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Founded at Unitec Institute of Technology in 2017.

Cover photo: Josie Galbraith.



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# Sarah Killick and Dan Blanchon



Some like it hot, but moth plant does not: The effect of commercia composting on moth plant (*Araujia hortorum*) seed viability by S. A. Killick and D. J. Blanchon, is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

This publication may be cited as: Killick, S. A., & Blanchon, D. J. (2018). Some like it hot, but moth plant does not: The effect of commercial composting on moth plant (*Araujia hortorum*) seed viability. *Perspectives in Biosecurity, 3*, pp. 27–37.

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ISSN 2538-0125

# Some like it hot, but moth plant does not: The effect of commercial composting on moth plant (*Araujia hortorum*) seed viability

## Sarah Killick and Dan Blanchon

# Abstract

Invasive plants threaten native biodiversity and ecosystem structure and function. Although the removal of invasive plant material is important for the conservation of native plant communities, the disposal of live seeds and propagative material can assist the spread of the invader. Commercial-scale composting windrows can reach temperatures sufficient to render weed seeds unviable, but research has shown that results vary intraspecifically. Here we examine the effects of commercial composting on the viability of the invasive vine moth plant (*Araujia hortorum*). Moth plant seeds were subject to preliminary viability tests to evaluate background viability and to allow post-composting comparison. Mature pods were then buried in a commercial composting windrow for 33 to 99 days, and assessed for viability by tetrazolium assay and germination trials. We further examined the minimum temperature and exposure time required to kill seeds using incubation and water-bath experiments. Background seed viability was estimated at 99%. After composting in a windrow with a mean temperature of 59°C, seeds were no longer viable. Exposure to temperatures of at least 55°C was lethal to hydrated moth plant seeds in laboratory experiments; however, dry-incubated seeds were substantially more resilient. Overall the findings of this study suggest that large-scale composting windrows maintained above 55°C are an effective and reliable method for the disposal of moth plant pods.

# Introduction

Invasive plants are a major threat to native biodiversity (van der Wal et al., 2008; Wardle & Peltzer, 2017), especially on islands and isolated habitats where native taxa are less resilient to change (Sala et al., 2000). Invasive plant establishment can affect plant community composition and structure, native animal populations, soil characteristics and fire regimes (Brooks et al., 2011; Pyšek et al., 2012). These changes are typically difficult to reverse and increase ecosystem vulnerability to further invasion, creating a positive-feedback cycle (Gaertner et al., 2014).

Inappropriate disposal of invasive plant material in garden and other green waste is a key human-mediated dispersal mechanism (Gill & Williams, 1996; McWilliam, Eagles, Seasons, & Brown, 2010). Dumped green waste can contain whole plants, plant fragments and seeds

(Esler, 1988), all of which can establish along the edge of forests and wetlands (Sullivan, Timmins, & Williams, 2005; Foxcroft, Richardson, & Wilson, 2007; McWilliam et al., 2010). However, to effectively dispose of pest plants from ecological restoration sites, parks and residential gardens, it is necessary to have somewhere for the plant material and propagules to be contained and ideally destroyed. Burial nearby or transport to a landfill for deep burial are common practices (Kollmann, Brink-Jensen, Frandsen, & Hansen, 2011; Hansford, 2015), but with both of these methods there is a risk of the plant material being disturbed and spread to form new invasion sites (Kollmann, et al., 2011; Plaza, Speziale, & Lambertucci, 2018), or spread during transport (Gill, Graham, Cross, & Taylor, 2018).

Composting provides an attractive alternative to landfill disposal. In compost windrows, heat-tolerant microbes break down organic matter and release heat as a metabolic by-product. The high temperatures



**Figure 1.** Dehisced moth plant pod showing seeds.

and microbial activity transform green waste into a commercially tradeable garden medium. Windrows maintained at 55-60°C are lethal to most seeds and propagative material (Grundy, Green, & Lennartsson, 1998; Meier, Waliczek, & Abbott, 2014), allowing some weeds to be composted without risk of further spread in contaminated compost. However, responses vary greatly interspecifically; for example, *Setaria faberi* R.A.W.Herrm. seeds are rendered unviable in compost at ≤ 45°C (Eghball & Lesoing, 2000), whereas the minimum lethal temperature for *Polygonum scabrum* Moench is 66.3°C (Larney & Blackshaw, 2003). In another study, water hyacinth (*Eichhornia crassipes* (Mart.) Solms) seeds retained 100% viability after 6.5 months at 40-57°C (Pérez et al., 2015).

