorrhizal fungi in Brazil. *Journal of Food Agriculture and Environment*, 12: 1159-1163.

Athar, H.-u.-R., Zulfiqar, F., Moosa, A., Ashraf, M., Zafar, Z. U., Zhang, L., Ahmed, N., Kalaji, H. M., Nafees, M., Hossain, M. A., et al. (2022). Salt stress proteins in plants: An overview. *Frontiers in Plant Science*, 13. doi: 10.3389/fpls.2022.999058.

Bacon, C. W. & White, J. F. (2016). Functions, mechanisms and regulation of endophytic and epiphytic microbial communities of plants. *Symbiosis*, 68 (1): 87-98. doi: 10.1007/s13199-015-0350-2.

Bulgarelli, D., Rott, M., Schlaeppi, K., Ver Loren van Themaat, E., Ahmadinejad, N., Assenza, F., Rauf, P., Huettel, B., Reinhardt, R., Schmelzer, E., et al. (2012). Revealing structure and assembly cues for Arabidopsis root-inhabiting bacterial microbiota. *Nature*, 488 (7409): 91-95. doi: 10.1038/nature11336.

Castagneri, D., Storaunet, K. O. & Rolstad, J. (2013). Age and growth patterns of old Norway spruce trees in Trillemarka forest, Norway. *Scandinavian Journal of Forest Research*, 28 (3): 232-240. doi: 10.1080/02827581.2012.724082.

Dahlberg, A. & Finlay, R. (1999). Suillus. *Ectomycorrhizal fungi key genera in profile*: 33-64.

Dastogeer, K. M. G., Tumpa, F. H., Sultana, A., Akter, M. A. & Chakraborty, A. (2020). Plant microbiome–an account of the factors that shape community composition and diversity. *Current Plant Biology*, 23: 100161. doi: https://doi.org/10.1016/j.cpb.2020.100161.

Defrenne, C. E., Philpott, T. J., Guichon, S. H. A., Roach, W. J., Pickles, B. J. & Simard, S. W. (2019). Shifts in Ectomycorrhizal Fungal Communities and Exploration Types Relate to the Environment and Fine-Root Traits Across Interior Douglas-Fir Forests of Western Canada. *Frontiers in Plant Science*, 10. doi: 10.3389/fpls.2019.00643.

Eyding, D., Lelgemann, M., Grouven, U., Härter, M., Kromp, M., Kaiser, T., Kerekes, M. F., Gerken, M. & Wieseler, B. (2010). Reboxetine for acute treatment of major depression: systematic review and meta-analysis of published and unpublished placebo and selective serotonin reuptake inhibitor controlled trials. *Bmj*, 341: c4737. doi: 10.1136/bmj.c4737.

Franceschi, V. R., Krokene, P., Christiansen, E. & Krekling, T. (2005). Anatomical and chemical defenses of conifer bark against bark beetles and other pests. *New Phytologist*, 167 (2): 353-375. doi: 10.1111/j.1469-8137.2005.01436.x.

Fruleux, A., Duclercq, J., Dubois, F. & Decocq, G. (2022). First report of ectomycorrhizae in Prunus serotina in the exotic range. *Plant and Soil*, 484: 1-11. doi: 10.1007/s11104-022-05780-z.

Gan, D., Feng, J., Han, M., Zeng, H. & Zhu, B. (2021). Rhizosphere effects of woody plants on soil biogeochemical processes: A meta-analysis. *Soil Biology and Biochemistry*, 160: 108310. doi: https://doi.org/10.1016/j.soilbio.2021.108310.

Haase, D. (2008). Understanding forest seedling quality: measurements and interpretation. *Tree Planters' Notes*, 52: 24-30.

Harrer, M., Cuijpers, P., Furukawa, T. A. & Ebert, D. D. (2021). *Doing Meta-Analysis With R: A Hands-On Guide*. 1st ed. Boca Raton, FL and London: Chapman & Hall/CRC Press.

Harrier, L. A. & Watson, C. A. (2004). The potential role of arbuscular mycorrhizal (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or

other sustainable farming systems. *Pest Manag Sci*, 60 (2): 149-57. doi: 10.1002/ps.820.
Herol, L., Shemesh, H., Avidar, M., Yirmiahu, S., Zach, Y., klein, T. & Livne-Luzon, S. (2022). The effects of drought and inter-plant competition on the ectomycorrhizal interaction between fungi and Aleppo pine seedlings. *bioRxiv*: 2022.10. 25.513645.
Higgins, J. P. T. & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, 21 (11): 1539-1558. doi: https://doi.org/10.1002/sim.1186.
Higgins, J. P. T. a. G., S. (2011). Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0. The Cochrane Collaboration. doi: http://handbook-5-1.cochrane.org.
Holden, S. & Treseder, K. (2013). A meta-analysis of soil microbial biomass responses to forest disturbances. *Frontiers in Microbiology*, 4. doi: 10.3389/fmicb.2013.00163.
Karst, J., Marczak, L., Jones, M. D. & Turkington, R. (2008). The mutualism-parasitism continuum in ectomycorrhizas: a quantitative assessment using meta-analysis. *Ecology*, 89 (4): 1032-42. doi: 10.1890/07-0823.1.
Karst, J., Jones, M. D. & Hoeksema, J. D. (2023). Positive citation bias and overinterpreted results lead to misinformation on common mycorrhizal networks in forests. *Nature Ecology & Evolution*, 7 (4): 501-511. doi: 10.1038/s41559-023-01986-1.
Kennedy, P. G., Sara, H., Bergemann, S. E. & Bruns, T. D. (2007). Competitive Interactions among Three Ectomycorrhizal Fungi and Their Relation to Host Plant Performance. *Journal of Ecology*, 95 (6): 1338-1345.
Khokon, A. M. & Meier, I. C. (2023). A synthesis on the role of mycorrhizal fungal traits for understanding forest tree functions. *bioRxiv*: 2023.03. 19.533308.
Koricheva, J. & Gurevitch, J. (2013). Place of Meta-analysis among Other Methods of Research Synthesis. In Koricheva, J., Gurevitch, J. & Mengersen, K. (eds) *Handbook of Meta-analysis in Ecology and Evolution*, pp. 3-13: Princeton University Press.
Lajeunesse, M. J. (2016). Facilitating systematic reviews, data extraction and meta-analysis with the metagear package for r. *Methods in Ecology and Evolution*, 7 (3): 323-330. doi: https://doi.org/10.1111/2041-210X.12472.
Lehto, T. & Zwiazek, J. (2011). Lehto T, Zwiazek J.. Ectomycorrhizas and water relations of trees: a review. Mycorrhiza 21: 71-90. *Mycorrhiza*, 21: 71-90. doi: 10.1007/s00572-010-0348-9.
LORTIE, C. J. & CALLAWAY, R. M. (2006). Re-analysis of meta-analysis: support for the stress-gradient hypothesis. *Journal of Ecology*, 94 (1): 7-16. doi: https://doi.org/10.1111/j.1365-2745.2005.01066.x.
Martin, F., Kohler, A., Murat, C., Veneault-Fourrey, C. & Hibbett, D. S. (2016). Unearthing the roots of ectomycorrhizal symbioses. *Nature Reviews Microbiology*, 14 (12): 760-773. doi: 10.1038/nrmicro.2016.149.
Moles, A. T., Warton, D. I., Warman, L., Swenson, N. G., Laffan, S. W., Zanne, A. E., Pitman, A., Hemmings, F. A. & Leishman, M. R. (2009). Global patterns in plant height. *Journal of Ecology*, 97 (5): 923-932. doi: https://doi.org/10.1111/j.1365-2745.2009.01526.x.
Page, Matthew, J, Jonathan, A.C., Sterne, Julian, P.T., Higgins, &Matthias Egger. 2020. “Investigating and Dealing with Publication Bias and Other Reporting Biases in Meta-Analyses of Health Research: A Review.” *Research Synthesis Methods*.
Policelli, N., Horton, T. R., Hudon, A. T., Patterson, T. R. & Bhatnagar, J. M. (2020). Back to Roots: The Role of Ectomycorrhizal Fungi in Boreal and Temperate Forest Restoration. *Frontiers in Forests and Global Change*, 3. doi: 10.3389/ffgc.2020.00097.

Quoreshi, A. M., Piché, Y. & Khasa, D. P. (2008). Field performance of conifer and hardwood species 5 years after nursery inoculation in the Canadian Prairie Provinces. *New Forests*, 35 (3): 235-253. doi: 10.1007/s11056-007-9074-3.

Read, D. J., Leake, J. R. & Perez-Moreno, J. (2004). Mycorrhizal fungi as drivers of ecosystem processes in heathland and boreal forest biomes. *Canadian Journal of Botany*, 82 (8): 1243-1263. doi: 10.1139/b04-123.

Rodrigues, A., Miguel, C., Chaves, I. & António, C. (2021). Mass spectrometry-based forest tree metabolomics. *Mass Spectrometry Reviews*, 40. doi: 10.1002/mas.21603.

Smith, S. E. a. R., D J. (2008). Mycorrhizal symbiosis. In: Elsevier academic press.

Sterne, J. A. & Harbord, R. M. (2004). Funnel plots in meta-analysis. *The stata journal*, 4 (2): 127-141.

Tang, J. L. & Liu, J. L. (2000). Misleading funnel plot for detection of bias in meta-analysis. *J Clin Epidemiol*, 53 (5): 477-84. doi: 10.1016/s0895-4356(99)00204-8.

Thomma, B., Cammue, B. P. A. & Thevissen, K. (2002). Plant defensins. *Planta*, 216 (2): 193-202. doi: 10.1007/s00425-002-0902-6.

Thornton, A. & Lee, P. (2000). Publication bias in meta-analysis: its causes and consequences. *Journal of Clinical Epidemiology*, 53 (2): 207-216. doi: https://doi.org/10.1016/S0895-4356(99)00161-4.

Tilly, N., Hoffmeister, D., Cao, Q., Huang, S., Lenz-Wiedemann, V., Miao, Y. & Bareth, G. (2014). Multitemporal crop surface models: Accurate plant height measurement and biomass estimation with terrestrial laser scanning in paddy rice. *Journal of Applied Remote Sensing*, 8: 083671-083671. doi: 10.1117/1.JRS.8.083671.

Van der Ent, S., Van Hulten, M., Pozo, M. J., Czechowski, T., Udvardi, M. K., Pieterse, C. M. J. & Ton, J. (2009). Priming of plant innate immunity by rhizobacteria and β-aminobutyric acid: differences and similarities in regulation. *New Phytologist*, 183 (2): 419-431. doi: https://doi.org/10.1111/j.1469-8137.2009.02851.x.

van der Heijden, M. G. A., Martin, F. M., Selosse, M.-A. & Sanders, I. R. (2015). Mycorrhizal ecology and evolution: the past, the present, and the future. *New Phytologist*, 205 (4): 1406-1423. doi: https://doi.org/10.1111/nph.13288.

Viechtbauer, W. (2010). Conducting Meta-Analyses in R with the metafor Package. *Journal of Statistical Software*, 36 (3): 1 - 48. doi: 10.18637/jss.v036.i03.

von Hippel, P. T. (2015). The heterogeneity statistic I(2) can be biased in small meta-analyses. *BMC Med Res Methodol*, 15: 35. doi: 10.1186/s12874-015-0024-z.

Wagg, C., Jansa, J., Schmid, B. & van der Heijden, M. G. (2011). Belowground biodiversity effects of plant symbionts support aboveground productivity. *Ecol Lett*, 14 (10): 1001-9. doi: 10.1111/j.1461-0248.2011.01666.x.

Whipps, J. M. (2004). Prospects and limitations for mycorrhizas in biocontrol of root pathogens. *Canadian Journal of Botany*, 82 (8): 1198-1227. doi: 10.1139/b04-082.

Zhang, R., Shi, X. F., Liu, P. G., Wilson, A. W. & Mueller, G. M. (2022). Host Shift Speciation of the Ectomycorrhizal Genus Suillus (Suillineae, Boletales) and Biogeographic Comparison With Its Host Pinaceae. *Front Microbiol*, 13: 831450. doi: 10.3389/fmicb.2022.831450.

