Kohlenstoffbindungspotenzial auf der Halbinsel Yucatán, Mexiko

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Wiederaufforstung gilt als eine der besten natürlichen Lösungen zum Ausgleich anthropogener CO2-Emissionen. Besonders groß ist das Potenzial der CO2 Bindung in hochgradig biodiversen Tropenwälder[1] in den ersten Wachstumsjahren[2].

Plant-for-the-Planet verfolgt bei der Renaturierung im südlichen Yucatán, einer artenreichen und stark degradierten tropischen Region Mexikos, zwei Ansätze:

1) Pflanzen von heimischen Baumarten auf vollständig abgeholzten degradierten Rinderweiden.

2) Pflanzen von heimischen Baumarten in teildegradierten Wäldern, in denen vor allem Baumarten mit hohem CO_2-Bindungspotenzial geplündert wurden („Enrichment Planting“).

Wissenschaftliche Studien liefern solide Schätzungen über die Menge an durchschnittlich gebundenem CO_2, für jeden dieser beiden Ansätze. Beachtenswert ist, dass Kohlenstoff nicht nur überirdisch gebunden wird, in der Biomasse von Stamm, Ästen und Blättern, sondern auch unterirdisch. Forscher berechneten für die am besten untersuchten tropischen Feuchtwälder der Welt (Barro Colorado Island), dass der **Waldboden in bis zu einem Meter Tiefe noch einmal mehr als das Doppelte** an Kohlenstoff bindet wie die oberirdische Baumbiomasse[3]. (Beispielrechnung: 100 kg CO_2 oberirdisch × 2,5, zusätzlich 150 kg unterirdisch gespeichertes CO_2 = 250 kg CO_2)

Für einen unweit von Constitución (200 km) **gelegenen halb-immergrünen ausgewachsenen Wald ermittelten Forscher** pro Hektar rund 106 Mg (Mg=Tonne) Kohlenstoff (entspricht 225 Mg Biomasse x 0,47 Verhältnis Kohlenstoff zu trockener Angiospermen-Biomasse) in der oberirdischen Biomasse – bezogen auf Stämme und Äste[4]. Für diese sehr genaue (und sehr seltene!) direkte Schätzung der oberirdischen Kohlenstoffakkumulation in Wäldern haben die Forscher alle Bäume in ihren Untersuchungsflächen vollständig geerntet, getrocknet und gewogen – anstatt weniger präzise Biomassegleichungen zur Schätzung der Kohlenstoffspeicherung zu verwenden. Berücksichtigt man die zusätzliche unterirdische Kohlenstoffspeicherung, bindet jeder in dieser Region gepflanzte Baum über seine Lebenszeit im **Durchschnitt rund 1.263 kg CO_2** (505 kg CO_2[5] oberirdisch gebundenes CO_2 × 2,5 unterirdisch = ~1.263 kg insgesamt gebundenes CO_2 pro gepflanztem Baum).

Brosimum alicastrum (Ramon), eine von Plant-for-the-Planet bevorzugt gepflanzte in der Region dominante Art, wächst zu enormen Größen heran und erreicht weit höhere Raten (1506 kg oberirdisch gebundenes CO_2 pro Baum bei einem Stammdurchmesser von 63,4 cm auf 1,3 m Brusthöhe)[6]. Auch weitere von Plant-for-the-Planet gepflanzte Baumarten, wie beispielsweise Manilkara zapota (durchschnittlich 574 kg CO_2 oberirdisch pro Baum), binden mehr CO_2 als der durchschnittliche Baum der Region.

Unter der **Berücksichtigung der hohen Bandbreite an Baumarten bei unserer großflächigen Renaturierung in Yucatán**, schätzen unsere Ökolog*innen **konservativ einen Wert von 200 kg oberirdisch** gebundenem CO_2 für einen durchschnittlich gepflanzten Baum bzw. 500 kg für Baumarten mit hohen Wuchsformen. Da, wie oben ausgeführt, das gesamte CO_2-Bindungspotenzial sehr viel höher liegt, wenn man den unterirdisch gebundenen Kohlenstoff mit einberechnet, können wir **konservativ mindestens 500 kg gesamt gebundenes CO_2 für einen durchschnittlichen Baum** in unseren Pflanzungen veranschlagen, der Wert liegt den oben folgenden Ausführungen gemäß aber erwartungsgemäß eher bei einem Bindungspotenzial ober- und unterirdisch von rund 1.263 kg gebundenem CO2 gesamt.

