Supplementary Materials

Supplement S1. Search information. Selection criteria. Literature included in the meta-analysis.

Search information for soil transfers:
We carried out a search for soil transfers using search terms similar than those in the biochar search: *(forest* OR tree* OR seedling* OR "woody plant*") AND ("soil inocul*" OR "soil add*")AND (restoration OR reclamation OR replanting) AND ("soil inocul*" OR "soil add*")*. This resulted in only 11 studies and not all abided by our selection criteria.

Selection criteria:
Studies focused on agricultural plants (such as *Prunus* spp. or *Malus* spp.) were excluded. Studies reporting only changes to soil (e.g., nutrient levels) were excluded. To reduce the heterogeneity of studies, we also excluded those based on other pyrolyzed wood products (e.g., wood ash, wood vinegar, and biochar pellets) and those studies focused on hearth or 'Terra Preta' soil, in which the charred material was burned decades ago, in indeterminate conditions. Some studies compared both biochar application and wood ash application to control, but in these cases we only extracted data related to biochar. When multiple levels of biochar application were present, we included data on the highest and lowest application rate. If studies examined multiple fertilization regimes, we used only data from the lowest fertilization application. Studies have to report biomass. There was only one study that reported height and stem diameter without reporting biomass; biomass can be estimated from these measurements but we decided to exclude this study in case the estimation might have biased the data.

Articles included in the analysis:

Aung, A. S.H. Han, W.B. Youn, L. Meng, M.S. Cho and B.B. Park. 2018. Biochar effects on the seedling quality of *Quercus serrata* and *Prunus sargentii* in a containerized production system. *Forest Science and Technology* 14: 112–118. https://doi.org/10.1080/21580103.2018.1471011

Budi, S.W., and L. Setyaningsih. 2013. Arbuscular mycorrhizal fungi and biochar improved early growth of Neem (*Melia azedarach* Linn.) seedling under Greenhouse conditions. *JMHT* 19: 103–110. https://doi.org/10.7226/jtfm.19.2.103

Cho, M.S., L. Meng, J.H. Song, S.H. Han, K. Bae, K. and B.B. Park. 2017. The effects of biochars on the growth of *Zelkova serrata* seedlings in a containerized seedling production system. *Forest Science and Technology* 13: 25–30. https://doi.org/10.1080/21580103.2017.1287778

de Farias, J., B.S. Marimon, L. de Carvalho Ramos Silva, F.A. Petter, F.R. Andrade, P.S. Morandi and B.H. Marimon-Junior. 2016. Survival and growth of native *Tachigali vulgaris* and exotic *Eucalyptus urophylla*×*Eucalyptus grandis* trees in degraded soils with biochar amendment in southern Amazonia. *Forest Ecology and Management* 368:173–182. https://doi.org/10.1016/j.foreco.2016.03.022

Dietrich, S.T. and M.D. MacKenzie M. D. 2018. Biochar affects aspen seedling growth and reclaimed soil properties in the Athabasca oil sands region. *Canadian Journal of Soil Science* 98: 519–530. https://doi.org/10.1139/cjss-2017-0113

Dietrich, S.T., M.D. MacKenzie, J.P. Battigelli and J.R. Enterina. 2017. Building a Better Soil for Upland Surface Mine Reclamation in Northern Alberta: Admixing Peat, Subsoil and Peat Biochar in a Greenhouse Study with Aspen. *Canadian Journal of Soil Science* CJSS-2017-0021. https://doi.org/10.1139/CJSS-2017-0021

Drake, J.A., T.R. Cavagnaro, S.C. Cunningham, W.R. Jackson and A.F. Patti. 2016. Does Biochar Improve Establishment of Tree Seedlings in Saline Sodic Soils? *Land Degradation & Development* 27:52–59. https://doi.org/10.1002/ldr.2374

Fagbenro, J.A., S.O. Oshunsanya and O.A. Onawumi. 2013. Effect of Saw Dust Biochar and NPK 15: 15: 15 Inorganic Fertilizer on *Moringa oleifera* Seedlings Grown in an Oxisol. *Agrosearch* 13: 57–68.