Here, we investigate the response of moth plant (*Araujia hortorum* E.Fourn.) to composting conditions. Moth plant is a perennial climbing vine native to Southeast America (Coombs & Peter, 2010), introduced to New Zealand as an ornamental in the 1880s (Webb,

Sykes, & Garnock-Jones, 1988). Moth plant has become fully naturalised in the North Island (Hill & Gourlay, 2011), and is now listed on the National Pest Plant Accord (NPPA) as an Unwanted Organism (Department of Conservation, 2001; NPPA 2010). In its exotic range, moth plant is ecologically harmful: the vine is known to climb and smother native vegetation (Environmental Protection Authority, 2015; Hill & Gourlay, 2011), and the abundant trumpet-shape flowers trap and kill pollinating invertebrates (Coombs & Peter, 2010). Moth plant produces a large number of windborne seeds (Elliott et al., 2009) (Figure 1), which are toxic to birdlife (Hart, 1940). Viability analysis of a closely related moth plant in Australia (Araujia sericifera Brot.) suggests very high (99.5%) seed viability (Vivian-Smith & Panetta, 2005). The purpose of this study is to determine whether moth plant seed viability is eliminated under temperatures experienced in a large-scale compost windrow, and to investigate the value of commercial composting as a disposal method for this weed.



Figure 2. Windrow at Living Earth.

# **Methods**

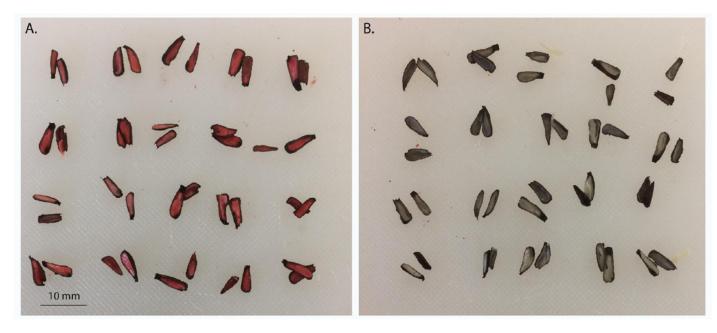
Mature Araujia hortorum fruit were collected from a minimum of 18 plants at Mount Albert (36°53'03"S, 174°42'56"E), Henderson (36°52'27"S, 174°37'40"E) and Mangere (36°58'10"S, 174°47'37"E) in Auckland during May 2016 for the compost treatment trial and in August 2018 for the *ex-situ* laboratory trials. Background viability levels were estimated using a 1% 2,3,5-triphenyltetrazolium chloride (TTC) assay as described by Baskin and Baskin (2001).

# Compost windrow experiment

This trial was conducted at Living Earth composting facility on Puketutu Island, Auckland (36°58'07"S, 174°44'57"E), from July to October, 2016. Windrows measuring 100-150 m in length were constructed with a variety of plant matter ('greenwaste'), including grass

clippings, small branches, leaves and shrubs. The windrows were regularly monitored for temperature, moisture content and oxygen content during the 100-day composting process, and turned when necessary to maintain temperatures over 55°C.

Breathable mesh bags containing 15 mature whole fruit were buried shallowly (c. 30 cm) in a newly formed compost windrow using methods similar to Tompkins, Chaw and Abiola (1998) and Van Rossum & Renz (2015) (Figure 2). To measure viability loss over this process, bags were retrieved from the windrow at 33, 6, and 99 days from windrow formation. Upon retrieval, 200 seeds were assayed for viability using a 1% TTC assay. The remaining seed material was sown into seed-raising mix and maintained at 20°C under growth lights (CFL 150W 6500K blue bulbs) to monitor germination success, determined by cotyledon emergence.



**Figure 3.** Results of tetrazolium trial: (A) Moth plant seeds after one hour of incubation at 45°C, (B) moth plant seeds after four hours of incubation at 55°C. Viable seeds are stained red.

