The SheetPot: A Low-Cost, Innovative Nursery Container

Asryelle Mora, Audrey Rollo, Kyle McDowell, Nicholas Yos, Raul Andres Molina Benavides, and Camilo Mora

Director, Carbon Neutrality Challenge project, Honolulu, HI; Assistant, Carbon Neutrality Challenge project, Honolulu, HI; Student, Department of Electrical Engineering, University of Hawaii, Honolulu, HI; Assistant, Carbon Neutrality Challenge project, Honolulu, HI; Professor, Universidad Nacional de Colombia, Palmira, Valle, Colombia; Professor, Department of Geography and Environment, University of Hawaii, Honolulu, HI

Abstract

The containers in which seedlings are grown play an instrumental role in the economic and practical viability of large- and small-scale tree planting operations. The type of container (pot) can affect the seedling quality when there are issues with root deformation, poor oxygen exchange, and water logging. Issues of planting shock can also emerge depending on how easily seedlings can be removed from the pot. The economic feasibility of planting operations is also affected by container choice and the associated price, packaging volume, and shipping costs. This article describes a new pot system that overcomes these challenges using a rectangular plastic sheet that can be rolled into a cylindrical pot. The sheet can be designed with a diversity of hole configurations to facilitate air pruning, maximize soil oxygenation, and improve irrigation efficiency. The sheets can be stacked into thousands with very small additions to their packaging volume and shipping cost. The research team made the pot and the existing file open-access, including free access to the die cut, with the expectation that this system can be broadly used and improved over time.

Introduction

The mass planting of trees is a key undertaking to achieve several economic and societal goals from timber production, to cooling cities, to mitigation of greenhouse gases (Griscom et al. 2017). More than 75 percent of the world's land is under direct human pressures (Venter et al. 2016a, 2016b), and approximately 46 percent of trees on Earth have been cut down since the onset of human civilization (Crowther et al. 2015). Currently, approximately 2.5 billion ac (1 billion ha) are available for canopy restoration, are mostly free of conflict for other land uses, and have a potential to store more than 200 gigatonnes of carbon (Bastin et al. 2019). This area of land highlights not only the potential for forest growth, but the latent benefits for mitigating climate change, maintaining biodiversity, and educating society if such a massive endeavor is undertaken by citizens (Mora et al. 2020). While the planning of large-scale tree plantings is by no means simple, one element often emerges as a bottleneck: the container (pot) system.

For container-grown seedling production, the pot is one of the key components determining the feasibility of large-scale plantings. The container needs to provide suitable conditions for growing healthy seedlings to maximize long-term tree survival after planting, while also being affordable as to allow its use at scale. Commercial seedling containers address some, but rarely all, of the potential functional and economic shortcomings of container-grown seedling production. Staff and volunteers with the Carbon Neutrality Challenge developed a new pot system that overcomes numerous challenges associated with seedling containers. The "SheetPot" is made open-source and a mold is freely available; the motivation is to increase its use and inspire future improvements.

The Project

The SheetPot is one of several developments of a citizen science project called the Carbon Neutrality Challenge. This project aims to mitigate climate change by having individuals estimate their CO2 footprint and then plant enough trees to offset it. Early on, organizers carried out numerous events planting 100 trees at a time with 20 people at most. In the last event, participants planted 10,000 trees with

Figure 1. During a large-scale planting operation in November 2021, more than 2,000 volunteers planted 10,000 tree seedlings in 2 hours on the Gunstock Ranch in Hawaii. (Photo by Mike Hinchey, 2021)

2,000 volunteers in 2 hours (figure 1). The project's goals are twofold: first, educate people about how individual emissions add up to create the big problem known as climate change, thereby encouraging people to reduce their carbon footprint; and second, secure the workforce to plant trees at scale. Beyond outreach and education, civic engagement toward the goal of mass tree planting is not trivial. Assuming an average density of 1,000 trees per hectare suggests the need to plant 1 trillion trees in the estimated 1 billion hectares of land available on Earth. Such a mammoth task will require each of the 8 billion humans on the planet to plant about 120 trees during their lifetime, which is a much more manageable undertaking.