Kuttner, B.G. and S.C. Thomas. 2017. Interactive effects of biochar and an organic dust suppressant for revegetation and erosion control with herbaceous seed mixtures and willow cuttings: Biochar, erosion control, and revegetation. *Restoration Ecology* 25: 367–375. https://doi.org/10.1111/rec.12439

Laungani, R., K. Elgersma, K. McElligott, M. Juarez and T. Kuhfahl. 2016. Biochar amendment of grassland soil may promote woody encroachment by Eastern Red Cedar. *Journal of Soil Science and Plant Nutrition* 16: 941-954. https://doi.org/10.4067/S0718-95162016005000067

Lefebvre, D., F. Román-Dañobeytia, J. Soete, F. Cabanillas, R. Corvera, C. Ascorra, L.E. Fernández and M. Silman. 2019. Biochar Effects on Two Tropical Tree Species and Its Potential as a Tool for Reforestation. *Forests* 10: 678. https://doi.org/10.3390/f10080678

Lima, S.L., S. Tamiozzo, E.C. Palomino, F.A. Petter and B.H. Marimon-Junior. 2015. Interactions of Biochar and Organic Compound for Seedlings Production of *Magonia pubescens* A. St.-Hil. *Revista Árvore* 39: 655–661. https://doi.org/10.1590/0100-67622015000400007

Marjenah, M., K. Kiswanto, S. Purwanti and F.P.M. Sofyan 2016. The effect of biochar, cocopeat and saw dust compost on the growth of two dipterocarps seedlings. *Nusantara Bioscience* 8: 39–44. https://doi.org/10.13057/nusbiosci/n080108

Noyce, G., T. Jones, R. Fulthorpe and N. Basiliko. 2017. Phosphorus uptake and availability and short-term seedling growth in three Ontario soils amended with ash and biochar. *Canadian Journal of Soil Science* CJSS-2017-0007. https://doi.org/10.1139/CJSS-2017-0007

Pluchon, N., M.J. Gundale, M. Nilsson, P. Kardol and D.A. Wardle. 2014. Stimulation of boreal tree seedling growth by wood-derived charcoal: Effects of charcoal properties, seedling species and soil fertility. *Functional Ecology* 28: 766–775. https://doi.org/10.1111/1365-2435.12221

Reverchon, F., H. Yang, T.Y. Ho, G. Yan, J. Wang, Z. Xu, C. Cheng and D. Zhang, D. (2015). A preliminary assessment of the potential of using an acacia—Biochar system for spent mine site rehabilitation. *Environmental Science and Pollution Research* 22:2138–2144. https://doi.org/10.1007/s11356-014-3451-1

Scharenbroch, B.C., E.N Meza, M. Catania and K. Fite. 2013. Biochar and biosolids increase tree growth and improve soil quality for urban landscapes. *Journal of Environment Quality* 42: 1372. https://doi.org/10.2134/jeq2013.04.0124

Somerville, P.D., C. Farrell, P.B. May and S.J. Livesley. 2019. Tree water use strategies and soil type determine growth responses to biochar and compost organic amendments. *Soil and Tillage Research* 192: 12–21. https://doi.org/10.1016/j.still.2019.04.023

Table S1. Studies included in meta-analysis (N = 18). Format adapted from Thomas and Gale (2015). When pH of biochar was measured with CaCl2, we used the formula pH-H2O = 1.65 + (0.86*[pH-CaCl2]), as per Biederman and Harpole (2013). v/v: percentage per volume.

Biome	Country	Type	Duration	pH	Feedstock	Temp. (C)	Dosage	Soil transfer	N spp.	Reference
tropical	Brazil	field	3 years	5.8	native savanna species	200-500	2.5% v/v, 20% v/v	yes	2	de Farias et al. (2016)
boreal	Canada	pot	< 1 year	unknown	peat	500	10 MT/ha	yes	1	Dietrich and MacKenzie (2018)
boreal	Canada	pot	< 1 year	unknown	peat	500	10 MT/ha	yes	1	Dietrich et al. (2017)
temperate	Canada	pot, field	< 1 year	8.3	*Picea glauca* wood chips	350-450	5 t/ha, 20 t/ha	yes	1	Kuttner and Thomas (2016)
temperate	United States of America	field	< 1 year	6.7, 7.5	native and invasive grass (n = 2)	350	4.4 t/ha, 3.4 t/ha	no	1	Laungani et al. (2016)
tropical	Peru	nursery	< 1 year	9.906	*Bertholletia excelsa* husks	unknown	1.1 t/ha, 5.5 t/ha	yes	2	Lefebvre et al. (2019)
arid	Australia	pot	< 1 year	9.22	*Eucalyptus marginata*	700	37 t/ha, 74 t/ha	yes	1	Reverchon et al. (2015)
temperate	Australia	pot	< 1 year	4.9, 6.7	eucalypt hardwoods	500-580	20% v/v	no	2	Somerville et al. (2019)
boreal	Sweden	pot	< 1 year	6.25-7.42	various tree species (n = 9)	450	2.5 g/pot (3000 kg/ha)	yes	4	Pluchon et al. (2014)
temperate	Republic of Korea	pot	< 1 year	5.1-8.8	pine and oak woodchips, pine cones, crab shells (n = 5)	250	20% v/v	no	1	Cho et al. (2017)
tropical	Nigeria	nursery	< 1 year	8.1	saw dust	~350	5 t/ha, 20 t/ha	yes	1	Fagbenro et al. (2013)

