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Organic Wastes and Tropical Forest Restoration

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Abstract

In a recent publication, we documented the benefits of using agricultural waste (specifically, leftover orange peels from a commercial orange juice factory) to promote forest recovery at a site in Costa Rica. While we showed unambiguously positive impacts on soil conditions, forest biomass, and tree diversity, our ability to infer mechanisms behind this recovery was limited because the project was never replicated. It appears our work is one of only a handful of peer-reviewed studies testing the use of unprocessed agricultural waste as part of a tropical forest restoration initiative. We argue that regardless of the mechanism, there are first-principle reasons to expect that minimally processed (and thus low-cost) agricultural wastes could be utilized to accelerate tropical forest restoration in a variety of contexts, potentially creating a new class of biodiversity-friendly carbon offsets that may address previous concerns about linking tropical forestry to global carbon markets. We outline research initiatives that could lead to a richer understanding of when and where it is safe and effective to utilize agricultural and other wastes in tropical forest restoration endeavors.

Keywords

agricultural waste, forest restoration, soil, carbon offsets, soil amendments, arrested succession, fire traps, nutrient depletion

In 1998, scientists and managers of Área de Conservación Guanacaste (ACG) in northwest Costa Rica looked on as trucks filled with orange peels drove across a wooden bridge and down a narrow dirt access road. The trucks unloaded what would eventually amount to an estimated 12,000 tonnes of organic byproducts from a nearby juicing and essential oil extraction facility onto a 3-hectare corner of an abandoned cattle pasture overgrown with jaragua (*Hyparrhenia rufa)*, an invasive, fire-adapted grass that had long restricted regrowth.

This unusual activity was the product of a groundbreaking 20-year contract between ACG and the juice company, Del Oro S.A., wherein the company received free waste disposal services (obviating the need for capital intensive investments in waste-processing equipment and infrastructure) in exchange for giving the park multiple blocks of hilly, still-forested land unsuitable for cultivation. Scientific advisers to the park (most prominently Daniel Janzen and Winnie Hallwachs) conducted a promising pilot trial 2 years before and were confident the orange peels would readily degrade and promote vegetation regrowth with minimal ecological risk to the park or the surrounding community. This formalized (and quite ahead of its time) ecosystem services agreement seemed to offer a compelling model for future mutually beneficial arrangements between agroindustry and conservation initiatives.

Then came the lawsuit. Alleging damage to a national park, a rival juice company successfully litigated an immediate termination to the project, voiding the contract between ACG and Del Oro. Janzen, Hallwachs,

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and others continued to visit the site long enough to know that the orange waste had initiated a regime shift in vegetation cover from grass to woody plants, but no attempt to rigorously quantify these changes was made until 2014, when we conducted a variety of soil, vegetation, and other surveys. We recently published these findings as a case study (Treuer et al., 2017). While we found dramatic improvements in aboveground biomass, soil condition, and tree diversity, we were unable to confidently ascribe a mechanism by which the deposition of orange waste accelerated forest recovery, due to the lack of replication of the treatment and the nature of the original experimental design, which was structured as a proof of concept rather than as a mechanistic study.

While we were greatly impressed by the rapid recovery at the site in 2014, we were also surprised to find that ours was one of the only studies that we could find in which a minimally processed organic waste was used as an active tropical forest restoration approach. We believe that there are first-principle reasons that future endeavors using such wastes would be highly effective in not only accelerating forest regeneration in a variety of contexts across the tropics but also in mitigating arrested succession. We discuss those reasons below and conclude with a brief discussion of promising research directions and the potential to incorporate these restoration methods into carbon markets.

Mitigating Arrested or Delayed Succession

Across the tropics, trends in globalization, urbanization, agricultural intensification, and traditional shifting-cultivation practices have driven forest regrowth on abandoned agricultural and pastoral lands. However, the pace of forest regeneration on abandoned agricultural lands is hardly uniform and varies with the broad diversity in tropical forest type (Holl, 2007; Janzen, 1988), soil conditions (Powers et al., 2009), rainfall gradients (Poorter et al., 2016), presence of weedy or invasive vegetation (Calvo-Alvarado, McLennan, Sánchez-Azofeifa, & Garvin, 2009), fire (D'Antonio & Vitousek, 1992), and land-use history (Crouzeilles et al., 2016; Holl & Zahawi, 2014). In some instances, these and other conditions (e.g., insufficient seed rain, seedling and sapling mortality, and slow woody biomass accumulation) present enough of a barrier to forest recovery as to fully arrest succession, at least along timescales that are relevant to human and conservation needs (D'Antonio & Vitousek, 1992; Holl, 2007; Holl, Loik, Lin, & Samuels, 2000). Of these variables, we believe there are two conditions that present particularly difficult obstacles to regeneration in ACG and across in the tropics.