## APPENDICES

### A- Abiotic factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

| study_id | year | author | tree_genus | soil_type | ecm_genus | growth_conditions | stress_type | tree_age | tree_category | measured_parameter | n_sample | n_control | treatment_mean | Control_mean | data_type | RR | logRR | SElogRR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 2022 | McHanen(2022) | picea | field | thelephora | growth facility | metal | 6 | seedling | field | 7 | 7 | 0.92 | 0.943 | percentage | 0.97560976 | -0.024692613 | 0.52411006 |
| 18 | 2021 | Paula(2021) | pinus | field | commecial ino | field | metal | 5 | seedling | final height | 18 | 18 | 0.288 | 0.288 | percentage | 1 | 0.001 | 0.52411006 |
| 18 | 2021 | Paula(2021) | pinus | field | commecial ino | field | metal | 5 | seedling | stem diameter | 18 | 18 | 0.516 | 0.05 | percentage | 10.32 | 2.33408376 | 1.05245703 |
| 22 | 2021 | Li(2021) | pinus | field | suillus | growth facility | drought | 12 | seedling | seedling height | 24 | 24 | 0.0213 | 0.02 | percentage | 1.065 | 0.062974799 | 1.98901522 |
| 27 | 2020 | Liu(2021) | pinus | sandy | suillus | growth facility | metal | 6 | seedling | seedling height | 45 | 45 | 0.13 | 0.08 | percentage | 1.625 | 0.485507816 | 0.63582506 |
| 29 | 2020 | Gerhring(2020) | pinus | field | ecm | field | drought | 6.72 | seedling | shoot length | 10 | 5 | 0.09 | 0.17 | percentage | 0.52941176 | -0.635988767 | 1.40981619 |
| 51 | 2016 | Yin(2016) | pinus | composite | suillus | growth facility | drought | 4 | seedling | plant height | 10 | 10 | 0.127 | 0.099 | percentage | 1.28282828 | 0.249067236 | 1.26392349 |
| 51 | 2016 | Yin(2016) | pinus | composite | suillus | growth facility | drought | 4 | seedling | plant height | 10 | 10 | 0.136 | 0.099 | percentage | 1.37373737 | 0.317535036 | 1.24313922 |
| 60 | 2015 | Franco(2015) | pinus | field | pisolithus | growth facility | herbicide | 1 | seedling | shoot height | 10 | 10 | 0.076 | 0.0567 | percentage | 1.34038801 | 0.29295913 | 1.69689655 |
| 60 | 2015 | Franco(2015) | pinus | field | suillus | growth facility | herbicide | 1 | seedling | shoot height | 10 | 10 | 0.0621 | 0.0567 | percentage | 1.0952381 | 0.090971778 | 1.78156515 |
| 66 | 2014 | Sousa(2015) | pinus | field | suillus | growth facility | metal | 6 | seedling | shoot height | 8 | 8 | 0.099 | 0.12 | percentage | 0.825 | -0.192371893 | 1.43328048 |
| 66 | 2014 | Sousa(2015) | pinus | field | rhizopogon | growth facility | metal | 6 | seedling | shoot height | 8 | 8 | 0.086 | 0.12 | percentage | 0.71666667 | -0.333144447 | 1.49838414 |
| 66 | 2014 | Sousa(2015) | pinus | field | suillus | growth facility | metal | 6 | seedling | shoot height | 8 | 8 | 0.0106 | 0.13 | percentage | 0.08153846 | -2.506680449 | 3.53609831 |
| 66 | 2014 | Sousa(2015) | pinus | field | rhizopogon | growth facility | metal | 6 | seedling | shoot height | 8 | 8 | 0.092 | 0.13 | percentage | 0.70769231 | -0.345745873 | 1.43883081 |
| 91 | 2012 | Sousa(2015) | pinus | field | suillus | growth facility | metal | 1.25 | seedling | seedling height | 10 | 10 | 0.11 | 0.09 | percentage | 1.22222222 | 0.200670695 | 1.34914863 |
| 91 | 2012 | Sousa(2015) | pinus | field | rhizopogon | growth facility | metal | 1.25 | seedling | seedling height | 10 | 10 | 0.091 | 0.09 | percentage | 1.01111111 | 0.011049836 | 1.41774899 |
| 143 | 2006 | Bakker(2006) | pinus | field | cenococcum | field | drought | 20 | seedling | root length | 4 | 4 | 0.297 | 0.247 | percentage | 1.20242915 | 0.184343802 | 1.16357062 |
| 168 | 2004 | Kim(2004) | pinus | composite | paxillus | growth facility | metal | 8 | seedling | stem length | 3 | 3 | 0.85 | 0.8 | percentage | 1.0625 | 0.060624622 | 0.37703695 |
| 168 | 2004 | Kim(2004) | pinus | composite | suillus | growth facility | metal | 8 | seedling | stem length | 3 | 3 | 0.9 | 0.8 | percentage | 1.125 | 0.117783036 | 0.34694433 |
| 172 | 2004 | Adriaensen(2004) | pinus | sandy | suillus | growth facility | metal | 1.5 | seedling | Relative growth rate | 5 | 5 | 0.027 | 0.029 | percentage | 0.93103448 | -0.071458964 | 3.7288013 |
| 172 | 2004 | Adriaensen(2004) | pinus | sandy | suillus | growth facility | metal | 1.5 | seedling | Relative growth rate | 5 | 5 | 0.022 | 0.029 | percentage | 0.75862069 | -0.276253377 | 3.94809585 |
| 184 | 2005 | Van Scholl(2005) | pinus | sandy | ecm | field | metal | 3.5 | seedling | root length | 8 | 8 | 0.0625 | 0.06 | percentage | 1.04166667 | 0.040821995 | 1.95789002 |
| 191 | 2001 | Ahonen-Jonnarth( | pinus | sandy | laccaria | growth facility | metal | 3.75 | seedling | relative shoot growth | 15 | 15 | 0.66 | 0.55 | percentage | 1.2 | 0.182321557 | 0.2981424 |
| 191 | 2001 | Ahonen-Jonnarth( | pinus | sandy | laccaria | growth facility | metal | 3.75 | seedling | relative shoot growth | 15 | 15 | 0.93 | 0.71 | percentage | 1.30985915 | 0.269919616 | 0.17957719 |
| 197 | 2000 | Rudawska(2000) | pinus | composite | suillus | growth facility | metal | 6 | seedling | shoot height | 23 | 23 | 0.66 | 0.54 | percentage | 1.22222222 | 0.200670695 | 0.2437928 |
| 197 | 2000 | Rudawska(2000) | pinus | composite | suillus | growth facility | metal | 6 | seedling | shoot height | 23 | 23 | 0.94 | 0.83 | percentage | 1.13253012 | 0.124454174 | 0.10807587 |
| 197 | 2000 | Rudawska(2000) | pinus | composite | suillus | growth facility | metal | 6 | seedling | shoot height | 23 | 23 | 0.73 | 0.59 | percentage | 1.23728814 | 0.212921997 | 0.21516205 |
| 203 | 1999 | Hartley(1999 | pinus | sandy | ecm | growth facility | metal | 10 | seedling | root length | 12 | 12 | 0.0368 | 0.053 | percentage | 0.69433962 | -0.364794068 | 1.91576437 |
| 203 | 1999 | Hartley(2000 | pinus | sandy | ecm | growth facility | metal | 10 | seedling | root length | 12 | 12 | 0.0448 | 0.053 | percentage | 0.84528302 | -0.168083774 | 1.80714676 |
| 203 | 1999 | Hartley(2001 | pinus | sandy | ecm | growth facility | metal | 10 | seedling | root length | 12 | 12 | 0.052 | 0.053 | percentage | 0.98113208 | -0.019048195 | 1.73442339 |
| 203 | 1999 | Hartley(2002 | pinus | sandy | ecm | growth facility | metal | 10 | seedling | root length | 12 | 12 | 0.049 | 0.053 | percentage | 0.9245283 | -0.078471615 | 1.76248139 |
| 203 | 1999 | Hartley(2003 | pinus | sandy | ecm | growth facility | metal | 10 | seedling | root length | 12 | 12 | 0.4 | 0.053 | percentage | 7.54716981 | 2.021172634 | 1.27043052 |
| 248 | 1989 | Wilkins(1989) | picea | sandy | paxillus | growth facility | metal | 2.5 | seedling | shoot height | 7 | 7 | 0.054 | 0.19 | percentage | 0.28421053 | -1.258040026 | 1.76399208 |
| 248 | 1989 | Wilkins(1989) | picea | sandy | paxillus | growth facility | metal | 2.5 | seedling | shoot height | 7 | 7 | 0.16 | 0.16 | percentage | 1 | 0.001 | 1.22474487 |
| 248 | 1989 | Wilkins(1989) | picea | field | paxillus | growth facility | metal | 2.5 | seedling | shoot height | 7 | 7 | 0.19 | 0.1 | percentage | 1.9 | 0.641853886 | 1.3764944 |
| 248 | 1989 | Wilkins(1989) | picea | field | paxillus | growth facility | metal | 2.5 | seedling | shoot height | 7 | 7 | 0.15 | 0.09 | percentage | 1.66666667 | 0.510825624 | 1.50132217 |
| 270 | 2018 | Nadeau(2018) | picea | composite | Cadophora | growth facility | metal | 8 | seedling | root length | 3 | 3 | 0.8458 | 0.8458 | percentage | 1 | 0.001 | 0.34862836 |
| 270 | 2018 | Nadeau(2018) | picea | composite | tricholoma | growth facility | metal | 8 | seedling | root length | 3 | 3 | 0.832 | 0.832 | percentage | 1 | 0.001 | 0.36689969 |
| 270 | 2018 | Nadeau(2018) | picea | composite | hebeloma | growth facility | metal | 8 | seedling | root length | 3 | 3 | 0.5301 | 0.5301 | percentage | 1 | 0.001 | 0.76873772 |
| 293 | 2019 | Patterson(2019) | pinus | field | ecm | field | drought | 2 | seedling | cumulative shoot gr | 12 | 4 | 0.36 | 0.44 | percentage | 0.81818182 | -0.200670695 | 0.68288357 |
| 293 | 2019 | Patterson(2019) | pinus | field | ecm | field | drought | 2 | seedling | cumulative shoot growth | 12 | 4 | 0.23 | 0.34 | percentage | 0.67647059 | -0.390866309 | 0.87423088 |
| 294 | 2005 | Tahara(2005) | pinus | composite | pisolithus | growth facility | metal | 1 | seedling | relative root length | 5 | 3 | 0.84 | 0.39 | percentage | 2.15384615 | 0.767255153 | 0.74797243 |
| 296 | 2004 | Kim(2004) | pinus | composite | paxillus | growth facility | metal | 8 | seedling | stem length | 9 | 9 | 0.84 | 0.85 | percentage | 0.98823529 | -0.011834458 | 0.20192044 |
| 296 | 2004 | kim(2004) | pinus | composite | suillus | growth facility | metal | 8 | seedling | stem length | 9 | 9 | 0.9 | 0.94 | percentage | 0.95744681 | -0.043485112 | 0.13941979 |
| 311 | 2015 | Moser(2015) | pinus | field | cenococcum | field | drought | 6 | seedling | cumulative root length | 25 | 25 | 0.0238 | 0.0164 | percentage | 1.45121951 | 0.372404246 | 2.00989966 |
| 320 | 2000 | Hartley-Whitaker( | pinus | composite | paxillus | growth facility | metal | 2 | seedling | root length | 5 | 5 | 0.0381 | 0.055 | percentage | 0.69272727 | -0.367118903 | 2.91302377 |
| 320 | 2000 | Hartley-Whitaker( | pinus | composite | suillus | growth facility | metal | 2 | seedling | root length | 5 | 5 | 0.0385 | 0.058 | percentage | 0.6637931 | -0.409784769 | 2.87107664 |
| 320 | 2000 | Hartley-Whitaker( | pinus | composite | paxillus | growth facility | metal | 2 | seedling | root length | 5 | 5 | 0.0482 | 0.051 | Percentage | 0.94509804 | -0.056466612 | 2.76964731 |
| 320 | 2000 | Hartley-Whitaker( | pinus | composite | suillus | growth facility | metal | 2 | seedling | root length | 5 | 5 | 0.0494 | 0.0539 | Percentage | 0.91651206 | -0.087180054 | 2.71277683 |
| 322 | 2018 | Yin(2018) | pinus | composite | suillus | growth facility | drought | 3 | seedling | plant height | 30 | 30 | 0.1 | 0.12 | Percentage | 0.83333333 | -0.182321557 | 0.73786479 |
| 322 | 2018 | Yin(2018) | pinus | composite | suillus | growth facility | drought | 3 | seedling | collar diameter | 30 | 30 | 0.12 | 0.112 | Percentage | 1.07142857 | 0.068992871 | 0.71325322 |
| 337 | 2020 | Sun(2020) | pinus | composite | suillus | field | metal | 24 | seedling | plant height | 3 | 3 | 0.43 | 0.58 | Percentage | 0.74137931 | -0.299242895 | 0.82658319 |
| 337 | 2020 | Sun(2020) | pinus | composite | suillus | field | metal | 24 | seedling | ground base diameter | 3 | 3 | 0.27 | 0.163 | Percentage | 1.65644172 | 0.504671758 | 1.61644394 |
| 43 | 2021 | Wang(2021) | pinus | composite | suillus | growth facility | drought | 5 | seedling | mortality | 3 | 3 | 0.0123 | 0.56 | percentage | 0.02196429 | -3.818337521 | 5.19892705 |
| 43 | 2021 | Wang(2021) | pinus | composite | suillus | growth facility | drought | 5 | seedling | mortality | 3 | 3 | 0.0141 | 0.66 | percentage | 0.02136364 | -3.846065038 | 4.84551811 |
| 288 | 1991 | Svenson(1991) | pinus | composite | pisolithus | growth facility | drought | 9.25 | seedling | Seedling height | 12 | 12 | 0.28 | 0.34 | percentage | 0.82352941 | -0.194156014 | 0.6132295 |
| 288 | 1991 | Svenson(1991) | pinus | composite | pisolithus | growth facility | drought | 9.25 | seedling | root collar diameter | 12 | 12 | 0.67 | 0.062 | Percentage | 10.8064516 | 2.380143327 | 1.14096339 |
| 300 | 2019 | Mueller(2019) | pinus | field | tuber | growth facility | drought | 72 | mature | mortality | 7 | 7 | 0.4 | 0.39 | Percentage | 1.02564103 | 0.025317808 | 0.66161087 |
| 300 | 2019 | Mueller(2019) | pinus | field | geopora | growth facility | drought | 72 | mature | mortality | 7 | 7 | 0.14 | 0.26 | Percentage | 0.53846154 | -0.619039208 | 1.13320096 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 1 | 1 | Percentage | 1 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 1 | 1 | Percentage | 1 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 0.4 | 1 | percentage | 0.4 | -0.916290732 | 0.54772256 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 0 | 1 | percentage | 0 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 0.8 | 1 | percentage | 0.8 | -0.223143551 | 0.2236068 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 0 | 1 | percentage | 0 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 1 | 1 | percentage | 1 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 1 | 1 | percentage | 1 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 0.4 | 1 | percentage | 0.4 | -0.916290732 | 0.54772256 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 0 | 1 | percentage | 0 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 1 | 1 | percentage | 1 | 0.001 | 0.001 |
| 173 | 2004 | Busse(2004) | pinus | sandy | ecm(unnamec | growth facility | herbicide | 4 | seedling | survival | 5 | 5 | 0.8 | 1 | percentage | 0.8 | -0.223143551 | 0.2236068 |

