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Rethinking the Impact of Large-Scale Tree-Planting on Soil Quality for the Chronically Poor

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Abstract

This paper examines how large-scale tree-planting strategies shape soil quality (SQ) and how SQ, in turn, affects the world's poorest communities. While afforestation and large-scale tree-planting efforts have been promoted as low-cost, climate-friendly solutions, their implications for SQ are complex and yield mixed results since SQ characteristics are largely context-specific. Nature-based solutions are only effective if they work for the people who live with them every day. However, when large-scale tree-planting degrades SQ and local livelihoods, these efforts fail to be "solutions" and instead widen the poverty gap. Using a systematic literature review of peer-reviewed empirical studies, this paper builds on previous unpublished research demonstrating that tree planting yields context-dependent soil quality outcomes and examines how poor soils create and perpetuate poverty traps. The paper then evaluates inorganic fertilization as a potential intervention but finds that, despite its effectiveness, cost barriers make it unaffordable for the communities that need it most. In response, this research identifies improved tree fallows, as well as the invasive species and hybrid fruit-bearing variants, as promising alternatives for soil restoration. In addition, these approaches require minimal cash investment, reduce labor demands, and provide valuable byproducts, making them accessible to even chronically poor farmers. The paper argues that a "business as usual" approach to large-scale tree-planting without regard to soil quality risks creating poverty traps for low-income farmers, and that improved, invasive, and hybrid fruit-bearing fallows offer a more people-centered, low-cash approach to restoring soils while contributing to reforestation goals.

Author's Note

Look at a coffee cup or an airline ticket, and you are likely to see something along the lines of "one-hundred cups plants one tree," or "this ticket helps plant trees." Tree planting is everywhere. However, large-scale tree planting is not the simple solution it is often advertised to be. While much of the world's carbon emissions originate in the Global North, many large-scale tree-planting initiatives are

implemented in the Global South, where their social and ecological consequences are most strongly felt. My professor, Vijay Ramprasad, inspired me to write this paper. In class, Ramprasad challenged us to approach environmental issues by thinking first about the people these problems impact. Case studies such as Aggarwal (2021) demonstrated how forest carbon projects in developing countries damage local livelihoods, and because these methods don't work for the people, they uproot the trees, leading to poor survival rates and ineffective carbon sequestration. This inspired me to look at other ways tree-planting affects livelihoods and the environment, and I found soil quality to be among the most important. Building on earlier unpublished research on soil quality, this paper adopts a people-centered approach and argues that soil metrics are meaningless if they are detached from livelihoods, health, and long-term well-being.

Keywords: Soil quality, Tree fallowing, Chronic poverty, Poverty traps, Soil degradation

Introduction

As large-scale tree-planting becomes an increasingly popular strategy to combat the effects of climate change through carbon sequestration, the question of how these practices affect SQ has become pressing. Though not specifically mentioned, SQ is an indirect focus of multiple United Nations Sustainable Development Goals (Helming et al., 2018). One reason is that the SDGs' number one goal is to end poverty in all its forms, and current research shows a strong link between economic status and soil quality (Barrett and Bevis, 2015). Because the world's poorest communities depend directly on degraded soils for food, fuel, income, and livelihoods, fully understanding the complex relationship between poverty and SQ, and then creating policy based on these findings, is important to preserving these communities' well-being (Barrett and Bevis, 2015). Furthermore, investigating SQ and its relationship to poverty is a pressing issue; soil degraded by deforestation has proven difficult to restore. This is problematic because soil-improving management options typically are advantageous only after long periods of time (Helming et al. 2018). Because of this dynamic, scientific and academic communities must set a high standard regarding large-scale tree-planting and SQ. Building upon previous unpublished research demonstrating that tree planting yields context-dependent soil quality outcomes, this paper examines the risks of large-scale tree planting, which may create poverty traps for the world's poorest communities through soil degradation. The paper evaluates inorganic fertilization as a potential soil restoration strategy, then investigates improved, invasive, and hybrid fruit-bearing fallows as alternative approaches that may better align with smallholder economic limitations.

Methodology

This paper used a systematic literature review methodology to examine the relationships between tree planting, SQ, and chronic poverty. The research is a continuation of unpublished work that analysed the impacts of tree planting on SQ across various contexts.

Literature Search Strategy: Research articles were identified through multiple academic databases, including Google Scholar, JSTOR, Web of Science, and ScienceDirect. Search terms included combinations of: "soil quality," "soil fertility," "poverty traps," "tree planting," "afforestation," "agroforestry," "tree fallows," and "soil degradation."

Selection Criteria: Sources were selected based on the following criteria: (1) peer-reviewed journal articles and reports from reputable institutions; (2) focus on soil-poverty relationships, agricultural interventions, or agroforestry practices; (3) empirical evidence or well-supported theoretical frameworks. Both quantitative and qualitative studies were included to capture multiple methodological approaches.

Literature Review

4.1 General Links Between Soil and Poverty

Despite SQ's direct ties to poverty, it is often overlooked in low-income farming communities. In addition, a growing body of research has found "strong links" between chronic poverty and soil (Barrett and Bevis, 2015). Further, it is difficult to directly "feel" the effects of long-term soil degradation, as it occurs gradually, sometimes over many years (Warui, 2024). Nevertheless, evidence suggests that economic status and SQ are linked and can even reinforce one another (Barrett and Bevis, 2015). Since many of the world's poorest communities rely on degraded or degrading land to support their agricultural livelihoods, these people are at risk of becoming victims of potential poverty traps due to a lack of soil fertility. In this way, planting trees on smallholder land may jeopardize and trap these pastoralists into chronic poverty.