Container (Pot) Challenges

While simple in theory, this project has faced numerous challenges in practice, and a recurring one is the container, or pot, used for growing trees.

Challenge 1: Removing Seedlings from the Pot

The inexperience of most volunteers at the planting projects, many of whom are children, highlights the need to use pots from which the seedlings can be easily removed and then planted into their hole with the least amount of stress to the seedling; otherwise, planting shock can be considerable. Planting shock can result in wilting, delayed growth, and even mortality. However, removing seedlings from their pots can be challenging, even for the most experienced planters. Depending on the pot's wall angle and how compact the growing medium is, the planter will remove the seedling by squeezing the pot to soften/loosen the soil or by pulling the seedling, both of which add considerable stress to the seedling. When squeezing is exaggerated the soil detaches from the roots, exposing them completely, resulting in a significant shock to the seedling at the critical time of planting. In addition, the angle of the pot's wall affects the pot's volume and its ability to be stacked, both of which influence shipping costs, which can be significant for remote places.

Challenge 2: Spiraled Roots

Spiraled roots occur when the seedling's roots reach the sides and bottom of the pot. If the container has smooth sides, such as polybags (Haase et al. 2021) and many types of commercially available plastic pots, the roots will spiral. After planting, seedlings with this deformed root system will struggle to maximize water and nutrient uptake and can have long-term issues with growth and stability.

Challenge 3: Water Logging

Waterlogging, or perched water table, results from the interaction among water, growing medium, and pot dimensions. Shorter containers tend to have a greater proportion of saturated medium than taller containers (Landis et al. 2014). Waterlogging occurs due to the interacting forces of gravity pulling the water downward, cohesion sticking the water and substrate together, and capillarity pulling the water upward. Where those three forces even up, the water gets “perched.” Waterlogging causes the saturated layer to be constantly submerged in water, which makes the seedling prone to disease, causes poor soil oxygenation, and reduces nutrient uptake. Some tree species are particularly sensitive to having “wet feet” and fail to grow any roots in the waterlogged parts of the growing medium.

Challenge 4: Root and Shoot Mass

When planting seedlings in harsh landscapes or in situations where maintenance will be limited to none, it is critical that the seedlings have a large root mass so they can quickly acquire nutrients and water. Ideally, seedlings should also be tall enough to gain a competitive advantage against weeds. A target shoot-to-root ratio should be selected based on expected site conditions. For example, seedlings with a smaller shoot-to-root ratio perform better on droughty sites compared with those that have larger shoot-to-root ratios. Container size, along with nursery culturing regimes, dictate the final seedling size. Another critical consideration about the pot size (and resulting seedling size) is the space they occupy at the nursery, with smaller containers being more desirable as many more seedlings can be produced in the same nursery space. This calls for some flexibility in pot dimensions to maximize the tradeoff between quantity and quality of seedlings.

Challenge 5: Soil Oxygenation

Oxygen in the soil is critical to seedling nutrient uptake and can be strongly affected by the pot. No oxygen exchange occurs in areas of the pot covered by solid plastic. Thus, oxygen exchange only occurs over the exposed area of the substrate at the top of the pot and at any holes at the bottom or wall of the pot. If the pot is tall, reduced oxygen levels can occur towards the middle of the pot, especially if the growing medium is poorly drained. Such a condition can cause problems of anoxia, evidenced by a rotten smell in the substrate. Reduced oxygen exchange and methane production becomes particularly problematic when over-irrigation occurs.

Challenge 6: Production and Shipping Costs

Polybags or simple plastic pots are used in many parts of the world because they are inexpensive to purchase and ship, but these containers are prone to all of the challenges described in the previous sections (Haase et al. 2021). Several containers have been designed to address the challenges and are commercially available, but unfortunately, they are too expensive for many volunteer programs and for seedling production programs in areas of the world with limited resources. Our volunteers refer to those containers as “Rolls Royce pots” because, as the cars, these sophisticated pots would be nice to have, but unaffordable to buy. Another major cost is shipping. For remote locations, the cost of shipping containers can often be higher than the price of the containers themselves. Pots that do not stack well or need bulky trays require a large volume of packaging and are especially costly to ship.