Beim ebenfalls von Plant-for-the-Planet praktizierten „**Enrichment Planting**“ werden einheimische Baumarten in bestehende Wälder gepflanzt, die durch die selektive Abholzung wertvoller Holzarten (z.B. Manilkara zapota) stark degradiert sind. Dieser Ansatz hat eine hohe wissenschaftliche Akzeptanz[7,8,9] und wird in dieser Region Mexikos sehr erfolgreich angewendet[10]. Da im „Enrichment Planting" gepflanzte Bäume mit dem erhaltenen Bestand um Nährstoffe konkurrieren, wachsen sie langsamer und lassen eine etwas geringere Überlebensrate erwarten[11]. Daher pflanzt Plant-for-the-Planet bei Anreicherungspflanzungen in höheren Dichten. Konservativ rechnen wir hier, dass **rund 60% der nachgepflanzten Bäume überleben**, was rund 374 kg (und damit nahezu doppelt so viel) oberirdisch gebundenem CO_2 entspricht (500 kg für großwüchsige Arten); oder **935 kg insgesamt gebundenes CO_2 pro durchschnittlichem Baum** (374 kg oberirdisch gebundenes CO_2 × 2,5, zusätzlich unterirdisch gebundenes CO_2 = 935 kg insgesamt gebundenes CO_2 pro gepflanztem Anreicherungsbaum).

Wälder wachsen lassen, statt Bäume zu pflanzen:
Oberstes Ziel von Plant-for-the-Planet ist die erfolgreiche Renaturierung. Daher pflanzen wir nicht einfach Bäume, sondern lassen Wälder wachsen. Unser Aufforstungsteam pflegt jeden gepflanzten Baum 2-5 Jahre lang und entfernt zweimal im Jahr wuchernde Gräser und Kräuter. So haben die Bäume sehr viel höhere Überlebensraten und erreichen ihr maximales CO_2-Bindungspotenzial. Zusätzlich erhöhen wir seit 2021 die Vielfalt der Baumarten in unseren Pflanzungen. Damit steigern wir nicht nur die Biodiversität in unseren Wäldern, sondern auch das darin gebundene CO_2, denn Wälder mit höherer Diversität speichern nachweislich auch mehr Kohlenstoff.[12]

Anmerkungen

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[5] 106,000 kg (=106Mg) carbon per hectare × 3.67 ratio(a) of unit carbon to unit CO_2 ÷ 770 trees per hectare = ~505 kg CO_2).

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Carbon accumulation potential of reforestation in the Yucatán peninsula, Mexico

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Reforestation has proven results as one of the best natural solutions to offset anthropogenic CO_2 emissions, potentially reaching 2.7–17.9*10^9 t CO_2 of emissions offset per year (Griscom et al., 2017). This is especially true in tropical forests (Busch et al., 2019), and planting trees in degraded landscapes can catalyze this process (Silver, Ostertag, & Lugo, 2000). Trees have enormous potential to capture CO_2 when growing in highly biodiverse tropical forests (Poorter et al., 2015). Additionally, there is growing scientific consensus that the most rapid rates of overall CO_2 accumulation happen during the early years of tropical forest growth (Cook-Patton et al., 2020; Rüger et al., 2020; Vargas, Allen, & Allen, 2008). Thus, to maximize the impacts of their reforestation efforts, Plant-for-the-Planet focuses on the early years of reforestation in a biodiverse and highly degraded tropical region of Mexico.

Plant-for-the-Planet takes two main approaches towards reforestation in Southern Yucatán, Mexico that have high potential for the accumulation of CO_2 in tree biomass: 1) planting native trees in degraded pastures that are completely deforested (*i.e.*, reforestation; 1,100 trees/hectare); and 2) planting native trees into degraded forests where almost all tree species with high CO_2 accumulation potential were previously harvested (*i.e.*, 'enrichment planting'; 1,400 trees/hectare). Leveraging the many scientific studies on forests CO_2 storage we are able to obtain robust estimates of the average amount of CO_2 captured using each one of these approaches.