## B- Growth factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

| study_id | year | author | tree_genus | soil_type | ecm_genus | growth_condition | tree_age | tree_category | Measured parameter | data_type | effect_size | var_d | source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 2022 | Tapwal | pinus | field | scleroderma | field | 21 | seedling | shoot height | mean | 3.38806394 | 0.66303858 | hedges_d |
| 4 | 2022 | Tapwal | pinus | field | scleroderma | field | 21 | seedling | root length | mean | 17.9258364 | 1.81897308 | hedges_d |
| 6 | 2022 | Fahey | pinus | composite | ecm group | growth facility | 7 | seedling | basal diameter | mean | 0 | 4.90577891 | hedges_d |
| 6 | 2022 | Fahey | pinus | composite | ecm group | growth facility | 7 | seedling | basal diameter | mean | 0 | 4.90577891 | hedges_d |
| 6 | 2022 | Fahey | pinus | composite | ecm group | growth facility | 7 | seedling | basal diameter | mean | 0 | 4.90577891 | hedges_d |
| 8 | 2022 | Huang | pinus | media | tuber | growth facility | 5 | seedling | stem diameter | mean | 3.68550399 | 1.0399382 | hedges_d |
| 8 | 2022 | Huang | pinus | media | tuber | growth facility | 5 | seedling | stem diameter | mean | 2.24149681 | 1.25782598 | hedges_d |
| 11 | 2022 | Repac | picea | composite | ectovit | growth facility | 36 | sapling | stem height | mean | 0 | 4.90577891 | hedges_d |
| 23 | 2021 | Peng | pinus | field | suillus | field | 54 | sapling | seedling height | mean | 604.778303 | 8.27496737 | hedges_d |
| 23 | 2021 | Peng | pinus | field | suillus | field | 54 | sapling | seedling height | mean | 680.615556 | 8.34826893 | hedges_d |
| 23 | 2021 | Peng | pinus | field | suillus | field | 54 | sapling | seedling height | mean | 495.411954 | 8.18358342 | hedges_d |
| 23 | 2021 | Peng | pinus | field | suillus | field | 54 | sapling | seedling height | mean | 297.050298 | 8.06263673 | hedges_d |
| 25 | 2021 | Lorenc | picea | sandy | ectovit | field | 36 | sapling | seedling height | mean | -7.98913065 | 13.6069853 | hedges_d |
| 25 | 2021 | Lorenc | picea | sandy | ectovit | field | 36 | sapling | seedling height | mean | 6.18273874 | 12.761251 | hedges_d |
| 30 | 2020 | verma | pinus | sandy | suillus | field | 9 | seedling | shoot length | mean | 40.4227467 | 2.6330341 | hedges_d |
| 30 | 2020 | verma | pinus | sandy | suillus | field | 9 | seedling | shoot length | mean | 27.3060644 | 2.42994941 | hedges_d |
| 31 | 2020 | zhang | pinus | sandy | tuber | growth facility | 8 | seedling | plant height | mean | 146.490187 | 12.0049424 | hedges_d |
| 31 | 2020 | Zhang | pinus | sandy | tuber | growth facility | 8 | seedling | plant height | mean | -39.2951055 | 12.0043023 | hedges_d |
| 31 | 2020 | zhang | pinus | sandy | tuber | growth facility | 8 | seedling | root length | mean | -195.508095 | 12.0054811 | hedges_d |
| 31 | 2020 | Zhang | pinus | sandy | tuber | growth facility | 8 | seedling | root length | mean | -499.399903 | 12.0122655 | hedges_d |
| 37 | 2020 | Li | pinus | sandy | tuber | growth facility | 8 | seedling | plant height | mean | -247.277512 | 5.33962002 | hedges_d |
| 37 | 2020 | Li | pinus | sandy | tuber | growth facility | 6 | seedling | plant height | mean | -195.4605 | 4.77244191 | hedges_d |
| 40 | 2017 | zhang | pinus | composite | handkea | growth facility | 6 | seedling | root length | mean | 84.4937786 | 3.64755096 | hedges_d |
| 40 | 2017 | zhang | pinus | composite | suillus | growth facility | 3 | seedling | root length | mean | 30.1529756 | 2.46859955 | hedges_d |
| 40 | 2017 | zhang | pinus | composite | suillus | growth facility | 3 | seedling | root length | mean | 56.6184389 | 2.95836221 | hedges_d |
| 44 | 2017 | rudawska | pinus | field | suillus | field | 24 | sapling | seedling height | mean | 107.315624 | 5.95587064 | hedges_d |
| 44 | 2017 | rudawska | pinus | field | wilcoxina | field | 24 | sapling | seedling height | mean | 29.9766491 | 5.92794916 | hedges_d |
| 44 | 2017 | rudawska | pinus | field | wilcoxina | field | 24 | sapling | seedling height | mean | -142.398829 | 5.97881005 | hedges_d |
| 44 | 2017 | rudawska | pinus | field | cenococcum | field | 24 | sapling | seedling height | mean | 135.069978 | 5.97349327 | hedges_d |
| 45 | 2018 | Gallart | pinus | composite | tylospora | growth facility | 7 | seedling | tree height | mean | 6.37186006 | 3.33542119 | hedges_d |
| 45 | 2018 | Gallart | pinus | composite | tylospora | growth facility | 7 | seedling | tree height | mean | -1.11702215 | 3.33339752 | hedges_d |
| 48 | 2017 | Hazard | pinus | composite | laccaria | growth facility | 2 | seedling | shoot height | mean | 1750.10691 | 29.2154997 | hedges_d |
| 48 | 2017 | Hazard | pinus | composite | laccaria | growth facility | 2 | seedling | shoot height | mean | 2474.20512 | 29.2157309 | hedges_d |
| 48 | 2017 | Hazard | pinus | composite | laccaria | growth facility | 2 | seedling | root length | mean | -509.304726 | 29.2152879 | hedges_d |
| 48 | 2017 | Hazard | pinus | composite | laccaria | growth facility | 2 | seedling | root length | mean | 70.2247853 | 29.2152687 | hedges_d |
| 51 | 2016 | yin | picea | composite | suillus | growth facility | 4 | seedling | plant height | mean | -73.7293623 | 3.81890098 | hedges_d |
| 51 | 2016 | yin | picea | composite | suillus | growth facility | 4 | seedling | plant height | mean | -298.146124 | 5.95380364 | hedges_d |
| 51 | 2016 | yin | pinus | composite | suillus | growth facility | 4 | seedling | plant height | mean | 42.1842529 | 3.69727978 | hedges_d |
| 51 | 2016 | yin | pinus | composite | suillus | growth facility | 4 | seedling | plant height | mean | 51.5035655 | 3.72668141 | hedges_d |
| 52 | 2016 | Barroetaveña | pinus | sandy | suillus | field | 54 | sapling | stem height | mean | 11.0567223 | 3.64081897 | hedges_d |
| 52 | 2016 | Barroetaveña | pinus | sandy | rhizopogon | field | 54 | sapling | stem height | mean | 23.0299468 | 3.65480432 | hedges_d |
| 52 | 2016 | Barroetaveña | pinus | sandy | hebeloma | field | 54 | sapling | stem height | mean | -5.98784466 | 3.6378515 | hedges_d |
| 52 | 2016 | Barroetaveña | pinus | sandy | suillus | field | 54 | sapling | stem height | mean | 4.90995289 | 3.63744786 | hedges_d |
| 52 | 2016 | Barroetaveña | pinus | sandy | rhizopogon | field | 54 | sapling | stem height | mean | 5.0481131 | 3.63749514 | hedges_d |
| 54 | 2016 | Barroetaveña | pinus | sandy | hebeloma | field | 54 | sapling | stem height | mean | -1.57666328 | 3.63670475 | hedges_d |
| 59 | 2015 | vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | 6.26883073 | 3.00839469 | hedges_d |
| 59 | 2015 | Vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | 7.84776961 | 3.01020299 | hedges_d |
| 59 | 2015 | vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | 3.0927723 | 3.00598079 | hedges_d |
| 59 | 2015 | vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | 11.0376474 | 3.01508493 | hedges_d |
| 59 | 2015 | vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | 9.63897674 | 3.0127423 | hedges_d |
| 59 | 2015 | vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | -1.49498508 | 3.00538538 | hedges_d |
| 59 | 2015 | vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | 0 | 3.00520382 | hedges_d |
| 59 | 2015 | vaario | pinus | composite | tricholoma | growth facility | 2 | seedling | shoot height | mean | 17.5483064 | 3.03011762 | hedges_d |
| 64 | 2015 | Repac | picea | composite | thelephora | growth facility | 24 | seedling | stem height | mean | -11.9399617 | 34.7062341 | hedges_d |
| 64 | 2015 | Repac | picea | composite | ectovit | growth facility | 24 | seedling | stem height | mean | 2019.58 | 34.7063274 | hedges_d |
| 67 | 2014 | Itoo | pinus | field | hebeloma | growth facility | 5.8 | seedling | seedling height | mean | 103.887067 | 8.93579366 | hedges_d |
| 67 | 2014 | Itoo | pinus | field | boletus | growth facility | 5.8 | seedling | seedling height | mean | 63.5850613 | 8.93431828 | hedges_d |
| 67 | 2014 | Itoo | pinus | field | scleroderma | growth facility | 5.8 | seedling | seedling height | mean | 83.537197 | 8.93495997 | hedges_d |
| 67 | 2014 | Itoo | pinus | field | suillus | growth facility | 5.8 | seedling | seedling height | mean | 51.787504 | 8.93402073 | hedges_d |
| 72 | 2013 | Dominguez-N | pinus | composite | rhizopogon | field | 5 | seedling | seedling height | mean | -15.2150103 | 3.3452204 | hedges_d |
| 74 | 2013 | Sanchez-Zaba | pinus | composite | lactarius | field | 9 | seedling | seedling height | mean | 56.8137841 | 3.49543137 | hedges_d |
| 74 | 2013 | Sanchez-Zaba | pinus | composite | lactarius | field | 9 | seedling | seedling height | mean | 58.9066289 | 3.50729159 | hedges_d |
| 74 | 2013 | Sanchez-Zaba | pinus | composite | pisolithus | field | 9 | seedling | seedling height | mean | 29.5819983 | 3.37804857 | hedges_d |
| 74 | 2013 | Sanchez-Zaba | pinus | composite | suillus | field | 9 | seedling | seedling height | mean | -54.5502199 | 3.4830437 | hedges_d |
| 79 | 2012 | Lazarević | pinus | composite | suillus | field | 11 | seedling | seedling height | mean | 2.25378578 | 7.27582008 | hedges_d |
| 79 | 2012 | Lazarevic | pinus | composite | suillus | field | 11 | seedling | seedling height | mean | -47.171341 | 7.27755735 | hedges_d |
| 81 | 2012 | Ragonezi | pinus | media | pisolithus | growth facility | 1 | seedling | root length | mean | 15.6685336 | 4.44074812 | hedges_d |
| 84 | 2012 | Sousa | pinus | composite | suillus | growth facility | 6 | seedling | shoot height | mean | 63.0732891 | 3.53205194 | hedges_d |
| 84 | 2012 | Sousa | pinus | composite | pisolithus | growth facility | 6 | seedling | shoot height | mean | 231.31477 | 5.42774344 | hedges_d |
| 84 | 2012 | Sousa | pinus | composite | rhizopogon | growth facility | 6 | seedling | shoot height | mean | 171.207244 | 4.6003489 | hedges_d |
| 84 | 2012 | Sousa | pinus | composite | suillus | growth facility | 6 | seedling | root length | mean | 26.4570343 | 3.36914786 | hedges_d |
| 84 | 2012 | Sousa | pinus | composite | pisolithus | growth facility | 6 | seedling | root length | mean | 65.9454468 | 3.54999575 | hedges_d |
| 84 | 2012 | Sousa | pinus | composite | rhizopogon | growth facility | 6 | seedling | root length | mean | 56.7580503 | 3.49512085 | hedges_d |
| 85 | 2012 | Otgonsuren | pinus | composite | Phialocephala | growth facility | 6 | seedling | seedling height | mean | -4.94281178 | 1.28760829 | hedges_d |
| 86 | 2012 | Otgonsuren | pinus | composite | Phialocephala | growth facility | 6 | seedling | root length | mean | 3.77969663 | 1.27212621 | hedges_d |
| 86 | 2012 | Dominguez | pinus | composite | tuber | growth facility | 1 | seedling | seedling height | mean | 48.5176226 | 4.22627432 | hedges_d |
| 86 | 2012 | Dominguez-N | pinus | composite | tuber | growth facility | 1 | seedling | seedling height | mean | -15.5973602 | 4.18999162 | hedges_d |
| 87 | 2012 | Oliveira | pinus | composite | thelephora | growth facility | 6 | seedling | shoot height | mean | -9.70134724 | 3.63985289 | hedges_d |
| 87 | 2012 | Oliveira | pinus | composite | rhizopogon | growth facility | 6 | seedling | shoot height | mean | 34.9672064 | 3.67840677 | hedges_d |
| 87 | 2012 | Oliveira | pinus | composite | ecm group | growth facility | 6 | seedling | shoot height | mean | 37.5525293 | 3.68477246 | hedges_d |
| 87 | 2012 | Oliveira | pinus | composite | ecm group | growth facility | 6 | seedling | shoot height | mean | 47.2538765 | 3.71257757 | hedges_d |
| 93 | 2011 | Buscardo | pinus | composite | ecm group | field | 54 | sapling | sapling height | mean | 0 | 0.35355339 | hedges_d |
| 96 | 2011 | Wagg | pinus | composite | ecm strain | field | 6 | seedling | growth rate | mean | 121.728445 | 5.7178305 | hedges_d |
| 96 | 2011 | wagg | picea | composite | ecm strain | field | 6 | seedling | growth rate | mean | 62.854965 | 7.96871021 | hedges_d |
| 97 | 2011 | Koele | picea | composite | ecm group | growth facility | 4 | seedling | shoot weight | mean | 88.4022821 | 5.9461515 | hedges_d |
| 97 | 2011 | Koele | picea | composite | ecm group | growth facility | 4 | seedling | root weight | mean | 74.0361124 | 5.94001617 | hedges_d |
| 98 | 2011 | Repác, | picea | composite | Cortinarius | growth facility | 5 | seedling | shoot length | mean | 53.2 | 4.92709997 | hedges_d |
| 98 | 2011 | Repac | picea | composite | gomphidius | growth facility | 5 | seedling | shoot length | mean | 0 | 4.90577891 | hedges_d |
| 98 | 2011 | Repac | picea | composite | Cortinarius | growth facility | 5 | seedling | root length | mean | -49.6833691 | 4.92437954 | hedges_d |
| 98 | 2011 | Repac | picea | composite | gomphidius | growth facility | 5 | seedling | root length | mean | -4.92255085 | 4.90596184 | hedges_d |