Solution: The SheetPot

Our (the Carbon Neutrality Challenge staff and volunteers) motivation to develop a new pot system emerged from the fact that most commercially available pots were prone to the technical and practical shortcomings outlined above and resulted in significant tree mortality after our planting events. Also, we were unable to afford “Rolls Royce pots.”

The SheetPot described here is the latest in a series of prototypes developed to address the container challenges, while remaining affordable in terms of the product itself and its shipping. The following sections summarize the evolution of this pot system to highlight ideas that were tested and to motivate future innovations.

Prototype: The Paper Pot

Interestingly, the origins of our work to design a better pot system stemmed from an error by an inexperienced

Figure 2. The motivation for developing the SheetPot originated following the observation that a volunteer erroneously planted a seedling with the plastic pot. Thus, the original idea was that seedling pots could be planted directly into the ground to lessen planting shock. (Photo by Audrey Rollo, 2015)

Figure 3. Different types of paper pots were tested to determine their feasibility as a low-cost container for producing quality seedlings on a large scale. (Photo by Audrey Rollo, 2022)

Figure 4. During evaluation of paper pots, the problem was noted that the pots stick to each other upon contact. (Photo by Audrey Rollo, 2022)

volunteer who planted a seedling with its plastic pot (figure 2). Perhaps this person was frustrated by being unable to remove the seedling and decided to plant it with the pot. Regardless, this incident made us realize that a major stress to the seedlings could be avoided if the seedlings were planted with their pot. A quick search into this option revealed numerous options, including the use of paper pots. We used existing concepts like the Zipset™ Plant Bands (Stuewe and Sons, Inc., Tangent, OR) and developed several designs using a diversity of paper materials with natural and plastic coatings (figure 3). We also used rolls of newspaper in a custom-made tray. Paper pots were very affordable and reduced planting shock considerably but were problematic because the paper material decomposed in a few weeks (figure 4). The use of different coating materials on the paper lengthened the longevity of the pots, but water eventually eroded the paper, causing the medium to break apart and expose the roots. An additional problem was that paper pots cannot be placed side by side as they stick to each other. We developed a tray to keep the paper pots separated and expected it could increase the pots' longevity, but it did not. We noted, however, that with certain fibrous substrates, there was no need for the pots to have a bottom.

Prototype: The Net Pot

The discovery that we did not need a bottom in the pot led us to test different types of nets as pots. Basically, we rolled a sheet of mesh into a cylinder and placed it in a custom-made tray to create a seedling container. Originally, we used plastic chicken mesh, but the holes were too large, and the soil slowly eroded from the pot (figure 5). We then tested mosquito nets, which worked much better (figure 6). This system created direct air-soil interaction that maximized oxygen exchange, allowed for air-pruned roots, eliminated water logging, and allowed for easy removal by unrolling the nets. These net pots were very effective at avoiding container challenges mentioned in previous sections, but required a tall, bulky tray to hold them. Additionally, the mesh could be reused, but washing them for sterilization was time consuming.

Final Product: The SheetPot

After trials with the net pot, we knew that we did not need a bottom for the pots and that the rolled materials (paper or mesh) could be used to hold the growing medium. But, we still needed to overcome the need for a bulky tray and for being able to easily reuse the pots. What was needed was a rigid material, such that the pot could maintain its shape and only require a smaller tray. The idea eventually emerged for a plastic sheet with locking tabs that hold the sheet in a rolled position, thereby only necessitating a relatively small tray (figure 7). The sheets can be perforated with holes in any configuration to control the speed at which soil dries, avoid waterlogging, and allow for oxygenation. We used 0.3-in (0.8-cm) diameter holes spaced 0.5 in (1.3 cm) apart. Each row of holes is offset by 0.25 in (0.64 cm) (figure 8). We found that this spacing and configuration provided enough aeration to facilitate air-pruning of the roots. During irrigation, each drop of water rolling down the pot's wall has 15 chances to intersect a hole and thus increase irrigation efficiency.