## Seed thermal tolerance

In a follow-up experiment, the minimum lethal exposure time to temperatures recorded in the compost windrow was assessed under controlled laboratory conditions. Seeds were removed from their pods prior to the heat treatment due to equipment size limitations. To test whether the wall thickness of whole pods, as used in the compost windrow experiment, protects seeds from thermal damage, whole fruit were submerged in 61.5°C (±.1°) water for one hour. Upon retrieval, internal temperature was immediately recorded using a probe-style digital thermometer. Individual fruit length, diameter and thickness was measured, and compared with internal temperature readings. Before analysis, temperature data were assessed for normality with a Shapiro-Wilk test. The relationship between fruit size and the internal fruit temperature was assessed by Pearson correlation.

Rate of seed viability loss under moist or dry conditions was assessed with an incubation experiment. Moth plant seeds were placed in glass beakers, either alone or with moist potting mix, and covered with aluminium foil to prevent moisture escape. The seeds were then incubated at the mean temperature recorded in the windrow experiment (59°C) for up to five hours, with one beaker of each treatment type retrieved every 30 minutes. Seeds were then tested for viability with a TTC assay. A Pearson's correlation test was computed for dry and hydrated seeds to estimate and compare the strength of relationship between seed viability and

incubation time under both treatments.

Seed tolerance to lower temperatures (40-55°C) was assessed to estimate minimum lethal temperature. Watertight bags containing twenty A. hortorum seeds in moist potting mix were submerged in water baths, rather than an incubator, to allow for four different temperatures to be tested simultaneously. One bag was removed from each water bath per hour for five hours. Following removal, seeds were assessed for viability using a TTC assay. The relationship between seed viability, temperature and time spent in the treatment was estimated with a two-way ANOVA, and single relationships were measured with a Pearson productmoment correlation test.

All statistical analyses were undertaken using R version 3.4.1 (R Development Team, 2017).

# Results

# **Background seed viability**

Fresh A. hortorum seed viability was very high (99%, n = 250); all non-viable seeds lacked embryo and endosperm presence, and were likely aborted due to pollination failure.

# **Compost windrow experiment**

Onsite windrow monitoring conducted by Living Earth recorded temperature fluctuations between 40-70°C, with a mean temperature of 59°C (SEM = 0.85). Fruit

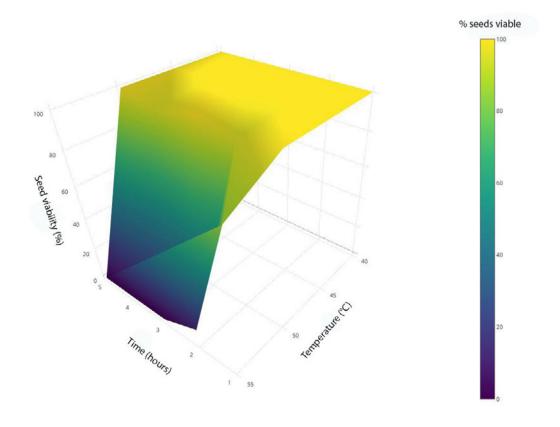


Figure 4. Moth plant seed viability (%) after exposure to 40-55°C temperatures over time.

retrieved at 33 days had disintegrated substantially. The seeds were found to be 3% viable by the tetrazolium assay, although none germinated. No viable or germinable seeds were identified after 66 or 99 days' composting.

# Seed thermal tolerance

Moth plant pods submersed in  $61.3-61.6^{\circ}$ C water had an average internal fruit temperature of  $59.3^{\circ}$ C after one hour. The temperature data were normally distributed (W=0.8), and no correlation was identified between internal temperature and fruit length (r=.227, p=.528), diameter (r=.231, p=.521) or thickness (r=.016, p=.965). It was therefore considered acceptable to continue the subsequent experiments on moth plant seeds removed from their pods.

The primary incubation trial subjected moth plant seeds to moist or dry incubation at 59°C for up to five hours. A moderate but statistically significant relationship between incubation time and seed viability was observed in the dry incubated seeds (r = -.68, p = .03); however, over 70% of dry seeds retained viability at

all test periods throughout the five-hour period. Seeds incubated in moist soil had a strong and significant negative relationship (r = -.86, p = .001), and had lost 90-100% viability within 2.5 hours. Seeds were consistently unviable after five hours of 59°C moist incubation.