(Growth)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 2010 | Sarjala | pinus | media | pisolithus | growth facility | 0.5 | seedling | root length | mean | 9.68403911 | 4.90648687 | hedges_d |
| 101 | 2010 | Sarjala | pinus | media | paxillus | growth facility | 0.5 | seedling | root length | mean | 206.159221 | 5.21679357 | hedges_d |
| 103 | 2010 | Vaario | pinus | media | tricholoma | growth facility | 8 | seedling | shoot height | mean | -2.64723476 | 2.64671641 | hedges_d |
| 103 | 2010 | vaario | pinus | media | tricholoma | growth facility | 8 | seedling | shoot height | mean | -2.86544682 | 2.64688204 | hedges_d |
| 103 | 2010 | Vaario | picea | media | tricholoma | growth facility | 8 | seedling | shoot height | mean | -11.7432913 | 2.66467892 | hedges_d |
| 103 | 2010 | Vaario | picea | media | tricholoma | growth facility | 8 | seedling | shoot height | mean | -0.27298422 | 2.64576158 | hedges_d |
| 104 | 2010 | Lesky | pinus | composite | suillus | growth facility | 24 | sapling | plant height | mean | -0.86513995 | 6.80000088 | hedges_d |
| 104 | 2010 | Lesky | pinus | composite | wilcoxina | growth facility | 24 | sapling | plant height | mean | 0 | 6.8 | hedges_d |
| 125 | 2008 | Zhu | pinus | sand | boletus | growth facility | 6 | seedling | shoot height | mean | 14.375 | 1.53937973 | hedges_d |
| 125 | 2008 | zhu | pinus | sand | lactarius | growth facility | 6 | seedling | shoot height | mean | 0.70554065 | 1.25077755 | hedges_d |
| 125 | 2008 | Zhu | pinus | sand | ecm group | growth facility | 6 | seedling | shoot height | mean | 12.1474679 | 1.4625013 | hedges_d |
| 125 | 2008 | Zhu | pinus | sand | pisolithus | growth facility | 6 | seedling | root length | mean | 11.4258657 | 1.43960499 | hedges_d |
| 125 | 2008 | Zhu | pinus | sand | boletus | growth facility | 6 | seedling | root length | mean | 13.7348427 | 1.51637662 | hedges_d |
| 125 | 2008 | Zhu | pinus | sand | ecm group | growth facility | 6 | seedling | root length | mean | 4.17534722 | 1.27694937 | hedges_d |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | seedling height | mean | -4.44813191 | 1.79988104 | hedges_d |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | seedling height | mean | 6.2730707 | 1.81071887 | hedges_d |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | seedling height | mean | 5.77968994 | 1.80743178 | hedges_d |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | seedling height | mean | 9.57932943 | 1.83943663 | hedges_d |
| 131 | 2007 | Rincón | pinus | field | amanita | field | 43.2 | sapling | seedling height | mean | 8.1450147 | 1.82556362 | hedges_d |
| 133 | 2007 | Aučina | pinus | field | ecm group | field | 24 | sapling | seedling height | mean | 28.2161172 | 6.80093658 | hedges_d |
| 134 | 2007 | Kozdrój | pinus | sand | amanita | growth facility | 3 | seedling | shoot length | mean | 2.32550423 | 0.61919878 | hedges_d |
| 134 | 2007 | Kozdrój | pinus | sand | hebeloma | growth facility | 3 | seedling | shoot length | mean | 2.25306987 | 0.61671414 | hedges_d |
| 134 | 2007 | Kozdrój | pinus | sand | amanita | growth facility | 3 | seedling | root length | mean | 10.9557894 | 1.20196337 | hedges_d |
| 134 | 2007 | Kozdrój | pinus | sand | hebeloma | growth facility | 3 | seedling | root length | mean | 10.6517744 | 1.17638924 | hedges_d |
| 136 | 2013 | Dominguez-N | pinus | sand | pisolithus | growth facility | 3 | seedling | seedling height | mean | 22.5997443 | 3.35950367 | hedges_d |
| 136 | 2013 | Dominguez-N | pinus | sand | pisolithus | growth facility | 3 | seedling | stem basal diameter | mean | 12.8169226 | 3.34177293 | hedges_d |
| 143 | 2006 | Bakker | pinus | sand | cenococcum | field | 54 | sapling | root length | mean | 2.27156856 | 1.2580367 | hedges_d |
| 145 | 2001 | Probanza | pinus | sand | pisolithus | growth facility | 4.8 | seedling | root length | mean | -2.41522512 | 3.33363339 | hedges_d |
| 145 | 2001 | Probanza | pinus | sand | pisolithus | growth facility | 4.8 | seedling | root length | mean | 33.2482081 | 3.38972077 | hedges_d |
| 145 | 2001 | Probanza | pinus | sand | pisolithus | growth facility | 4.8 | seedling | root length | mean | 12.224736 | 3.34101195 | hedges_d |
| 155 | 2005 | Choi | pinus | composite | pisolithus | growth facility | 4.5 | seedling | stem diameter | mean | 13.0523654 | 5.12601436 | hedges_d |
| 156 | 2005 | Rincón | pinus | composite | suillus | growth facility | 4.5 | seedling | tap root length | mean | -71.9519303 | 6.80608796 | hedges_d |
| 156 | 2005 | Rincón | pinus | composite | suillus | growth facility | 4.5 | seedling | tap root length | mean | 12.0208153 | 6.80017 | hedges_d |
| 160 | 2003 | Boukcim | picea | composite | paxillus | growth facility | 4 | seedling | tap root length | mean | 21.4881778 | 4.90926367 | hedges_d |
| 160 | 2003 | Boukcim | picea | composite | paxillus | growth facility | 4 | seedling | tap root length | mean | -12.0129897 | 4.90686829 | hedges_d |
| 166 | 2004 | Hilszczańska | pinus | sand | thelephora | field | 3 | seedling | shoot height | mean | -27.6184218 | 3.6627441 | hedges_d |
| 166 | 2004 | Hilszczańska | pinus | sand | thelephora | field | 3 | seedling | shoot height | mean | -3.63661931 | 3.63707386 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | growth facility | 5 | seedling | seed height | mean | 17.7322305 | 6.80036991 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | growth facility | 5 | seedling | seedling height | mean | 61.5643073 | 6.80445756 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | growth facility | 5 | seedling | seedling height | mean | 16.0030766 | 6.80030129 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | growth facility | 5 | seedling | stem diameter | mean | 0 | 6.8 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | growth facility | 5 | seedling | stem diameter | mean | 45.6157867 | 6.80244756 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | growth facility | 5 | seedling | stem diameter | mean | 53.7244681 | 6.80339482 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | field | 5 | seedling | seed height | mean | 2.33238076 | 6.8000064 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | field | 5 | seedling | seedling height | mean | 12.7760107 | 6.80019203 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | field | 5 | seedling | seedling height | mean | 15.8732255 | 6.80029642 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | field | 5 | seedling | stem diameter | mean | 11.814925 | 6.80016422 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | field | 5 | seedling | stem diameter | mean | 5.21536192 | 6.800032 | hedges_d |
| 174 | 2004 | Duñabeitia | pinus | composite | rhizopogon | field | 5 | seedling | stem diameter | mean | 17.1174163 | 6.8003447 | hedges_d |
| 189 | 2003 | Guerin-Laguet | pinus | composite | lactarius | field | 5 | seedling | shoot height | mean | 14.7526513 | 1.6209365 | hedges_d |
| 189 | 2003 | Guerin-Laguet | pinus | field | lactarius | field | 5 | seedling | shoot height | mean | 13.3364862 | 1.58996478 | hedges_d |
| 189 | 2003 | Guerin-Laguet | pinus | field | lactarius | field | 5 | seedling | shoot height | mean | 5.02728578 | 1.46509977 | hedges_d |
| 189 | 2003 | Guerin-Laguet | pinus | field | lactarius | field | 5 | seedling | shoot height | mean | 11.4863728 | 1.55343981 | hedges_d |
| 232 | 1995 | Shaw | pinus | composite | ecm group | growth facility | 4 | seedling | growth rate | mean | -1.49383981 | 2.24594067 | hedges_d |
| 282 | 2018 | Jenkins | pinus | sand | suillus | growth facility | 6 | seedling | seedling height | mean | 7.31095974 | 4.75214867 | hedges_d |
| 282 | 2018 | Jenkins | pinus | sand | suillus | growth facility | 6 | seedling | stem diameter | mean | -1.7104491 | 4.75167205 | hedges_d |
| 288 | 1991 | Svenson | pinus | composite | pisolithus | growth facility | 9.25 | seedling | seedling height | mean | -10.0375567 | 4.18753027 | hedges_d |
| 288 | 1991 | Svenson | pinus | composite | pisolithus | growth facility | 9.25 | seedling | root collar diameter | mean | 0.1549103 | 4.18578987 | hedges_d |
| 340 | 2003 | Mari | picea | composite | laccaria | growth facility | 4.5 | seedling | plant height | mean | 0 | 1.25 | hedges_d |
| 308 | 2008 | Dominguez Nu | pinus | composite | tuber | field | 7 | seedling | shoot height | mean | 56.1582585 | 4.23994163 | hedges_d |
| 308 | 2008 | Dominguez Nu | pinus | composite | tuber | field | 7 | seedling | stem basal diameter | mean | 37.5625133 | 4.21010246 | hedges_d |
| 321 | 2002 | Niemi | pinus | media | pisolithus | growth facility | 2 | seedling | root length | mean | -0.86671906 | 0.38532462 | hedges_d |
| 321 | 2002 | Niemi | pinus | media | pisolithus | growth facility | 2 | seedling | root length | mean | -0.93334561 | 0.39015758 | hedges_d |
| 321 | 2002 | Niemi | pinus | media | pisolithus | growth facility | 6.25 | seedling | root length | mean | -1.70108597 | 0.46414213 | hedges_d |
| 321 | 2002 | Niemi | pinus | media | pisolithus | growth facility | 5.5 | seedling | root length | mean | 0.3933128 | 0.36032516 | hedges_d |
| 11 | 2022 | Repac | picea | composite | ectovit | growth facility | 36 | seedling | stem height | mean | 0 | 4.90577891 | hedges_d |
| 342 | 1995 | Shaw | pinus | media | ecm group | growth facility | 3 | seedling | growth rate | mean | 0.11026495 | 2.24536873 | hedges_d |
| 346 | 2022 | Wang | pinus | composite | hymenochaet | growth facility | 16 | seedling | shoot length | mean | 74.1714286 | 3.76866046 | hedges_d |
| 346 | 2022 | Wang | pinus | composite | hymenochaet | growth facility | 16 | seedling | stem diameter | mean | 12.6490783 | 1.87616587 | hedges_d |
| 346 | 2022 | Wang | pinus | composite | hymenochaet | growth facility | 16 | seedling | shoot length | mean | 61.9762749 | 3.29880544 | hedges_d |
| 346 | 2022 | Wang | pinus | composite | hymenochaet | growth facility | 16 | seedling | stem diameter | mean | 26.1992092 | 2.13840995 | hedges_d |
| 347 | 2007 | Niemi | pinus | media | suillus | growth facility | 0.5 | seedling | root length | mean | 186.278321 | 5.16110534 | hedges_d |
| 347 | 2007 | Niemi | pinus | media | suillus | growth facility | 0.5 | seedling | root length | mean | 276.403104 | 5.45213975 | hedges_d |
| 335 | 2002 | Niemi | pinus | media | pisolithus | growth facility | 2 | seedling | root length | mean | -0.56288575 | 4.9057813 | hedges_d |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | -0.17079 | 0.27247906 | logRR |
| 213 | 1998 | Scagel, | Picea | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | 0.001 | 0.27247906 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | -0.37688177 | 0.38422426 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | 0.04155723 | 0.27771915 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | 0.12107793 | 0.25837182 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | 1.13435591 | 0.61410965 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | -0.06774599 | 0.83902976 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | 0.14600782 | 0.78360686 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | -0.77028291 | 1.0863137 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | -0.14041718 | 0.8597638 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | -0.47087737 | 0.96746159 | logRR |
| 213 | 1998 | Scagel, | picea | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | -0.03689272 | 0.34767659 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | -0.36685027 | 0.42982908 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | 0.06552229 | 0.32399528 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | -0.11150358 | 0.36542667 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | 0.01251973 | 0.33615668 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | 0.10599024 | 0.31483865 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | height relative growth rate | percentage | -1.77451766 | 0.89421943 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | -1.3834 | 0.72316127 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | 0.28768207 | 0.23156681 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | 0.001 | 0.2529331 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | -1.23338669 | 0.66516161 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | 0.001 | 0.84859963 | logRR |
| 213 | 1998 | Scagel, | pinus | composite | laccaria | growth facility | 4 | seedling | diameter relative growth rate | percentage | 0.001 | 0.32688002 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | height relative growth rate | percentage | 0.43655203 | 0.31178172 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | height relative growth rate | percentage | 0.28653772 | 0.32934334 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | height relative growth rate | percentage | -0.17641867 | 0.39503613 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | height relative growth rate | percentage | 0.18317336 | 0.3424448 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | height relative growth rate | percentage | -0.1147937 | 0.3852001 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | height relative growth rate | percentage | 0.25562014 | 0.38691144 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | diameter relative growth rate | percentage | 0.2925247 | 0.38218869 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | diameter relative growth rate | percentage | 0.19118186 | 0.39544041 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | diameter relative growth rate | percentage | 0.68876868 | 0.33831757 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | diameter relative growth rate | percentage | 0.55693073 | 0.35159644 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | diameter relative growth rate | percentage | 0.23203594 | 0.38999089 | logRR |
| 344 | 1998 | Scagel, | pinus | composite | laccaria | field | 6 | seedling | diameter relative growth rate | percentage | -0.15591825 | 0.53928685 | logRR |
| 315 | 2006 | van Hees | pinus | field | hebeloma | growth facility | 18.5 | seedling | root relative growth rate | percentage | -0.05913763 | 0.54358205 | logRR |
| 315 | 2006 | van Hees | pinus | field | hebeloma | growth facility | 18.5 | seedling | shoot relative growth rate | percentage | 0.91689115 | 0.42851324 | logRR |
| 348 | 2007 | Niemi | pinus | media | pisolithus | growth facility | 4.5 | seedling | embryo growth | percentage | 1.01296498 | 0.41768365 | logRR |
| 348 | 2007 | Niemi | pinus | media | pisolithus | growth facility | 4.5 | seedling | embryo growth | percentage | 1.01296498 | 0.41768365 | logRR |