Figure 6. The pot system based on chicken fencing (figure 5) was redesigned using mosquito net during the process to develop a low-cost container for production of high-quality seedlings. (Photo by Audrey Rollo, 2022)

Figure 5. A pot prototype based on chicken fencing was tested to determine its feasibility as an easy-to-use and low-cost container. (Photo by Audrey Rollo, 2022)

The sheet can be built with a variety of plastic materials, thicknesses, and UV protection. The sheet can be made of any color, but we chose white to reduce pest camouflage. The sheet is made of polypropylene, which can be mixed with UV preservatives to increase the longevity. Other materials, such as polyvinyl chloride, could also be suitable. Our current sheet is 0.02 in (0.5 mm) thick, 15-in (38 cm) tall, and 4-in (10-cm) diameter. The current cost is $0.30 per sheet; using thinner and shorter sheets can reduce the cost proportionally. We have tested sheets as thin as 0.1 mm and found they performed just as well while reducing cost and shipping volume fivefold. The sheets can be modified to varying heights by cutting the sheet or using custom, affordable die cuts. The only constraint is the pot diameter which was set to fit a custom-made tray. We chose a 4-in (10-cm) diameter to match the size of the drill bit of the popular BT 45 earth auger (STIHL Inc., Virginia Beach, VA). Seedlings produced in our pot can be put directly into these holes without any additional soil and with minimal stress to the roots. The sheet can be designed in other diameters, provided a holding tray is available. We recommend elevating the trays to ensure air pruning at the bottom and to avoid spiraling roots. Further improvement may include a different locking mechanism or no locking mechanism at all.

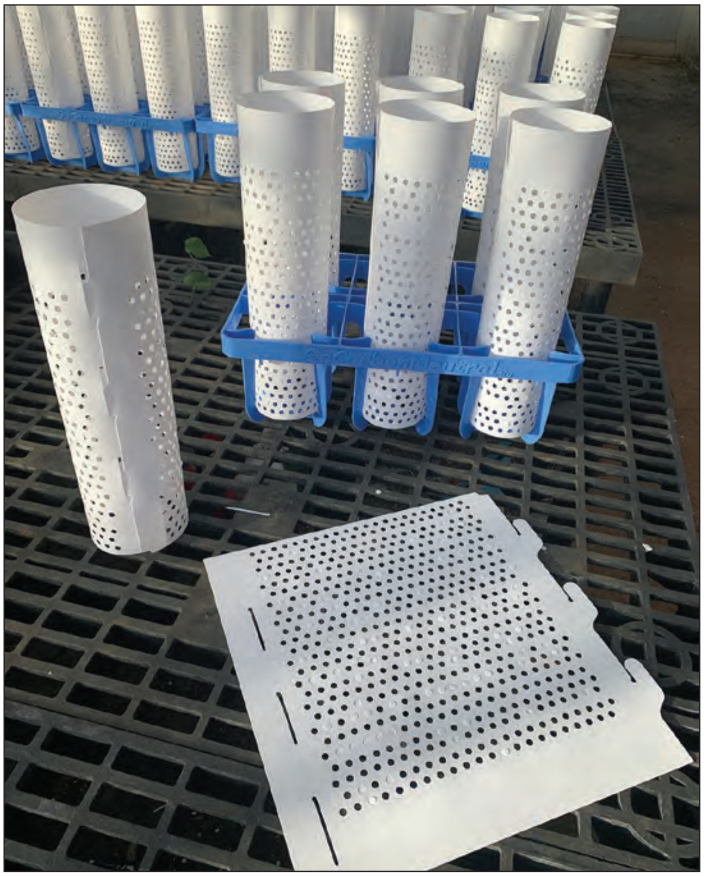

Figure 7. Using the SheetPot overcomes many challenges associated with seedling production. (Photo by Audrey Rollo, 2022)

Figure 8. The SheetPot has proven to be a successful design for production of high-quality seedlings in a low-cost pot and is available open-source for wide use. (Photo by Audrey Rollo, 2022)

In addition to being able to grow a quality seedling, the SheetPot can be stacked flat for shipping then assembled onsite, thereby reducing bulky packaging and shipping costs. Also, the plastic is durable enough that it can be sanitized and reused multiple times, thereby further reducing long-term costs and avoiding the use of single-use plastics.