tropical	Indonesia	pot	< 1 year	8.9	unknown	unknown	5% v/v, 15% v/v	yes	1	Budi and Setyaningsih (2013)
temperate	Australia	pot	< 1 year	7.4	*Acacia pycnantha*	550	5 Mg/ha	no	2	Drake et al. (2016)
tropical	Indonesia	nursery	< 1 year	unknown	rice husk	unknown	20% v/v	no	2	Marjenah et al. (2016)
boreal	Canada	pot	< 1 year	7.584	maple saw dust	450	5 t/ha, 50 t/ha	yes	2	Noyce et al. (2017)
temperate	Republic of Korea	pot	< 1 year	unknown	oak, bamboo (n = 3)	700-1200	40% v/v	no	2	Aung et al. (2018)
temperate	USA	pot	1.5 years	9.18	*Pinus* spp.	550-600	25 Mg/ha	yes	1	Scharenbroch et al. (2013)
tropical	Brazil	pot	< 1 year	6.638	native woody plants	200-500	20% v/v, 30% v/v	no	1	Lima et al. (2015)

Biederman LA, Harpole WS (2013) Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. GCB Bioenergy 5(2): 202–214. https://doi.org/10.1111/gcbb.12037

Thomas SC, Gale N (2015) Biochar and forest restoration: A review and meta-analysis of tree growth responses. New Forests 46(5): 931–946 https://doi.org/10.1007/s11056-015-9491-7

Supplement S2. Analysis code for OpenBugs 3.2.3. Meta-analysis

```
#Effect size calculation

model{


for(i in 1:171){
model{
tauC[i]<-N[i]/(sdC[i]*sdC[i]) # calculating precision from reported variance
tauT[i]<-N[i]/(sdT[i]*sdT[i])  # and weighing sample size

C[i]~dnorm(meancon[i],tauC[i])C(0,) #limiting biomass to positive values
T[i]~dnorm(meantreat[i],tauT[i])C(0,) #limiting biomass to positive values

ES[i]<-log(T[i]/C[i])

}

}#end
```

```
#Analysis of ES by genus


model{


for(i in 1:171){

#missing SD were estimated as latent variables with mean 1.39, largest SD found
in the data
ESSD[i]~dnorm(1.39,1)C(0,)


EStau[i]<-1/(Essd[i]*Essd[i])

ES[i]~dnorm(ESG[genus[i]],EStau[i])

}


tau<-1/var

var~dunif(0,100)

}

for(g in 1:21){ESgenus[g]~dnorm(ESoverall,tau)}

ESoverall~dnorm(0,0.0001)  #overall


}#end


#initials


list(var = 1, ESoverall = 0)
```

Supplement S3. Field experiment specifics.

Table S2. Seed sources for field experiment (2018-2019).

Year	Collector	Location
2018	Sheffield Seed Co.	Pennsylvania
2018	Wildtype	Michigan
2019	Wildtype	Michigan

Table S3. Biochar properties (Wakefield Biochar, 2017).

Attribute	
Pyrolysis temperature	500
Ash (%)	2.22
Moisture (%)	54.44
pH	7.4
Elemental composition	
Bulk density (g/cm -3)	0.48
Total Carbon	40
Nitrogen (% wt)	0.27
Total Phosphate (mg/kg)	2.06
Potassium (mg/kg)	280
Sulfur (% wt)	0.014
Hydrogen	0.18
Oxygen (% wt)	2.77
Calcium (mg/kg)	1881
Copper (mg/kg)	2.45
Iron (mg/kg)	271
Magnesium (mg/kg)	558
Manganese (mg/kg)	107
Zinc	2.09
Particle Size <0.5 mm (%)	22.4
Particle Size <1 mm (%)	70.1
Particle Size <2 mm (%)	93.9

Supplement S4. Model code for OpenBugs 3.2.3. Field experiment.