The first of these conditions is the nutrient-poor nature of many tropical forest soils. Ecologists have long noted that tropical forest soils are depauperate in key nutrients, with a high proportion found in living tissues that quickly get recycled upon decomposition (Vitousek & Sanford, 1986). During the process of land conversion, often via slash and burn agriculture, nutrients are lost from the ecosystem via the harvesting and removal of nutrient-rich plant tissue, the volatilization of nitrogen by fire, and increased runoff (Griscom & Ashton, 2011). Nutrient deficiency decreases the establishment and growth of tree species during succession (Davidson et al., 2004; Kitajima & Tilman, 1996), has been documented in many settings, including at least one site with nutrient-rich soils (Chou, Hedin, & Pacala, 2018), and is also evidenced by high rates of symbiotic nitrogen fixation early in succession (Batterman et al., 2013).

The second challenge—the presence of weedy, often nonnative vegetation that competes with seedlings for resources—interacts with the challenges posed by nutrient limitation. In treeless cattle pastures, aggressive herbaceous vegetation (e.g., perennial grasses and bracken ferns) can grow rapidly, competing for resources and shading out later successional species (Calvo-Alvarado et al., 2009; Shoo & Catterall, 2013). Such vegetation fuel hot fires that kill seedlings and saplings—the so-called 'fire trap' that drives the bistability of savannas and forests in certain climates (Pellegrini, 2016). Availability of nitrogen and phosphorus, or even micronutrients like Ca^{2+} and Mg^{2+} (Hoffmann et al., 2009), by increasing tree seedling growth rates, can allow systems to escape the fire trap (Pellegrini, 2016).

Both of these challenges can potentially be overcome through traditional tropical forest restoration techniques involving fertilizer and herbicide application (Griscom & Ashton, 2011), but these approaches are typically expensive and can incur negative carbon and health outcomes. Scientists have engaged in a wide variety of regenerative efforts, including the application of manure, compost, or biochar, as well as direct seeding or seedling planting (Griscom & Ashton, 2011). However, we believe the application of many types of agricultural wastes may achieve the same results at a far lower material and labor cost. Indeed, we suspect the application of orange waste at our site in Costa Rica led to forest recovery by mitigating these two interacting challenges. Within a couple of months of their application, the orange waste had killed off the grasses (likely via asphyxiation) and broken down into a nutrient-rich organic layer. These fertilized soils, long after catalyzing extensive regrowth, still hold more nutrients than the surrounding area, even after accounting for their lower bulk density.

Promising Directions

While whole industries now exist to convert various agricultural and other nutrient-rich wastes into useful

Figure 1. Orange peels gathered for disposal in Ghana. Photo courtesy of Lyndon Estes.

products, these ventures are often capital-intensive or yield products with limited markets, conditions that may prevent widespread adoption in tropical developing nations. In the case of our study, it was largely the costs of turning the orange peels into a benign product, in this case cattle feed, which drove interest in the waste disposal contract with ACG (Daniel Janzen (DJ), occurring in July 2016, personal communication). After media coverage of our study, we were contacted by numerous citrus growers interested in exploring similar arrangements, suggesting that for this particular type of waste, lucrative markets for waste derivatives are not universal and alternative disposal costs are high (Figure 1).

Beyond citrus waste, future research should examine other organic wastes, including noncitrus fruits grown for juice or oil extraction as well as nonmarketed fleshy fruits like the skins of coffee fruit or cashew fruits, for their tropical forest restoration potential. Agricultural waste has long been used in forestry settings to ameliorate soil conditions on the scale of individual trees (Harris, 1992). The application of biochars, manures, and agricultural waste residues in applied forest restoration settings has also demonstrated great potential to increase biomass production and improve a suite of soil characteristics (Box 1). Beyond plant-based agriculture by-products, organic municipal waste, chicken litter, and sewage from concentrated feedlots all are nutrient wastes that at least in some contexts are costly to process otherwise.