The minimum lethal temperature was recorded at  $55^{\circ}\text{C}$  amongst seeds exposed to three or more hours in the water-bath experiment. Seed viability was moderately but inconsistently reduced in the  $50^{\circ}\text{C}$  treatment group (85% viability after two and four hours). No effect on viability was observed over the five-hour period from submersion in  $45^{\circ}\text{C}$ . A two-way ANOVA confirmed strong and significant coupling between temperature and seed viability (p = .001), but not between incubation time and seed viability (p = .334). Among the  $55^{\circ}\text{C}$  treatment group only, a Pearson correlation identified a strong but insignificant negative correlation between incubation time and seed viability (r = .7661, p = .131) (Figures 3 and 4).

# **Discussion**

In this study we examined the effect of commercial composting on the viability of moth plant seeds. Our in situ composting experiment demonstrated that commercial composting can effectively kill moth plant seeds over a one-to-two-month period. Under controlled laboratory conditions, the critical lethal temperature for hydrated moth plant seeds was identified as 55°C. Seeds exposed to the same temperatures without moisture remained viable, suggesting that ex situ heat-tolerance experiments also need to simulate compost moisture levels to accurately predict seed compostability. Although our laboratory trials used only seeds removed from the fruit, a small water-bath experiment indicated that moth plant fruit does not protect the seeds from external heat. This also suggests that entire pods may be composted safely without splitting.

To our knowledge, this study is the first to report the effects of commercial composting on moth plant seeds; however, our results are consistent with those reported for other weedy taxa. Eghball and Lesoing (2000) noted that composting systems that reach at least 60°C rapidly kill weed seeds of northern temperate herbaceous annuals (Nebraska, USA), and that lower temperatures can also be lethal under moist conditions, possible due to 'compost phytotoxins'. Larney & Blackshaw (2003) found that in windrows of barley straw and cattle manure, temperatures lethal to weed seeds (grass and broadleaf weeds from Alberta, Canada) ranged from 39° to > 60°C. Similarly Tompkins et al. (1998) found that a range of weed seeds of twelve herbaceous weeds from Alberta lost viability after four weeks at temperatures of 55-65°C in a composting system composed of cattle manure and bedding. Conversely, Thompson, Jones and Blair (1997) suggest that compost holding a temperature of 65°C is not likely to be an effective method of weed control as Rumex obtusifolius L. seeds retained viability after exposure to 65-81°C. However, as Grundy et al. (1998) argue, seed survival in the Thompson et al. (1997) trial may be attributable to a lack of moisture in the heat treatment. This was also evident in our study, where moist incubated seeds were substantially less resistant to high temperatures, likely due to the greater thermal conductivity of water relative to air (Hillel, 2004). Dahlquist, Prather and Stapleton (2010) found that in laboratory experiments on the seeds of barnyard grass, London rocket, common purslane, black nightshade, annual sowthistle and tumble pigweed, temperatures of 50°C were lethal, but the critical lethal temperature for

some of the species varied from 39-50°C. Meier et al. (2014) tested the effectiveness of composting on killing weed seeds of a range of aquatic/wetland plants in Texas (Giant reed, *Arundo donax* L.; hydrilla, *Hydrilla verticillata* (L. f.) Royle; water hyacinth, *Eichhornia crassipes*; water lettuce, *Pistia stratiotes* L.) and found that temperatures of 57.2°C were required to effectively kill all the plant material (including seeds). Similar results (57°C) for water hyacinth were reported by Montoya et al. (2013).

Windrow temperature can vary depending on the ambient temperature (Tirado & Michel, 2010), the size of the windrow (Tirado & Michel, 2010), the composition of the composting material (Van Herk et al., 2004), and whether the compost has recently been turned (Joshua, Macauley, & Mitchell, 1998). Joshua et al. (1998) found that in an Australian windrow composting system temperatures ranged from 17.6-72.8°C, but 55-70°C was more normal in the inner zone of the windrow, particularly after turning. Home composting systems can achieve 55°C, but there can be difficulty in reaching or maintaining this temperature due to their smaller mass, which is particularly problematic in colder climates (Arrigoni, Paladino, Garibaldi, & Laos, 2018). In Palmerston North, New Zealand, Mensah (2017) reported temperatures of up to 53°C in domestic composting systems, but observed that most compost units failed to exceed 45°C. This suggests that home composting systems may not be appropriate disposal solutions for moth plant pods without pre-treatment. One possible solution is to treat moth plant pods with immersion in hot water at above 55°C for four or more hours prior to composting.