Pools of carbon storage in tropical forests

When thinking about the CO_2 captured by a forest, the image that most often comes to mind is one of tree trunks and branches. While these parts of a tree do accumulate a great deal of carbon as a result of tree planting, belowground tree parts and the soil itself accumulates an even higher proportion of CO_2 than what is stored aboveground. For instance, forest soil itself holds an immense amount of carbon. In one of the most extensively studied tropical wet forests in the world (Barro Colorado Island and surrounding peninsulas) researchers estimated that forest soil from 0-100 cm depth typically stores more than double the amount of carbon stored in aboveground tree biomass (Jones et al. 2019). Therefore, we conservatively estimate that each tree planted at least as much carbon will be stored in the soil as is stored aboveground, (e.g., at least 100 kg CO_2 captured in soil for every 100 kg CO_2 captured aboveground), and it is likely that this number is closer to 200 kg CO_2 captured in soil for every 100 kg CO_2 captured aboveground. Moreover, there is strong evidence that this study and many others systematically underestimate the amount of carbon stored in belowground tree parts by using standardized allometric equations to estimate root biomass. A recent global analysis showed that ~50% of carbon stored in tree biomass in mature tropical forests can be found in woody tree roots (e.g., ~50 kg CO_2 captured in tree roots for every 100 kg CO_2 captured aboveground; Waring & Powers, 2017) -- over seven times higher than the ~7% estimated by Jones et al. (2019). Overlooking these belowground carbon pools greatly underestimates potential CO_2 accumulation as a result of tropical reforestation. Thus, we can conservatively estimate that for every 100 kg of CO_2 accumulated aboveground as a result of Plant-for-the-Planet tree planting efforts in Yucatán, Mexico, another ~150 kg CO_2 will be accumulated belowground over the lifetime of an average tree (~50 kg stored in tree roots + ~100 kg stored in soil). Therefore, we estimate that total carbon storage is ~2.5 times the amount of CO_2 accumulated aboveground (e.g., 100 kg CO_2 aboveground × 2.5 to account for an additional 150 kg CO_2 captured belowground = 250 kg CO_2)

Reforestation CO_2 accumulation potential

Research across the most extensive network of forest plots across Latin America indicates that many tropical forests can recover a majority of carbon lost following deforestation within 20-40 years (Poorter et al., 2016). Thus, reforestation efforts within the Plant-for-the-Planet reserves in Constitución, Campeche have the potential to accumulate ecosystem CO_2 storage to levels reaching that of mature forests over relatively short time scales. In a mature semi-evergreen forest ~200 km from Constitución (the same forest type Plant-for-the-Planet is reforesting) researchers found ~106 Mg of carbon (225 Mg biomass × 0.47 ratio carbon to dry angiosperm tree biomass; Thomas and Martin 2012) was stored aboveground per hectare (Cairns, Olmsted, Granados, & Argaez, 2003). This study provides a very precise (and very rare!) direct estimate of aboveground forest carbon accumulation because its researchers fully harvested, dried, and weighed all of the trees in their study plots – rather than using less precise biomass equations to estimate carbon storage. While this study is an excellent point of comparison for our reforestation efforts, it is important to note that the researchers only examined carbon stored aboveground (*i.e.,* only in tree stems and branches). This overlooks the enormous potential for belowground carbon storage as a result of tree planting. Thus, in the following calculations we detail the potential Plant-for-the-Planet's reforestation efforts have in accumulating CO_2 both above- (*i.e.,* in tree stems and branches) and belowground (*i.e.,* in tree roots and over time in the soil).

Assuming conservatively that not all trees planted in Plant-for-the-Planet reforestations survive in the long term (~70% or ~770 out of 1,100 trees/hectare) we estimate that each tree we plant has the potential to accumulate ~505 kg CO_2 aboveground over its lifetime when persisting at this density (106,000 kg carbon per hectare × 3.67 ratio[a] of unit carbon to unit CO_2 ÷ 770 trees per hectare = ~505 kg CO_2). Further considering the even larger potential for belowground carbon storage, we estimate that each tree planted in this region can easily accumulate ~1263 kg of CO_2 total over its lifetime on average (~505 kg CO_2 captured aboveground × 2.5 to account for additional CO_2 stored belowground = ~1263 kg total CO_2 captured per planted tree). Moreover, the region Plant-for-the-Planet is reforesting receives more ~300 mm more rainfall per year than the Cairns, Olmsted, Granados, & Argaez (2003) comparison forest and likely has even higher aboveground CO_2 accumulation potential per tree, a relationship well documented by scientific evidence both across the Americas (Poorter et al., 2016) and globally (Reich et al., 2014). Moreover, some tree species can store much more CO_2 over their lifetime. One of the most dominant trees in this region, and one of Plant-for-the-Planet's focal planting species, *Brosimum alicastrum* (Ramon), can grow to enormous sizes and stores much more carbon than an average tree **(1506 kg CO_2 captured aboveground per tree on average; 63.4 cm maximum trunk diameter at 1.3 m; Cairns et al., 2003)**, and Plant-for-the-Planet also plants other tree species that capture more CO_2 than the average tree in this region (*e.g., Manilkara zapota;* 574 kg CO_2 captured aboveground per tree on average).