Closing Remarks

Currently, there is a large global opportunity to significantly increase forest coverage of our planet. Since the onset of human civilization, people have removed nearly half of the trees that ever existed, yet there is an obvious opportunity to replant many deforested areas. While there is an eagerness to plant trees, we have learned that there are numerous challenges to such a task. Restoring the world's tree canopy requires a concerted global social effort, development of tools, and improvement of processes. We decided to make our SheetPot design open-source so it can be used by anyone without limitation. Additional information, photos, videos, and files for the pot are publicly available at: https://github.com/Camilo-Mora/MorasPot/tree/main. A discussion forum is also available, which we hope can become a hub for ideas that can help the continued evolution of the Sheetpot.

Address correspondence to—

Camilo Mora, Professor, Department of Geography and Environment, University of Hawaii, Honolulu, HI; email: cmora@hawaii.edu; phone: 808–956–7093.

REFERENCES

Bastin, J-F.; Finegold, Y.; Garcia, C.; Mollicone, D.; Rezende, M.; Routh, D.; Zohner, C.M.; Crowther, T.W. 2019. The global tree restoration potential. Science. 365: 76–79. https://doi.org/10.1126/science.aax0848.

Crowther, T.W.; Glick, H.B.; Covey, K.R.; Bettigole, C.; Maynard, D.S.; Thomas, S.M.; Smith, J.R.; Hintler, G.; Duguid, M.C.; Amatulli, G. 2015. Mapping tree density at a global scale. Nature. 525: 201–205. https://doi.org/10.1038/nature14967.

Griscom, B.W.; Adams, J.; Ellis, P.W.; Houghton, R.A.; Lomax, G.; Miteva, D.A.; Schlesinger, W.H.; Shoch, D.; Siikamäki, J.V.; Smith, P.; Woodbury, P.; Zganjar, C.; Blackman, A.; Campari, J.; Conant, R.T.; Delgado, C.; Elias, P.; Gopalakrishna, T.; Hamsik, M.R.; Herrero, M.; Kiesecker, J.; Landis, E.; Laestadius, L.; Leavitt, S.M.; Minnemeyer, S.; Polasky, S.; Potapov, P.; Putz, F.E.; Sanderman, J.; Silvius, M.; Wollenberg, E.; Fargione, J. 2017. Natural climate solutions. Proceedings of the National Academy of Sciences. 114(44): 11645–11650. https://doi.org/10.1073/pnas.1710465114.

Haase, D.L.; Bouzza, K.; Emerton, L.; Friday, J.B.; Lieberg, B.; Aldrete, A.; Davis, A.S. 2021. The high cost of the low-cost polybag system: a review of nursery seedling production systems. Land. 10: 826. https://doi.org/10.3390/land10080826.

Landis, T.D.; Luna, T.; Dumroese, R.K. 2014. Containers. In: Wilkinson, K.M.; Landis, T.D.; Haase, D.L.; Daley, B.F.; Dumroese, R.K., ed. Tropical nursery manual: a guide to starting and operating a nursery for native and traditional plants. Ag. Hand. 732. Washington, DC: U.S. Department of Agriculture, Forest Service: 123–139.

Mora, A.; Rollo, A.; Mora, C. 2020. The tree-lined path to carbon neutrality. Nature Reviews Earth & Environment. 1: 332–332. https://doi.org/10.1038/s43017-020-0069-3.

Venter, O.; Sanderson, E.W.; Magrach, A.; Allan, J.R.; Beher, J.; Jones, K.R.; Possingham, H.P.; Laurance, W.F.; Wood, P.; Fekete, B.M.; Levy, M.A.; Watson, J.E.M. 2016a. Global terrestrial human footprint maps for 1993 and 2009. Scientific Data. 3: 1–10. https://doi.org/10.1038/sdata.2016.67.

Venter, O.; Sanderson, E.W.; Magrach, A.; Allan, J.R.; Beher, J.; Jones, K.R.; Possingham, H.P.; Laurance, W.F.; Wood, P.; Fekete, B.M.; Levy, M.A.; Watson, J.E.M. 2016b. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature Communications. 7: 12558. https://doi.org/10.1038/ncomms12558.