## C- Survival factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

| study_id | year | author | tree_genus | soil_type | ecm_genus | growth_conditions | tree_age | tree_category | measured parameter | treatment_n | control_n | treatment_mean | control_mean | data_type | RR | logRR | SElogRR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 2021 | Taniguchi | pinus | sandy | suillus | field | 36 | sapling | survival | 10 | 10 | 0.6458 | 0.4427 | percentage | 1.458775695 | 0.37759752 | 0.13847701 |
| 25 | 2021 | Lorenc | picea | sandy | ectovit | field | 36 | sapling | survival | 100 | 100 | 0.35 | 0.943 | percentage | 0.371155885 | 0.001 | 0.13847701 |
| 25 | 2021 | Lorenc | picea | sand | ectovit | field | 36 | sapling | survival | 100 | 100 | 0.77 | 0.4445 | percentage | 1.732283465 | 0.54944046 | 0.12443553 |
| 33 | 2020 | Hewitt | pinus | field | ecm | field | 24 | sapling | survival | 192 | 192 | 0.63 | 0.4445 | percentage | 1.417322835 | 0.34876976 | 0.09781521 |
| 33 | 2020 | Hewitt | pinus | field | ecm | field | 24 | sapling | survival | 192 | 192 | 0.17 | 0.819 | percentage | 0.207570208 | -1.57228565 | 0.16303365 |
| 33 | 2020 | Hewitt | pinus | field | ecm | field | 24 | sapling | survival | 192 | 192 | 0.96 | 0.8 | percentage | 1.2 | 0.18232156 | 0.0389756 |
| 33 | 2020 | Hewitt | pinus | field | ecm | field | 24 | sapling | survival | 192 | 192 | 0.38 | 0.8 | percentage | 0.475 | -0.74444047 | 0.0989944 |
| 44 | 2017 | Rudawska | pinus | field | suillus | field | 24 | sapling | survival | 20 | 20 | 0.8791 | 0.83 | percentage | 1.059156627 | 0.05747296 | 0.13083316 |
| 44 | 2017 | Rudawska | pinus | field | wilcoxina | field | 24 | sapling | survival | 20 | 20 | 0.9613 | 0.08 | percentage | 12.01625 | 2.4862599 | 0.75961365 |
| 44 | 2017 | Rudawska | pinus | field | wilcoxina | field | 24 | sapling | survival | 20 | 20 | 0.8274 | 1 | percentage | 0.8274 | -0.18946702 | 0.10212866 |
| 44 | 2017 | Rudawska | pinus | field | cenococcum | field | 24 | sapling | survival | 20 | 20 | 0.8062 | 0.42 | percentage | 1.91952381 | 0.65207714 | 0.28472262 |
| 50 | 2016 | Nakashima | pinus | field | ecm | field | 24 | sapling | survival | 150 | 150 | 0.753 | 0.53 | percentage | 1.420754717 | 0.35118822 | 0.0899931 |
| 50 | 2016 | Nakashima | pinus | field | ecm | field | 24 | sapling | survival | 150 | 150 | 0.76 | 0.53 | percentage | 1.433962264 | 0.36044143 | 0.08953889 |
| 50 | 2016 | Nakashima | pinus | field | ecm | field | 24 | sapling | survival | 150 | 150 | 0.8 | 0.53 | percentage | 1.509433962 | 0.41173472 | 0.08705525 |
| 67 | 2014 | Itoo | pinus | field | hebeloma | growth facility | 5.8 | seedling | survival | 40 | 40 | 0.68 | 0.6769 | percentage | 1.004579702 | 0.00456925 | 0.15394084 |
| 67 | 2014 | Itoo | pinus | field | boletus | growth facility | 5.8 | seedling | survival | 40 | 40 | 0.62 | 0.6628 | percentage | 0.935425468 | -0.06675381 | 0.16745552 |
| 67 | 2014 | Itoo | pinus | field | scleroderma | growth facility | 5.8 | seedling | survival | 40 | 40 | 0.57 | 0.8086 | percentage | 0.704922088 | -0.349668 | 0.15740802 |
| 67 | 2014 | Itoo | pinus | field | suillus | growth facility | 5.8 | seedling | survival | 40 | 40 | 0.54 | 0.6299 | percentage | 0.857278933 | -0.15399194 | 0.18969748 |
| 68 | 2014 | Onwuchekwa | pinus | sandy | suillus | field | 12 | seedling | survival | 20 | 20 | 0.495 | 0.64 | percentage | 0.7734375 | -0.25691041 | 0.28130962 |
| 68 | 2014 | Onwuchekwa | pinus | sandy | laccaria | field | 12 | seedling | survival | 20 | 20 | 0.39 | 0.64 | percentage | 0.609375 | -0.49532144 | 0.32608301 |
| 68 | 2014 | Onwuchekwa | pinus | sandy | hebeloma | field | 12 | seedling | survival | 20 | 20 | 0.41 | 0.64 | percentage | 0.640625 | -0.44531102 | 0.31634826 |
| 68 | 2014 | Onwuchekwa | picea | sandy | hebeloma | field | 12 | seedling | survival | 20 | 20 | 0.4993 | 0.35 | percentage | 1.426571429 | 0.35527396 | 0.37814989 |
| 68 | 2014 | Onwuchekwa | picea | sandy | suillus | field | 12 | seedling | survival | 20 | 20 | 0.4797 | 0.35 | percentage | 1.370571429 | 0.31522775 | 0.38352178 |
| 68 | 2014 | Onwuchekwa | picea | sandy | laccaria | field | 12 | seedling | survival | 20 | 20 | 0.3315 | 0.35 | percentage | 0.947142857 | -0.05430534 | 0.44009852 |
| 98 | 2011 | Repác, | picea | composite | ectovit | growth facility | 6 | seedling | survival | 15 | 15 | 0.6481 | 0.35 | percentage | 1.851714286 | 0.61611185 | 0.40000955 |
| 98 | 2011 | Repac | picea | composite | trichomil | growth facility | 6 | seedling | survival | 15 | 15 | 0.696 | 0.3434 | percentage | 2.026790914 | 0.70645371 | 0.39571349 |
| 98 | 2011 | Repac | picea | composite | cortinarius | growth facility | 6 | seedling | survival | 15 | 15 | 0.6941 | 0.3434 | percentage | 2.021258008 | 0.70372009 | 0.39604465 |
| 98 | 2011 | Repac | picea | composite | gomphidius | growth facility | 6 | seedling | survival | 15 | 15 | 0.5521 | 0.3434 | percentage | 1.607746069 | 0.47483324 | 0.42609248 |
| 98 | 2011 | Repac | picea | composite | vetozen | growth facility | 6 | seedling | survival | 15 | 15 | 0.712 | 0.314 | percentage | 2.267515924 | 0.81868493 | 0.41546823 |
| 98 | 2011 | Repac | picea | composite | bactofil | growth facility | 6 | seedling | survival | 15 | 15 | 0.608 | 0.314 | percentage | 1.936305732 | 0.6607819 | 0.43431557 |
| 98 | 2011 | Repac | picea | composite | beads | growth facility | 6 | seedling | survival | 15 | 15 | 0.4561 | 0.314 | percentage | 1.452547771 | 0.3733191 | 0.47449728 |
| 104 | 2010 | Lesky | pinus | composite | suillus | growth facility | 24 | sapling | survival | 25 | 25 | 0.014 | 0.744 | percentage | 0.018817204 | -3.97298371 | 1.68252973 |
| 104 | 2010 | Lesky | pinus | composite | wilcoxina | growth facility | 24 | sapling | survival | 25 | 25 | 0.014 | 0.744 | percentage | 0.018817204 | -3.97298371 | 1.68252973 |
| 123 | 2008 | Adomas | pinus | media | laccaria | growth facility | 0.9 | seedling | survival | 10 | 10 | 0.95 | 0.744 | percentage | 1.27688172 | 0.001 | 0.19917771 |
| 123 | 2008 | Adomas | pinus | media | laccaria | growth facility | 0.9 | seedling | mortality | 10 | 10 | 0.05 | 0.744 | percentage | 0.067204301 | -2.70001803 | 1.39083018 |
| 127 | 2008 | Jha | pinus | sandy | *Collybia* | growth facility | 0.9 | seedling | survival | 14 | 14 | 0.8 | 0.744 | percentage | 1.075268817 | 0.07257069 | 0.20599688 |
| 127 | 2008 | Jha | pinus | sandy | pisolithus | growth facility | 0.9 | seedling | survival | 14 | 14 | 0.7 | 0.744 | percentage | 0.940860215 | 0.001 | 0.23492513 |
| 127 | 2008 | Jha | pinus | sandy | rhizopogon | growth facility | 0.9 | seedling | survival | 14 | 14 | 0.8 | 0.744 | percentage | 1.075268817 | 0.001 | 0.20599688 |
| 127 | 2008 | Jha | pinus | sandy | laccaria | growth facility | 0.9 | seedling | survival | 14 | 14 | 0.7 | 0.251 | percentage | 2.788844622 | 0.001 | 0.49372022 |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | survival | 5 | 5 | 0.3846 | 0.041 | Percentage | | 2.23863177 | 2.23563628 |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | survival | 5 | 5 | 0.7133 | 1 | Percentage | 9.380487805 | -0.33785319 | 0.2835259 |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | survival | 5 | 5 | 0.6964 | 1 | Percentage | 0.7133 | 0.08380367 | 0.29528168 |
| 131 | 2007 | Rincón | pinus | field | suillus | field | 43.2 | sapling | survival | 5 | 5 | 0.70682 | 0.65 | Percentage | 1.087415385 | 0.08380367 | 0.43663461 |
| 131 | 2007 | Rincón | pinus | field | CCMA44 | field | 43.2 | sapling | survival | 5 | 5 | 0.5565 | 0.65 | Percentage | 0.856153846 | -0.15530519 | 0.51679914 |
| 131 | 2007 | Rincón | pinus | field | rhizopogon | field | 43.2 | sapling | survival | 5 | 5 | 0.13 | 0.65 | Percentage | 0.2 | -1.60943791 | 1.20256137 |
| 133 | 2007 | Aučina | pinus | field | ecm | field | 24 | sapling | survival | 25 | 25 | 0.64 | 0.65 | percentage | 0.984615385 | -0.01550419 | 0.20985343 |
| 154 | 2005 | Kayama | picea | field | ecm | field | 48 | small tree | survival | 16 | 16 | 0.32 | 0.4266 | Percentage | 0.750117206 | -0.28752581 | 0.46563909 |
| 154 | 2005 | Kayama | picea | field | ecm | field | 48 | small tree | survival | 16 | 16 | 0.206 | 0.4266 | Percentage | 0.482887951 | -0.72797064 | 0.57000467 |
| 154 | 2005 | Kayama | picea | field | ecm | field | 48 | small tree | survival | 16 | 16 | 0.94 | 0.4266 | Percentage | 2.203469292 | 0.79003307 | 0.29664226 |
| 154 | 2005 | Kayama | picea | field | ecm | field | 48 | small tree | survival | 16 | 16 | 0.139 | 0.4266 | Percentage | 0.325832161 | -1.12137287 | 0.68640189 |
| 154 | 2005 | Kayama | picea | field | ecm | field | 48 | small tree | survival | 16 | 16 | 0.082 | 0.4266 | Percentage | 0.192217534 | -1.64912756 | 0.88526967 |
| 208 | 1999 | Cram | pinus | sandy | pisolithus | field | 60 | small tree | survival | 8 | 8 | 0.81 | 0.4266 | percentage | 1.898734177 | 0.64118744 | 0.44422463 |
| 208 | 1999 | Cram | pinus | sandy | pisolithus | field | 60 | small tree | survival | 8 | 8 | 0.9 | 0.436 | percentage | 2.064220183 | 0.72475252 | 0.41902999 |
| 271 | 2006 | Nowak | pinus | composite | pisolithus | field | 5 | seedling | survival | 5 | 5 | 0.9 | 0.2 | percentage | 4.5 | 1.5040774 | 0.9067647 |
| 271 | 2006 | Nowak | pinus | composite | pisolithus | field | 5 | seedling | survival | 5 | 5 | 0.81 | 1 | percentage | 0.81 | -0.21072103 | 0.21659543 |
| 279 | 2007 | Menkis | pinus | field | cenococcum | field | 36 | sapling | survival | 20 | 20 | 0.71 | 0.315 | percentage | 2.253968254 | 0.81269233 | 0.3593782 |
| 279 | 2007 | Menkis | pinus | field | piceirhiza | field | 36 | sapling | survival | 20 | 20 | 0.6915 | 0.144 | percentage | 4.802083333 | 1.56904985 | 0.56526879 |
| 279 | 2007 | Menkis | pinus | field | hebeloma | field | 36 | sapling | survival | 20 | 20 | 0.6717 | 0.2 | percentage | 3.3585 | 1.21149445 | 0.47374887 |
| 279 | 2007 | Menkis | picea | field | cenococcum | field | 36 | sapling | survival | 20 | 20 | 0.7242 | 0.172 | percentage | 4.210465116 | 1.43757312 | 0.50964632 |
| 279 | 2007 | Menkis | pinus | field | piceirhiza | field | 36 | sapling | survival | 20 | 20 | 0.6628 | 0.38 | percentage | 1.744210526 | 0.001 | 0.001 |
| 279 | 2007 | Menkis | pinus | field | hebeloma | field | 36 | sapling | survival | 20 | 20 | 0.571 | 1 | percentage | 0.571 | 0.001 | 0.001 |
| 285 | 2006 | Kayama | picea | field | ecm | field | 36 | sapling | survival | 16 | 16 | 0.07 | 1 | percentage | 0.07 | -2.65926004 | 0.91123934 |
| 285 | 2006 | Kayama | picea | field | ecm | field | 36 | sapling | survival | 16 | 16 | 0.05 | 1 | percentage | 0.05 | 0.001 | 0.001 |
| 285 | 2006 | Kayama | picea | field | ecm | field | 36 | sapling | survival | 16 | 16 | 0.21 | 1 | percentage | 0.21 | -1.56064775 | 0.48489076 |
| 298 | 2011 | Menkis | picea | composite | amphinema | field | 24 | sapling | survival | 10 | 10 | 0.882 | 1 | percentage | 0.882 | 0.001 | 0.001 |
| 298 | 2011 | Menkis | picea | composite | amphinema | field | 24 | sapling | survival | 10 | 10 | 0.817 | 1 | percentage | 0.817 | 0.001 | 0.001 |
| 321 | 2002 | Niemi | pinus | media | pisolithus | growth facility | 6.25 | seedling | survival | 2 | 2 | 100 | 1 | percentage | 100 | 0.001 | 0.001 |
| 321 | 2002 | Niemi | pinus | media | pisolithus | growth facility | 5.5 | seedling | survival | 2 | 2 | 100 | 1 | percentage | 100 | 4.60517019 | 0.001 |