[a] A molecule of CO_2 has an atomic weight of 44 and consists of one carbon atom (molecular weight 12) and two oxygen atoms (molecular weight 16 × 2 = 32). To convert one unit of carbon to a unit of CO_2 we multiply by a ratio of 3.67 (44/12 = 3.67).

Considering the above, to be sufficiently conservative with our estimates of CO_2 accumulation, our team settled on a value of **200 kg CO_2 accumulated aboveground per average planted tree** or **500 kg CO_2 accumulated aboveground for tree species with large growth forms** (*e.g., Brosimum alicastrum*) to account for the high variability in large-scale reforestation outcomes. However, as highlighted above, total CO_2 accumulation potential (aboveground + belowground) is much higher on average per planted tree, so we can conservatively estimate that **at least 500 kg total CO_2 is accumulated for an average tree**, and this figure is likely closer to 1263 kg total CO_2 (accounting for both above- and belowground storage).

Enrichment planting CO_2 accumulation potential

Plant-for-the-Planet also uses an approach called 'enrichment planting,' where native tree species are planted into existing forest that have been severely degraded by selective logging of valuable timber species. This approach has a great deal of scientific support (Griscom & Ashton, 2011; Paquette, Hawryshyn, Senikas, & Potvin, 2009; Schweizer & Brancalion, 2020) and it has been very successful in this region of Mexico (Dalle, de Blois, Caballero, & Johns, 2006). Plant-for-the-Planet has used this technique effectively to plant important tree species that were widely deforested in this region (*e.g., Manilkara zapota*). Trees planted using an 'enrichment planting' approach have many other trees to compete with, so they can grow slower and have lower survival compared to a typical reforestation approach (Werden et al., 2020). To account for this, Plant-for-the-Planet reforesters plant trees at slightly higher densities when making enrichment plantings (1,400 trees/hectare).

Again, assuming conservatively that not all of these planted trees survive (~60% or ~840 out of 1,400 trees/hectare) and that 200 trees/hectare already exist where enrichment plantings are made, we estimate that each tree planted using enrichment planting can accumulate ~374 kg CO_2 over aboveground its lifetime (106,000 kg carbon per hectare × 3.67 ratio of unit carbon to unit CO_2 ÷ 1,040 trees per hectare = ~374 kg CO_2). Thus, the carbon accumulation potential in enrichment plantings may be slightly lower per planted tree, but still has a large and well demonstrated CO_2 accumulation potential (Paquette et al., 2009) that is almost double our 200 kg CO_2 captured aboveground per average tree assumption (500 kg CO_2 accumulated aboveground for large growth form species); or 935 kg total CO_2 accumulated per average tree (~374 kg CO_2

captured aboveground × 2.5 to account for additional CO_2 captured belowground = ~935 kg total CO_2 captured per enrichment tree planted).

Growing forests rather than planting trees

Plant-for-the-Planet's ultimate goal is to ensure that reforestation efforts are successful. As such, we do not simply plant trees, we grow forests. To that end, our reforestation team performs maintenance on every planted tree twice a year for 2-5 years to remove competition from exotic grass species and other herbs. This ensures that all trees not only have much higher survival, but also are able to reach their maximum CO_2 storage potential. Additionally, we are rapidly working to increase the diversity of tree species that we plant. This will not only help to add biodiversity back to our forests, but it will lead to additional accumulation of CO_2 given the strong evidence that higher diversity forests accumulate carbon at higher rates (Poorter et al., 2015; Potvin & Gotelli, 2008; Zemp et al., 2019).

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