For future studies, it is interesting to note the discrepancy between the TTC results and germination success rate during the compost windrow experiment. The TTC assay is widely used to estimate seed viability, and is accepted to be in close agreement with germination response (Soares, Elias, Gadotti, Garay, & Villela, 2016). The solution reacts with dehydrogenase enzymes found in respiring tissue to produce formazan, which stains the respiring tissues red. TTC solution has also been successfully used to detect bacterial activity (Moussa, Tayel, Al-Hassan, & Farouk, 2013), but is a poor detector of fungal colonies (Praveen-Kumar & Tarafdar, 2003). We suggest that our initial compost windrow TTC result was a false-positive result, as evidenced by the negative germination response, and offer bacterial activity as a potential explanation.

# **Conclusions**

Overall, this study demonstrates potential value in commercial-scale composting as a disposal tool for moth plant pods. It is important to note that the field portion of this study was conducted at a single large-scale composting facility, and the laboratory experiments were designed to measure seed viability loss over short periods of time. Further research is needed to determine whether longer exposure to temperatures below 55°C is fatal to moth plant seeds before generalised recommendations on the use of smaller-scale domestic composting systems at lower temperatures can be made. For this reason it is only recommended that moth plant pods are disposed of at compost facilities meeting the New Zealand Composting Standard (NZS4454), which requires windrow temperature to be maintained at  $\geq$ 55°C for  $\geq$ 15 days.

# **Acknowledgements**

The authors would like to thank the Auckland Council for funding this research, and the Society Totally Against Moth Plant (STAMP) for assisting in the collection of moth plant pods. We would also like to thank Bob Shao and Bruce Law from Living Earth, and Matt McClymont (United Institute of Technology) for technical assistance.

# References

Arrigoni, J. P., Paladino, G., Garibaldi, L. A., & Laos, F. (2018). Inside the small-scale composting of kitchen and garden wastes: Thermal performance and stratification effect in vertical compost bins. *Waste Management*, *76*, 284-293. doi.org/10.1016/j. wasman.2018.03.010.

Brooks, M. L., Antonio, C. M. D., Richardson, D. M., Grace, J. B., Keeley, E., Ditomaso, J. M., ... Keeley, J. O. N. E. (2011). Effects of invasive alien plants on fire regimes. *BioScience*, 54(7), 677-688.

Baskin, C. C., & Baskin, J. M. (2001). Seeds: Ecology, biogeography, and evolution of dormancy and germination. Cambridge, MA: Academic Press.

Coombs, G., & Peter, C. I. (2010). The invasive 'mothcatcher' (*Araujia sericifera* Brot.; Asclepiadoideae) co-opts native honeybees as its primary pollinator in South Africa. *Annals of Botany PLANTS*, 1-14. https://doi.org/10.1093/aobpla/plq021

Dahlquist, R. M., Prather, T. S., & Stapleton, J. J. (2007). Time and temperature requirements for weed seed thermal death. *Weed Science*, 55(6), 619-625.

Department of Conservation. (2001). Unwanted Organism – *Araujia hortorum*. Retrieved from https://www1.maf.govt.nz/uor/searchframe.htm

Eghball, B., & Lesoing, G. W. (2000). Viability of weed seeds following manure windrow composting. *Compost Science and Utilization*, 8(1), 46-53. https://doi.org/10.1080/1065657X.2000.10701749

Elliott, M. S., Massey, B., Cui, X., Hiebert, E., Charudattan, R., Waipara, N., & Hayes, L. (2009). Supplemental host range of *Araujia* mosaic virus, a potential biological control agent of moth plant in New Zealand. *Australasian Plant Pathology*, *38*, 603-607. https://doi.org/10.1071/AP09046

Environmental Protection Authority. (2015). Decision on Application APP202529 to import and release the moth plant rust fungus, *Puccinia araujiae*, as a biocontrol agent for the weed moth plant, *Araujia hortorum*. Wellington, New Zealand: Author.

Esler, A. E. (1988). The naturalisation of plants in urban Auckland, New Zealand, 4. The nature of the naturalised species. *New Zealand Journal of Botany*, *26*(3), 345-385. DOI:10.1080/0028825X.1988.10410640.

Foxcroft, L. C., Richardson, D. M., & Wilson, J. R. (2007). Ornamental plants as invasive aliens: Problems and solutions in Kruger National Park, South Africa. *Environmental Management*, 41, 32-51.