## D-Biotic factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

| study_id | year | author | tree_genus | soil_type | ecm_genus | growth_conditions | stress_type | tree_age | tree_category | measured_parameter | data_type | effect_size | var_d | source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 2021 | Chu | pinus | composite | amanita | growth facility | insect | 9 | seedling | disease incidence | mean | -2.02780972 | 0.41398961 | Hedges_d |
| 20 | 2021 | Chu | pinus | composite | suillus | growth facility | insect | 9 | seedling | disease incidence | mean | 0.53158842 | 0.40463384 | Hedges_d |
| 211 | 1998 | Manninen | pinus | media | cenoccocum | growth facility | Insect | 2.75 | seedling | root length | mean | -1.82440703 | 0.22571024 | Hedges_d |
| 211 | 1998 | Manninen | pinus | media | cenoccocum | growth facility | Insect | 3.25 | seedling | root length | mean | -2.10582351 | 0.22887826 | Hedges_d |
| 218 | 1997 | Gerhring | pinus | field | ecm | field | Insect | 96 | seedling | mortality | mean | -0.87014149 | 0.40580496 | Hedges_d |
| 218 | 1997 | Gerhring | pinus | field | ecm | field | Insect | 96 | seedling | mortality | mean | -4.74396802 | 0.45626071 | Hedges_d |
| 277 | 2018 | Piculell | pinus | field | ecm | growth facility | pathogen | 5.5 | seedling | relative growth rate | mean | 0.93802036 | 0.13500372 | Hedges_d |
| 277 | 2018 | Piculell | pinus | field | ecm | growth facility | pathogen | 5.5 | seedling | relative growth rate | mean | 0 | 0.15123825 | Hedges_d |
| 277 | 2018 | Piculell | pinus | field | ecm | growth facility | pathogen | 5.5 | seedling | relative growth rate | mean | 0.64744052 | 0.12515279 | Hedges_d |
| 277 | 2018 | Piculell | pinus | field | ecm | growth facility | pathogen | 5.5 | seedling | relative growth rate | mean | 0 | 0.14031362 | Hedges_d |
| 323 | 2007 | Liiri | pinus | composite | ecm | growth facility | insect | 6.5 | seedling | root length | mean | 0 | 0.13371318 | Hedges_d |
| 323 | 2007 | Liiri | pinus | composite | ecm | growth facility | insect | 6.5 | seedling | root length | mean | -0.49529781 | 0.15470792 | Hedges_d |
| 324 | 2007 | Niemi | pinus | media | pisolithus | growth facility | pathogen | 0.5 | seedling | cell masses with developing embryo | mean | 0.94742786 | 0.47079149 | Hedges_d |
| 325 | 2006 | Machon | pinus | composite | laccaria | greenhouse | pathogen | 3.25 | seedling | pre-emergence damping off | mean | 0.58304539 | 0.46527513 | Hedges_d |
| 325 | 2006 | Machon | pinus | composite | laccaria | greenhouse | pathogen | 3.25 | seedling | pre-emergence damping off | mean | -3.44056987 | 0.56827811 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | shoot height | mean | 0.98923827 | 0.47158708 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | diameter | mean | 0.3092284 | 0.25123464 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | root length | mean | 0.24324324 | 0.25122926 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | shoot height | mean | 0.36978551 | 0.2512407 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | diameter | mean | -0.77815449 | 0.2513098 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | root length | mean | 0 | 0.25122054 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | shoot height | mean | 11.3762552 | 0.26962635 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | diameter | mean | -0.09760033 | 0.25122195 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | root length | mean | -0.17199895 | 0.2512249 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | shoot height | mean | 12.3934138 | 0.27292727 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | diameter | mean | -0.07358928 | 0.25122134 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | root length | mean | 0.34399789 | 0.25123799 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | shoot height | mean | 10.1199055 | 0.26589071 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | diameter | mean | -0.03771614 | 0.25122075 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | lactarius | growth facility | pathogen | 5 | seedling | root length | mean | 0 | 0.25122054 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | shoot height | mean | -1.02333836 | 0.25137488 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | diameter | mean | -0.38828141 | 0.25124277 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | root length | mean | 0 | 0.25122054 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | shoot height | mean | -0.46028913 | 0.25125177 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | diameter | mean | -0.04689805 | 0.25122087 | Hedges_d |
| 326 | 2018 | Suarez | pinus | composite | rhizopogon | growth facility | pathogen | 5 | seedling | root length | mean | -0.34399789 | 0.25123799 | Hedges_d |
| 327 | 2020 | Berk | pinus | field | wilkoxina | growth facility | pathogen | 2.7 | seedling | seedling height | mean | -1.87664869 | 0.25173922 | Hedges_d |
| 329 | 2006 | Mueller | pinus | composite | ecm | field | pathogen | 96 | mature tree | shoot growth | mean | -0.87347081 | 0.251333 | Hedges_d |
| 329 | 2006 | Mueller | pinus | composite | ecm | field | pathogen | 96 | mature tree | mortality | mean | 0 | 0.25122054 | Hedges_d |
| 334 | 1995 | Hwang | pinus | composite | paxillus | growth facility | pathogen | 2.5 | seedling | seedling mortality | mean | 0.3355963 | 0.25123714 | Hedges_d |
| 334 | 1995 | Hwang | pinus | composite | paxillus | growth facility | pathogen | 2.5 | seedling | seedling mortality | mean | 0.36323253 | 0.4632008 | Hedges_d |
| 334 | 1995 | Hwang | pinus | composite | suillus | growth facility | pathogen | 2.5 | seedling | seedling mortality | mean | 0.4912867 | 0.30296563 | Hedges_d |
| 204 | 1999 | Chakravarty, | pinus | composite | paxillus | growth facility | pathogen | 2 | seedling | survival | mean | -0.23141273 | 0.16487542 | Hedges_d |
| 204 | 1999 | Chakravarty, | pinus | composite | laccaria | growth facility | pathogen | 2 | seedling | survival | mean | -0.19568249 | 0.16487517 | Hedges_d |
| 9 | 2022 | Wang | pinus | thunbergia | hymenochaete | growthfacility | pathogen | 5 | seedling | Infection rate | percentage | -1.82939167 | 0.85279501 | logRR |
| 9 | 2022 | Wang | pinus | thurnbergia | hymenochaete | growth facility | pathogen | 5 | seedling | Infection rate | percentage | 0.001 | 0.85279501 | logRR |
| 25 | 2021 | Lorenc | picea | abies | ectovit | field | pathogen | na | na | Infection rate | percentage | 0.09703581 | 0.69456387 | logRR |
| 25 | 2021 | Lorenc | picea | abies | ectovit | field | pathogen | na | na | Infection rate | percentage | -0.03783997 | 0.72120705 | logRR |
| 108 | 2010 | Holusa | picea | abies | ectovit | field | pathogen | 72 | mature tree | seedling height | percentage | -0.25297888 | 0.2575645 | logRR |
| 108 | 2010 | Holusa | picea | abies | ectovit | field | pathogen | 72 | mature tree | root length | percentage | -0.36050732 | 0.28872018 | logRR |
| 268 | 2019 | Chu | pinus | tabulaeformis | suillus | growth facility | pathogen | 0.9 | seedling | cumulative mortality | percentage | -6.68461173 | 2.88602957 | logRR |
| 268 | 2019 | Chu | pinus | tabulaeformis | suillus | growth facility | pathogen | 0.9 | seedling | cumulative mortality | percentage | -6.68461173 | 14.1368313 | logRR |
| 268 | 2019 | Chu | pinus | tabulaeformis | schizophyllum | growth facility | pathogen | 0.9 | seedling | cumulative mortality | percentage | 0.35468679 | 1.59326795 | logRR |
| 272 | 2001 | Nieminen | pinus | sylvestris | ecm | growth facility | insect | 8.25 | seedling | stem length | percentage | 0.04481933 | 1.98817723 | logRR |