#Survival

```
model{

for(i in 1:648){

sur[i]~dbern(p[i])

logit(p0[i])<-alpha[treat[i]]+beta*PheightS[i]+LRE[location[i]] #planted
height standardized

}

#prior
for(i in 1:4){ alpha [i]~dnorm(0,0.0001)

survp[i]<-exp(alpha [i])/(1+exp(alpha [i])) #predicted survival at average
planted height

}
beta~dnorm(0,0.0001)
for(i in 1:9){LRE[i]~dnorm(0,tau)}

tau~dgamma(0.001,0.001)
var<-1/tau


} #end model

#initials
list( tau =1, alpha =c(0,0,0,0), beta = 0   )
```

#Biomass

```
model{

for(i in 1:55){

biomass[i]~dlnorm(B[i],tau[1])

B[i]<-alpha[treat[i]]+beta*Pheights[i]+SRE[site[i]]

}

#priors
for(i in 1:2){
tau[i]~dgamma(0.001,0.001)
var[i]<-1/tau[i]
}

for(i in 1:4){alpha[i]~dnorm(0,0.0001)
}
```

```
for(i in 1:3){SRE[i]~dnorm(0,tau[2])}

beta~dnorm(0,0.0001)

} #end model

#initials
list(tau = c(1,1), alpha = c(1,1,1,1), beta = 0 )
```

Supplement S5. Parameter values field experiment.

Table S4. Survival model parameters (α), posterior mean SD and 95%CI. C: control, BC: biochar, SI: soil inoculation, SB: soil inoculation and biochar.

	Mean	**St. Dev.**	**95% CI**	
αC	-3.13	0.426	-4.047	-2.382
αBC	-2.275	0.2986	-2.887	-1.701
αSI	-2.085	0.3091	-2.744	-1.511
αSB	-2.901	0.3916	-3.713	-2.21
β initial plant height	0.2243	0.1493	-0.06934	0.5216
$\sigma^2_{\text{location random effects}}$	0.2776	0.428	0.001197	1.353

Figure S1. Location random effects.

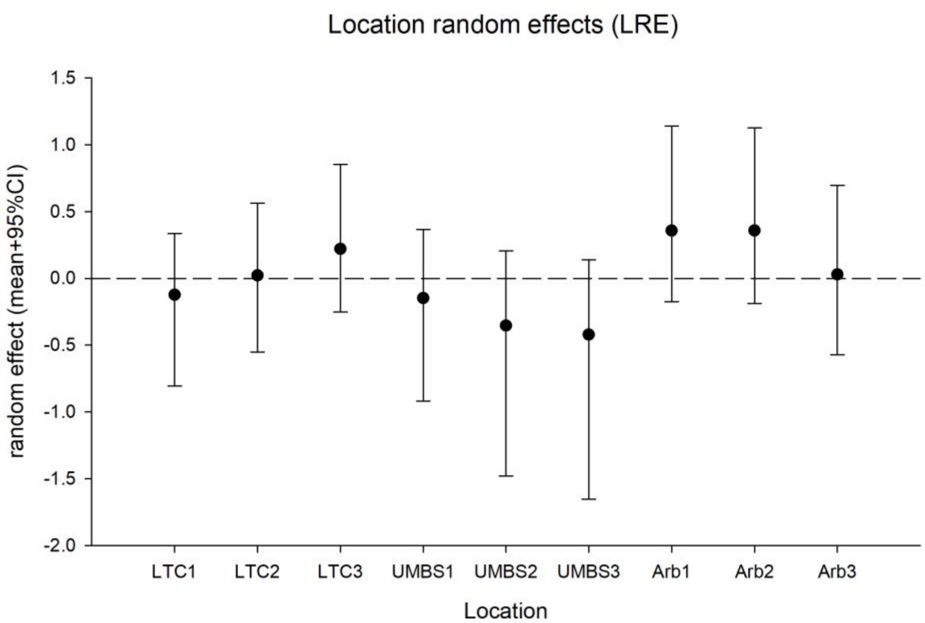

Table S5. Biomass model parameters (α), posterior mean, SD and 95%CI. C: control, BC: biochar, SI: soil inoculation, SB: soil inoculation and biochar.

	Mean	**St. Dev.**	**95% CI**	
α_C	0.433	0.2531	-0.07337	0.9361
α_{BC}	-0.1042	0.2008	-0.5061	0.2986

α_{SI}	0.2178	0.1966	-0.1921	0.609
α_{SB}	0.1672	0.2273	-0.2911	0.617
β initial plant height	0.1267	0.2194	-0.3096	0.5459
σ^2 overall	0.1927	0.007786	0.001224	0.4655
σ^2 site random effects	0.1663	0.007917	0.001137	0.4572

Figure S2. Site random effects.