In all cases, but particularly with organic wastes with the potential to negatively impact downstream communities (Herrera et al., 2017), scientifically guided and carefully managed enterprises are essential. Pilot studies are necessary both to establish that organisms present in the surrounding environment are capable of breaking down the organic waste and that runoff will not pose a health risk to local waterways and populations. Likewise, life-cycle analysis of wastes and methane and nitrous oxide emissions are needed to ensure that negative climate impacts do not offset the carbon sequestration benefits of enhanced tree growth. In addition, projects guided by input from local stakeholders should have greater odds of acceptance than those led by private enterprises without meaningful public input, which can trigger accusations of pollution, profiteering, or other malfeasance.

Ensuring the efficient application of organic waste for the maximum environmental impact should be a major focus of future research efforts. In our study, orange waste from several hundred hectares of productive orchards was used to accelerate forest succession on just 3 hectares. Additional research should determine the quantity of agricultural waste needed in a particular area to jumpstart regrowth as well as the minimum spatial scale of application needed to prevent the reinvasion of grasses. Research should also address the marginal impact of additional waste per area on forest biomass and species diversity.

Other important research directions include whether waste application techniques can be deployed successfully in other climates. Most of the citrus growers we were contacted by hailed from Mediterranean biomes, where forest regeneration may not be nutrient limited, and organisms that break down agricultural wastes may be less likely to occur in needed densities (though increased soil water retention may offer a separate mechanism for organic wastes to speed vegetation regrowth). In all biomes, it is also worth comparing how effective waste application is relative to other more established techniques.

Box 1. Effective Use of Processed Agricultural Waste to Ameliorate Soil Conditions and Catalyze Succession.

Biochars: Agricultural waste residues converted to biochars can be high in soluble nutrients (phosphorus and potassium) and can retain water, cations, and anions. A meta-analysis showed over 40% mean increases in biomass production in restoration applications after biochar applications (Thomas & Gale, 2015). However, the effectiveness of these soil amendments deserves further investigation as biochars can have both positive and negative impacts on forest regrowth (Thomas & Gale, 2015). For example, a forest restoration project in the ACG used agricultural waste to ameliorate degraded soil and showed no impact of biochar application on tree seedling growth or survival (Werden et al., 2018).

Composts and manures: The application of urban household compost to abandoned agricultural land can led to increased plant recruitment from existing seed bank and increased plant grow rates (Ros et al., 2003). The application of composts can also stimulate microbial activity and renew soil nutrient cycles by increasing nitrogen mineralization, microbial respiration, and soil carbon storage (Harris, 2003). Many studies have also found manure application to increase total soil organic carbon and water holding capacity of degraded soils (Khaleel et al., 1981).

Climate Mitigation

Improving the carbon sequestration potential of pastures and fields to mitigate climate change has been the subject of considerable recent research (Ryals, Kaiser, Torn, Berhe, & Silver, 2014) and has implications for existing international carbon regimes, such as the United Nations' Reducing Emissions from Deforestation and Forest Degradation in Developing Countries Programme (REDD+) and the Bonn Challenge. However, many schemes suffer from difficulties in demonstrating the two pillars of carbon mitigation, namely additionality and a lack of leakage. From an economic perspective, the laws of supply and demand and the inherent fungibility of timber sources from different locales means that scaling up payments to prevent logging in one place will only lead to timber harvest in another. Likewise, payments to set aside areas for forest regeneration may end up going to landowners who would have let forest recover anyway. Accelerating natural forest regeneration offers a potentially scalable mode of carbon offsetting but with fewer concerns of leakage or missing additionality.

Incorporating the use of organic wastes as a form of carbon offsetting into carbon markets could divert otherwise only marginally beneficial organic wastes, such as oil palm fibers that are often burned for power at oil extraction facilities, to projects related to forest restoration, all while providing other positive externalities like improved local air quality and enhanced biodiversity. As such, ecologists should work with environmental economists to better understand how organic wastes might be incorporated into carbon market schemes.

Ultimately, our study has demonstrated large potential for low-cost agricultural waste to catalyze tropical forest recovery and further research to optimize the effectiveness of its application should be encouraged.

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