Gaertner, M., Biggs, R., Te Beest, M., Hui, C., Molofsky, J., & Richardson, D. M. (2014). Invasive plants as drivers of regime shifts: Identifying high priority invaders that alter feedback relationships. *Diversity and Distributions*, 20(7), 733-744.

Gill, A. M., & Williams, J. E. (1996). Fire regimes and biodiversity: The effects of fragmentation of southeastern Australian eucalypt forests by urbanisation, agriculture and pine plantations. *Forest Ecology and Management*, 85, 261-278.

Gill, N., Graham, S., Cross R., & Taylor E. (2018). Weed hygiene practices in rural industries and public land management: Variable knowledge, patchy implementation, inconsistent coordination. *Journal of Environmental Management, 223*, 140-149, http://dx.doi.org/10.1016/j.jenvman.2018.06.017

Grundy, A. C., Green, J. M., & Lennartsson, M. (1998). The effect of temperature on the viability of weed seeds in compost. *Compost Science and Utilization*, 6(3), 26-33. https://doi.org/10.1080/1065657X.1998.10701928

Hansford, M. (2015). Karroo thorn, *Vachellia* (Acacia) karroo: A State prohibited weed close to eradication. *Plant Protection Quarterly*, 30(2) 51-58.

Hart, L. (1940). Poisonous to fowls. Seeds of the plant Araujia serificifera. Agricultural Gazette of New South Wales, 51, 472-474.

Hill, R., & Gourlay, H. (2011). Ecology and pest status of moth plant, Araujia hortorum Fournier. Lincoln, New Zealand: Landcare.

Hillel, D. (2004). Introduction to environmental soil physics. Boston, MA: Elsevier Academic Press.

Joshua, R. S., Macauley, B. J., & Mitchell, H. J. (1998). Characterization of temperature and oxygen profiles in windrow processing systems. *Compost Science & Utilization*, 6(4), 15-28. DOI: 10.1080/1065657X.1998.10701937

Kollmann, J., Brink Jensen, K., Frandsen, S. I., & Hansen, M. K. (2011). Uprooting and burial of invasive alien plants: A new tool in coastal restoration? *Restoration Ecology*, 19, 371-378. DOI:10.1111/j.1526-100X.2009.00569.x

Larney, F. J., & Blackshaw, R. E. (2003). Weed seed viability in composted beef cattle feedlot manure. *Journal of Environmental Quality*, 32, 1105-1113. DOI:10.2134/jeq2003.1105

Mensah, S. (2017). Development and trial of a methodology for the quantification and evaluation of home composting in Palmerston North, New Zealand. Palmerston North, New Zealand: Massey University.

McWilliam, W., Eagles, P., Seasons, M., & Brown, R. (2010). Assessing the degradation effects of local residents on urban forests in Ontario, Canada. *Journal of Arboriculture*, *36*, 253.

Meier, E., Waliczek, T., & Abbott, M. (2014). Composting invasive plants in the Rio Grande River. *Invasive Plant Science and Management*, 7(3), 473-482. doi:10.1614/IPSM-D-13-00089.1

Montoya, J., Waliczek, T., & Abbott, M. (2013). Large scale composting as a means of managing water hyacinth (*Eichhornia crassipes*). *Invasive Plant Science and Management*, 6(2), 243-249. doi:10.1614/IPSM-D-12-00013.1

Moussa, S. H., Tayel, A. A., Al-Hassan, A. A., & Farouk, A. (2013). Tetrazolium/Formazan test as an efficient method to determine fungal chitosan antimicrobial activity. *Journal of Mycology*, 2013, 1-7. https://doi.org/10.1155/2013/753692

New Zealand National Plant Pest Accord (NPPA). (2010). Araujia hortorum. Retrieved from https://www.mpi.govt.nz

Pérez, E. A., Téllez, T. R., Maqueda, S. R., Linares, P. J. C., Pardo, F. M. V., Medina, P. L. R., ... Guzmán, J. M. S. (2015). Seed germination and risks of using the invasive plant *Eichhornia crassipes* (Mart.) Solms-Laub. (water hyacinth) for composting, ovine feeding and biogas production. *Acta Botanica Gallica*, 162(3), 203-214. https://doi.org/10.1080/12538078.2015.1056227