| 277 | 2018 | Piculell | pinus | Taeda | thelephora | growth facility | pathogen | 5.5 | seedling | relative growth rate | percentage | 4.38507808 | 0.20500389 | logRR |
| 326 | 2018 | Suarez | pinus | sylvestris | lactarius | growth facility | pathogen | 5 | seedling | diameter | percentage | -0.03886452 | 0.36890751 | logRR |
| 326 | 2018 | Suarez | pinus | sylvestris | lactarius | growth facility | pathogen | 5 | seedling | root length | percentage | -1.28519824 | 0.87050223 | logRR |
| 326 | 2018 | Suarez | pinus | sylvestris | lactarius | growth facility | pathogen | 5 | seedling | shoot height | percentage | -1.28519824 | 0.87050223 | logRR |
| 334 | 1995 | Hwang | pinus | banksiana | suillus | growth facility | pathogen | 2.5 | seedling | seedling mortality | percentage | -0.32016753 | 0.22882448 | logRR |
| 336 | 2018 | Velmala | picea | abies | meliniomyces | growth facility | pathogen | 12 | seedling | shoot length | percentage | 0.11341758 | 0.18859114 | logRR |
| 336 | 2018 | Velmala | picea | abies | meliniomyces | growth facility | pathogen | 12 | seedling | shoot length | percentage | -0.14939123 | 0.26261032 | logRR |
| 336 | 2018 | Velmala | picea | abies | meliniomyces | growth facility | pathogen | 12 | seedling | damaged needles | percentage | -0.58530065 | 0.38460264 | logRR |
| 336 | 2018 | Velmala | picea | abies | meliniomyces | growth facility | pathogen | 12 | seedling | damaged needles | percentage | -0.07855036 | 0.24306634 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | citocybe | growth facility | pathogen | 2 | seedling | survival | percentage | 0.51082562 | 3.84177814 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | paxillus | growth facility | pathogen | 2 | seedling | survival | percentage | 0.001 | 4.29685501 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | laccaria | growth facility | pathogen | 2 | seedling | survival | percentage | 0.22314355 | 3.52766841 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | citocybe | growth facility | pathogen | 2 | seedling | survival | percentage | 0.001 | 3.71931893 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | paxillus | growth facility | pathogen | 2 | seedling | survival | percentage | 0.001 | 3.71931893 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | laccaria | growth facility | pathogen | 2 | seedling | survival | percentage | -0.28768207 | 4.01847585 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | Citocybe | growth facility | pathogen | 2 | seedling | survival | percentage | 0.26436485 | 0.30795331 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | paxillus | growth facility | pathogen | 2 | seedling | survival | percentage | 0.34281346 | 0.4782272 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | laccaria | growth facility | pathogen | 2 | seedling | survival | percentage | 1.57242928 | 0.51657261 | logRR |
| 204 | 1999 | Chakravarty, | pinus | sylvestris | Citocybe | growth facility | pathogen | 2 | seedling | survival | percentage | 0.56426201 | 0.19232944 | logRR |

## E -Included articles.

| **Author name** | **Year of publication** | **Title** |
|---|---|---|
| Tapwal, A. | 2022 | Growth enhancement in containerized *Pinus gerardiana* seedlings inoculated with ectomycorrhizal fungi |
| McMahen, K. | 2022 | Soil microbial legacies influence plant survival and growth in mine reclamation |
| Fahey, C | 2022 | Effects of dual mycorrhizal inoculation on *Pinus strobus* seedlings are influenced by soil resource availability |
| Huang, L.-L. | 2022 | Ectomycorrhizal synthesis between two *Tuber* species and six tree species: are different host-fungus combinations having dissimilar impacts on host plant growth? |
| Wang, Y. | 2022 | Improvement of *Sphaeropsis* Shoot Blight Disease Resistance by Applying the Ectomycorrhizal Fungus *Hymenochaete* sp. Rl and Mycorrhizal Helper Bacterium *Bacillus pumilus* HR10 to *Pinus thunbergii* |
| Chen, H. | 2022 | Effects of *Suillus luteus* and *S. bovinus* on the physiological response and nutrient absorption of *Pinus massoniana* seedlings under phosphorus deficiency |
| Repac, I. | 2022 | Ectomycorrhiza-hydrogel additive enhanced growth of Norway spruce seedlings in a nutrient-poorpeat substrate |
| Wang, J. | 2021 | Effects of ectomycorrhizal fungi (*Suillus variegatus*) on the growth, hydraulic function, and non-structural carbohydrates of *Pinus tabulaeformis* under drought stress |
| Castro, D. | 2021 | Effects of early, small-scale nitrogen addition on germination and early growth of scots pine (*Pinus sylvestris*) seedlings and on the recruitment of the root-associated fungal community |
| Madejon, P. | 2021 | Plant response to mycorrhizal inoculation and amendments on a contaminated soil |
| Chu, H. | 2021 | Inoculation With Ectomycorrhizal Fungi and Dark Septate Endophytes Contributes to the Resistance of *Pinus* spp. to Pine Wilt Disease |
| Taniguchi, | 2021 | Plantation soil inoculation combined with straw checkerboard barriers enhances ectomycorrhizal colonization and subsequent growth of nursery grown *Pinus tabulaeformis* seedlings in a dryland |
| Li, M. | 2021 | Role of *Suillus placidus* in improving the drought tolerance of masson pine (*Pinus massoniana* lamb.) seedlings |
| Peng, L. | 2021 | Soil phosphorus mobilization and utilization by *Suillus* isolates and *Suillus*-mycorrhized pine plants |
| Lorenc, | 2021 | Influence of mycorrhizal preparation on seedling growth and *Armillaria* infestation |
| Liu, H. | 2020 | Identification of candidate genes conferring tolerance to aluminum stress in *Pinus massoniana* inoculated with ectomycorrhizal fungus |
| Gehring, C. | 2020 | Ectomycorrhizal and Dark Septate Fungal Associations of Pinyon Pine Are Differentially Affected by Experimental Drought and Warming |
| Verma, B. | 2020 | Biochar augmentation improves ectomycorrhizal colonisation, plant growth and soil fertility |
| Zhang, X. | 2020 | Colonization by *Tuber melanosporum* and *Tuber indicum* affects the growth of *Pinus armandii* and phoD alkaline phosphatase encoding bacterial community in the rhizosphere |
| Hewitt, R.E. | 2020 | Limited overall impacts of ectomycorrhizal inoculation on recruitment of boreal trees into Arctic tundra following wildfire belie species-specific responses |
| Li, X. | 2020 | Root-tip cutting and uniconazole treatment improve the colonization rate of *Tuber indicum* on *Pinus armandii* seedlings in the greenhouse |
| Gallart, M | 2018 | Host Genotype and Nitrogen Form Shape the Root Microbiome of *Pinus radiata* |
| Zhang, H. | 2017 | Prior contact of *Pinus tabulaeformis* with ectomycorrhizal fungi increases plant growth and survival from damping-off |
| Hazard, C. | 2017 | Strain identity of the ectomycorrhizal fungus *Laccaria bicolor* is more important than richness in regulating plant and fungal performance under nutrient rich conditions |
| Rudawska, M | 2017 | Forest litter amendment during nursery stage influence field performance and ectomycorrhizal community of Scots pine (*Pinus sylvestris* L.) seedlings outplanted on four different sites |
| Hazard, C. | 2017 | Contrasting effects of intra- and interspecific identity and richness of ectomycorrhizal fungi on host plants, nutrient retention and multifunctionality |
| Nakashima, H. | 2016 | Effect of ectomycorrhizal composition on survival and growth of *Pinus thunbergii* seedlings varying in resistance to the pine wilt nematode |
| Yin, D. | 2016 | Synergistic effects between *Suilllus luteus* and *Trichoderma virens* on growth of Korean spruce seedlings and drought resistance of Scotch pine seedlings |
| BarroetaveÃa, C | 2016 | Field performance of *Pinus ponderosa* seedlings inoculated with ectomycorrhizal fungi planted in steppe-grasslands of andean patagonia, Argentina |