Plaza, P. I., Speziale, K. L. & Lambertucci, S. A. (2018). Rubbish dumps as invasive plant epicentres. *Biological Invasions*, 20, 2277-2283. https://doi.org/10.1007/s10530-018-1708-1

Praveen-Kumar, & Tarafdar, J. C. (2003). 2,3,5-Triphenyltetrazolium chloride (TTC) as electron acceptor of culturable soil bacteria, fungi and actinomycetes. *Biology and Fertility of Soils*, 38(3), 186-189. https://doi.org/10.1007/s00374-003-0600-y

Pyšek, P., Jarošík, V., Hulme, P. E., Pergl, J., Hejda, M., Schaffner, U., & Vilà, M. (2012). A global assessment of invasive plant impacts on resident species, communities and ecosystems: The interaction of impact measures, invading species' traits and environment. *Global Change Biology*, 18(5), 1725-1737. http://doi.org/10.1111/j.1365-2486.2011.02636.x

R Development Team. (2017). R [Computer software]. Retrieved from www.r-project.org

Sala, O. E., Iii, F. S. C., Armesto, J. J., Berlow, E., Dirzo, R., Huber-sanwald, E., ... Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. Science, 287, 1770-1774. http://doi.org/10.1126/science.287.5459.1770

Soares, V. N., Elias, S. G., Gadotti, G. I., Garay, A. E., & Villela, F. A. (2016). Can the Tetrazolium Test be used as an alternative to the Germination Test in determining seed viability of grass species? *Crop Science*, *56*(2), 707. DOI:10.2135/cropsci2015.06.0399

Sullivan, J. J., Timmins, S. M., Williams, P. A. (2005). Movement of exotic plants into coastal native forests from gardens in northern New Zealand. *New Zealand Journal of Ecology*, 29(1), 1-10.

Thompson, A. J., Jones, N. E., & Blair, A. M. (1997). The effect of temperature on viability of imbibed weed seeds. *Annals of Applied Biology*, 130, 123-134. doi:10.1111/j.1744-7348.1997.tb05788.x

Tirado, S. M., & Michel, F. C., Jr. (2010). Effects of Turning Frequency, Windrow Size and Season on the Production Of Dairy Manure/Sawdust Composts. *Compost Science & Utilization*, 18(2), 70-80. DOI: 10.1080/1065657X.2010.10736938

Tompkins, D. K., Chaw, D & Abiola, A. T. (1998). Effect of windrow composting on weed seed germination and viability. *Compost Science & Utilization, 6*(1), 30-34. DOI:10.1080/1065657X.1998.10701906

Van der Wal, R., Truscott, A. M., Pearce, I. S. K., Cole, L., Harris, M. P., & Wanless, S. (2008). Multiple anthropogenic changes cause biodiversity loss through plant invasion. *Global Change Biology*, 14(6), 1428-1436. http://doi.org/10.1111/j.1365-2486.2008.01576.x

Van Herk, F. H., McAllister, T. A., Cockwill, C. L., Guselle, N., Larney, F. J., Miller, J. J., & Olson, M. E. (2004). Inactivation of *Giardia* cysts and *Cryptosporidium* oocysts in beef feedlot manure by thermophilic windrow composting. *Compost Science & Utilization*, 12(3), 235-241. DOI:10.1080/1065657X.2004.10702188

Van Rossum, J., & Renz, M. J. (2015). Composting reduces seed viability of garlic mustard (*Alliaria petiolata*) and common buckthorn (*Rhamnus cathartica*). *Invasive Plant Science and Management*, 8(3), 284-291.

Vivian-Smith, G., & Panetta, F. D. (2005). Seedling recruitment, seed persistence and aspects of dispersal ecology of the invasive moth vine, *Araujia sericifera* (Asclepiadaceae). *Australian Journal of Botany*, 53(3), 225-230. http://doi.org/10.1071/BT04118

Wardle, D. A., & Peltzer, D. A. (2017). Impacts of invasive biota in forest ecosystems in an aboveground-belowground context. *Biological Invasions*, 19(11), 3301-3316. http://doi.org/10.1007/s10530-017-1372-x

Webb, C. J., Sykes, W. R., & Garnock-Jones, P. J. (1988). Flora of New Zealand, volume IV: Naturalised pteridophytes, gymnosperms, dicotyledons. Lincoln, New Zealand: Department of Scientific and Industrial Research.

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