| | | |
|---|---|---|
| Vaario, L.-M. | 2015 | Variation among matsutake ectomycorrhizae in four clones of *Pinus sylvestris* |
| Franco, A.R. | 2015 | Effect of benfluralin on *Pinus pinea* seedlings mycorrhized with *Pisolithus tinctorius* and *Suillus bellinii* - Study of plant antioxidant response |
| Klavina, D. | 2015 | Seed provenance impacts growth and ectomycorrhizal colonisation of *Picea abies* seedlings |
| Repac • , I. | 2015 | Effects of substrate and ectomycorrhizal inoculation on the development of two-years-old container-grown Norway spruce (*Picea abies* Karst.) seedlings |
| Sousa, N.R. | 2014 | A genotype dependent-response to cadmium contamination in soil is displayed by *Pinus pinaster* in symbiosis with different mycorrhizal fungi |
| Itoo, Z.A. | 2014 | Influence of ectomycorrhizal inoculation on *Pinus wallichiana* and *Cedrus deodara* seedlings under nursery conditions |
| Onwuchekwa, N.E. | 2014 | Growth of mycorrhizal jack pine (*Pinus banksiana*) and white spruce (*Picea glauca*) seedlings planted in oil sands reclaimed areas |
| Dominguez, J.A. | 2013 | Short communication. Physiological effects of *Rhizopogon roseolus* on *Pinus halepensis* seedlings |
| Sanchez-Zabala, J. | 2013 | Physiological aspects underlying the improved outplanting performance of *Pinus pinaster* Ait. seedlings associated with ectomycorrhizal inoculation |
| Lazarevia, J.. | 2012 | Mycorrhization of containerized *Pinus nigra* seedlings with *Suillus granulatus* under open field conditions |
| Ragonezi, C. | 2012 | *Pisolithus Arhizus* (Scop.) rauschert improves growth of adventitious roots and acclimatization of In vitro regenerated plantlets of *Pinus pinea* L. |
| Sousa, N.R. | 2012 | Mycorrhizal symbiosis affected by different genotypes of *Pinus pinaster* |
| Otgonsuren, B. | 2012 | *Pinus sylvestris* can form ectomycorrhiza with *Phialocephala fortinii* |
| Dominguez, J.A. | 2012 | The combined effects of *Pseudomonas fluorescens* and *Tuber melanosporum* on the quality of *Pinus halepensis* seedlings |
| Oliveira, R.S. | 2012 | Combined use of *Pinus pinaster* plus and inoculation with selected ectomycorrhizal fungi as an ecotechnology to improve plant performance |
| Sousa, N.R. | 2012 | Ectomycorrhizal fungi as an alternative to the use of chemical fertilisers in nursery production of Pinus pinaster |
| Sousa, N.R. | 2012 | The effect of ectomycorrhizal fungi forming symbiosis with *Pinus pinaster* seedlings exposed to cadmium |
| Sousa, N.R. | 2011 | Reforestation of burned stands: The effect of ectomycorrhizal fungi on *Pinus pinaster* establishment |
| Buscardo, E. | 2011 | Common environmental factors explain both ectomycorrhizal species diversity and pine regeneration variability in a post-fire Mediterranean forest |
| Wagg, C. | 2011 | Soil microbial communities from an elevational cline differ in their effect on conifer seedling growth |
| Koele, N. | 2011 | Differences in growth and nutrient uptake from a coarse-soil substrate by ectomycorrhizal- and fungicide-treated *Picea abies* seedlings |
| Repac, I. | 2011 | Testing of microbial additives in the rooting of Norway spruce (*Picea abies* [L.] Karst.) stem cuttings |
| Sarjala, T. | 2010 | Mycorrhiza formation is not needed for early growth induction and growth-related changes in polyamines in Scots pine seedlings in vitro |
| Vaario, L.-M | 2010 | Ectomycorrhization of *Tricholoma matsutake* and two major conifers in Finland-an assessment of in vitro mycorrhiza formation |
| Leski, T. | 2010 | Ectomycorrhizal community structure of different genotypes of Scots pine under forest nursery conditions |
| Holusa, J. | 2009 | Impact of mycorrhizal inoculation on spruce seedling: Comparisons of a 5-year experiment in forests infested by honey fungus |
| Karst, J. | 2009 | Ectomycorrhizal colonization and intraspecific variation in growth responses of lodgepole pine |
| CorrÃ, A. | 2008 | Response of plants to ectomycorrhizae in N-limited conditions: Which factors determine its variation? |
| Zhu, J.-J | 2008 | The role of ectomycorrhizal fungi in alleviating pine decline in semiarid sandy soil of northern China: An experimental approach |
| Jha, B.N. | 2008 | Effect of ectomycorrhizal development on growth in pine seedlings |
| Repac • , I. | 2007 | Ectomycorrhiza formation and growth of *Picea abies* seedlings inoculated with alginate-bead fungal inoculum in peat and bark compost substrates |
| Rincoln, A. | 2007 | Inoculation of *Pinus halepensis* Mill. with selected ectomycorrhizal fungi improves seedling establishment 2 years after planting in a degraded gypsum soil |
| KozdrÃj, J. | 2007 | Mycorrhizal fungi and ectomycorrhiza associated bacteria isolated from an industrial desert soil protect pine seedlings against Cd(II) impact |
| Dominguez-Nunez, JA | 2013 | Effects of *Pseudomonas fluorescens* on the Water Parameters of Mycorrhizal and Non-Mycorrhizal Seedlings of *Pinus halepensis* |

| | | |
|---|---|---|
| Probanza, A | 2001 | Effects of inoculation with PGPR *Bacillus* and *Pisolithus tinctorius* on *Pinus pinea* L. growth, bacterial rhizosphere colonization, and mycorrhizal infection |
| Rincon, A. | 2005 | Effects of ectomycorrhizal inoculation and the type of substrate on mycorrhization, growth and nutrition of containerised *Pinus pinea* L. seedlings produced in a commercial nursery |
| Choi, D.S. | 2005 | Effect of ectomycorrhizal infection on growth and photosynthetic characteristics of *Pinus densiflora* seedlings grown under elevated CO 2 concentrations |
| Kim, C.-G. and Power, S.A. and Bell, J.N.B. | 2004 | Response of *Pinus sylvestris* seedlings to cadmium and mycorrhizal colonisation |
| Dunabeitia, M.K. | 2004 | Differential responses of three fungal species to environmental factors and their role in the mycorrhization of *Pinus radiata* D. Don |
| Mari, S. | 2003 | Genetic variation in nitrogen uptake and growth in mycorrhizal and nonmycorrhizal Picea abies (L.) karst. seedlings |
| van Scholl. | 2005 | Effect of ectomycorrhizal colonization on the uptake of Ca, Mg and Al by Pinus sylvestris under aluminium toxicity |
| Guerin-Laguette. | 2003 | The ectomycorrhizal symbiosis between *Lactarius deliciosus* and *Pinus sylvestris* in forest soil samples: Symbiotic efficiency and development on roots of a rDNA internal transcribed spacer-selected isolate of *L. deliciosus* |
| Ahonen-Jonnarth, | 2001 | Effects of evated nickel and cadmium concentrations on growth and nutrient uptake of mycorrhizal and non-mycorrhizal *Pinus sylvestris* seedlings |
| Hartley, J. | 1999 | The effects of multiple metal contamination on ectomycorrhizal Scots pine (*Pinus sylvestris*) seedlings |
| Chakravarty, P. | 1999 | Integrated control of *Fusarium* damping-off in conifer seedlings |
| Hartley, J. | 1999 | Cross-colonization of scots pine (*Pinus sylvestris*) seedlings by the ectomycorrhizal fungus *Paxillus involutus* in the presence of inhibitory levels of Cd and Zn |
| Cram, M.M. | 1999 | Successful reforestation of south carolina sandhills is not influenced by seedling inoculation with *Pisolithus tinctorius* in the nursery |
| Manninen, A.-M. | 1998 | Susceptibility of ectomycorrhizal and nonmycorrhizal Scots pine (*Pinus sylvestris*) seedlings to a generalist insect herbivore**, Lygus rugulipennis**, at two nitrogen availability levels |
| Scagel, C.F. | 1998 | Relationships between differential in vitro Indole-Acetic Acid or ethylene production capacity by ectomycorrhizal fungi and conifer seedling responses in symbiosis |
| Scagel, C.F. | 1998 | Influence of ectomycorrhizal fungal inoculation on growth and root IAA concentrations of transplanted conifers |
| Gehring, C.A. | 1997 | Three-way interactions among ectomycorrhizal mutualists, scale insects, and resistant and susceptible pinyon pines |
| Shaw, T.M. | 1995 | Interactions between ectomycorrhizal and saprotrophic fungi on agar and in association with seedlings of lodgepole pine (*Pinus contorta*) |
| BONELLO, P. | 1993 | Ozone effects on root • disease susceptibility and defence responses in mycorrhizal and non • mycorrhizal seedlings of Scots pine (*Pinus sylvestris* L.) |
| WILKINS, D.A. | 1989 | The effects of aluminium and *Paxillus involutus* Fr. on the growth of Norway spruce [*Picea abies* (L.) Karst.] |
| Berry, C.R. | 1977 | Growth of loblolly pine seedlings in strip mined kaolin spoil as influenced by sewage sludge |
| Chu, H.L. | 2019 | The Dark Septate Endophytes and Ectomycorrhizal Fungi Effect on *Pinus tabulaeformis* Carr. Seedling Growth and their Potential Effects to Pine Wilt Disease Resistance |
| Nadeau, M.B. | 2018 | Mycorrhizae and Rhizobacteria on Precambrian Rocky Gold Mine Tailings: I. Mine-Adapted Symbionts Promote White Spruce Health and Growth |
| Nowak, J. | 2006 | Loblolly pine and slash pine responses to acute aluminum and acid exposures |
| Nieminen, J.K. | 2001 | Influence of carbon and nutrient additions on a decomposer food chain and the growth of pine seedlings in microcosms |
| Piculell, B.J. | 2018 | Genetically determined fungal pathogen tolerance and soil variation influence ectomycorrhizal traits of loblolly pine |

| | | |
|---|---|---|
| Menkis, A. | 2007 | Afforestation of abandoned farmland with conifer seedlings inoculated with three ectomycorrhizal fungi-impact on plant performance and ectomycorrhizal community |
| Jenkins, M.L. | 2018 | Scorched Earth: *Suillus* colonization of *Pinus albicaulis* seedlings planted in wildfire-impacted soil affects seedling biomass, foliar nutrient content, and isotope signatures |
| Kayama, M . | 2006 | Comparison of growth characteristics and tolerance to serpentine soil of three ectomycorrhizal spruce seedlings in northern Japan |
| SVENSON, S.E. | 1991 | Ectomycorrhizae and drought acclimation influence water relations and growth of loblolly-pine |
| Wen, Z.G. | 2019 | Distributions and Compositions of Brominated Diphenyl Ethers-209 in Pine Seedlings Inoculated with Ectomycorrhizal Fungi |
| Sun, Y.J . | 2020 | Effects of slippery jack (*Suillus luteus*) on the heavy metal accumulation and soil properties of masson's pine (*Pinus massoniana* lamb) in a mining area of china |
| Velmala, S.M. | 2018 | Ectomycorrhizal fungi increase the vitality of Norway spruce seedlings under the pressure of *Heterobasidion* root rot in vitro but may increase susceptibility to foliar necrotrophs |
| Niemi, K. | 2007 | Spermidine and the ectomycorrhizal fungus *Pisolithus tinctorius* synergistically induce maturation of Scots pine embryogenic cultures |
| Hwang, S.F. | 1995 | The effect of two ectomycorrhizal fungi, *Paxillus involutus* and *Suillus tomentosus*, and of *Bacillus subtilis* on *Fusarium* damping-off in jack pine seedlings |
| Wang, Y.H. | 2022 | Mycorrhiza helper bacterium *Bacillus pumilus* HR10 improves growth and nutritional status of *Pinus thunbergii* by promoting mycorrhizal proliferation |
| Mueller, R.C. | 2006 | Interactions between an above-ground plant parasite and below-ground ectomycorrhizal fungal communities on pinyon pine |
| Beck, J.L. | 2020 | Changes in soil fungal communities following anthropogenic disturbance are linked to decreased lodgepole pine seedling performance |
| Suarez, J.O. | 2018 | Effects of *Lactarius deliciosus* and *Rhizopogon roseolus* ectomycorrhyzal fungi on seeds and seedlings of Scots and stone pines inoculated with *Fusarium oxysporum* and Fusarium verticillioides |
| Machon, P. | 2006 | Influence of the ectomycorrhizal fungus *Laccaria laccata* on pre-emergence, post-emergence and late damping-off by *Fusarium moniliforme* and F-oxysporum on Scots pine seedlings |
| Niemi, K | 2007 | *Suillus variegatus* causes significant changes in the content of individual polyamines and flavonoids in Scots pine seedlings during mycorrhiza formation in vitro |
| Liiri, M | 2007 | Variable impacts of enchytraeid worms and ectomycorrhizal fungi on plant growth in raw humus soil treated with wood ash |
| Yin, DC | 2018 | Ectomycorrhizal fungus enhances drought tolerance of *Pinus sylvestris* var. mongolica seedlings and improves soil condition |
| Niemi, K . | 2002 | *Pisolithus tinctorius* promotes germination and forms mycorrhizal structures in Scots pine somatic embryos in vitro |
| Hartley-Whitaker, J. | 2000 | Sensitivity to Cd or Zn of host and symbiont of ectomycorrhizal *Pinus sylvestris* L. (Scots pine) seedlings |
| van Hees, | 2006 | The biogeochemical impact of ectomycorrhizal conifers on major soil elements (Al, Fe, K and Si) |
| Kipfer, T. | 2015 | Drought resistance of *Pinus sylvestris* seedlings conferred by plastic root architecture rather than ectomycorrhizal colonisation |
| Dominguez Nunez, J.A. | 2008 | The effect of Tuber melanosporum Vitt. mycorrhization on growth, nutrition, and water relations of *Quercus petraea Liebl.*, *Quercus faginea* Lamk., and *Pinus halepensis* Mill. seedlings |
| Nadeau, M.B. | 2018 | Mycorrhizae and Rhizobacteria on Precambrian Rocky Gold Mine Tailings: II. Mine-Adapted Symbionts Alleviate Soil Element Imbalance for a Better Nutritional Status of White Spruce Seedlings |
| Franco, A.R. | 2015 | Inoculation of *Pinus pinea* seedlings with *Pisolithus tinctorius* and *Suillus bellinii* promotes plant growth in benfluralin contaminated soil |
| Mueller, R.C. | 2019 | Legacy effects of tree mortality mediated by ectomycorrhizal fungal communities |
| Menkis, A. | 2011 | Mycorrhization, Establishment and Growth of Outplanted *Picea abies* Seedlings Produced under Different Cultivation Systems |

| | | |
|---|---|---|
| Kim, C.G. | 2004 | Effects of host plant exposure to cadmium on mycorrhizal infection and soluble carbohydrate levels of *Pinus sylvestris* seedlings |
| Tahara, C. | 2005 | Ectomycorrhizal association enhances Al tolerance by inducing citrate secretion in *Pinus densiflora* |
| Patterson, A. | 2019 | Common garden experiments disentangle plant genetic and environmental contributions to ectomycorrhizal fungal community structure |

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