4.2 Poverty Traps

Soil can create poverty traps in numerous ways. Soil is a limiting factor that directly constrains agricultural productivity and incomes derived from agriculture (Barrett and Bevis, 2015). Therefore, a vicious cycle can occur in which smallholders working on poor soils generate low agricultural incomes in the present, leaving them without sufficient resources to invest in soil improvements that could benefit future yields (Barrett and Bevis, 2015). Further, even if smallholders can provide enough capital to invest in SQ, some land has become so degraded that such investments would yield no return, further reinforcing the poverty trap (Barrett and Bevis, 2015). Because degrading practices, such as large-scale tree planting, alter soil fertility, tree-planting practices may pose a problem for farmers who buy, inherit, or rent land with a history of large-scale tree planting.

The poverty trap can also extend to affect the broader development of human settlements and infrastructure. Lower-fertility soils typically cannot support high-density human settlement, meaning that small, low-density settlements are the norm. This increases the per-capita cost for governments to provide essential infrastructure such as roads, electricity, and telecommunications, making it harder to sell produce, maintain health, education, and other important benefits that come with high-density populations (Barrett and Bevis, 2015). Beyond infrastructure, SQ-induced poverty traps can also threaten human health and productivity.

The effects of SQ may harm human health, further reinforcing poverty traps. Micronutrients derived solely from soil may be deficient in degraded soils, leading to dietary mineral deficiencies and detrimental human health outcomes (Barrett and Bevis, 2015). Additionally, if modern infrastructure (roads, electricity, and telecommunications) is limited due to low population density, households become more dependent on locally grown produce, which could make specific minerals hard to come by (Barrett and Bevis, 2015). Further, when non-palatable foreign tree saplings are planted in areas where pastoralists herd their livestock, these plants can sicken or kill livestock, reducing herd productivity and increasing livelihood vulnerability

(Ramprasad et al., 2020). When herd productivity decreases, this may lead to a deficiency in nutrients and protein. If members of a household have a deficiency in essential nutrients, they may become susceptible to illness and disease, which may reduce or eliminate their ability to continue contributing to household income or well-being. Further, lack of nutrients at a young age can affect adult labor productivity over the long term (Barrett and Bevis, 2015). One example in Xinjiang, China, saw a 50% decrease in infant mortality after an iodine micronutrient was introduced into the soil. This demonstrates the role that SQ plays in human well-being and livelihoods (Barrett and Bevis, 2015). These soil-based mineral deficiencies contribute to the SQ poverty trap since much of the world's poorest have livelihoods that depend on physical labor, and when they are unable to reach their full earnings potential due to compromised health and development, they fall behind. In addition to health and nutrition concerns, soil poverty can also contribute to ecological risk and environmental shocks.

4.3 Soils and Risk

Beyond the direct yield effects of soil in agriculture, soils have been shown to influence how well smallholders recover from environmental and economic shocks (Barrett and Bevis, 2015). For example, poor soil fertility may make a farmer's field more susceptible to drought, pests, and disease. In particular, Barrett and Bevis's 2015 study examined how parasitic weeds, particularly Striga, thrive in low-nutrient soil conditions. This poses yet another challenge to low-income farmers, which in turn creates more labor, more strain, and susceptibility to falling into a poverty trap. In addition, poor farmers working in susceptible soils are less likely to invest in improvements or adopt new farming strategies because they cannot afford potential losses if yields are diminished. In contrast, farmers working fertile fields face lower crop yield risk, allowing them to pursue higher-return agricultural activities (Barrett and Bevis, 2015). This difference in susceptibility between poor and healthy soils demonstrates how soils influence future investment. However, many of the world's poorest communities depend on degraded lands for their agricultural livelihoods (Barrett and Bevis, 2015). Degraded soil, in turn, makes agricultural pursuits and future investments increasingly less fruitful. Given the numerous ways in which degraded soils can trap people in poverty, intervention is necessary to break these cycles.

4.4 Inorganic Soil Fertilization

Given that SQ holds importance in poverty alleviation, inorganic fertilization of degraded soils seems like a simple solution. Further, inorganic fertilization is a popular approach to agriculture, especially in first-world countries where nearly 100% of farmland uses inorganic fertilization (Kim and Bevis, 2019). However, research has shown that inorganic soil fertilization is not a widespread approach in much of the global south; less than one-third of sub-Saharan African farmers use inorganic fertilizer (Kim and Bevis, 2019). Additionally, one-third of the world's soils are degraded, with over 40% located in Africa (Warui, 2024). This demonstrates that fertilizer adoption remains low in the areas that need it the most. This is because inorganic fertilizer is expensive in developing countries (Kim and Bevis, 2019). The price may exclude participants who want to improve SQ but cannot afford it. Additionally, inorganic fertilizers may increase operating costs but not produce the necessary profitability, further jeopardizing poor communities and forcing them into poverty traps. For these reasons, inorganic fertilizers do not work for the world's poorest communities. This is problematic because many of the world's poorest people disproportionately live in areas with degraded soil (Kim and Bevis, 2019). Given the financial barriers to chemical fertilization, one method involving tree-planting has emerged as a potentially more accessible alternative that works for the world's poorest while improving SQ in cash-strapped environments.

Main Findings

5.1 The Improved Fallow

The improved tree fallow is a cost-effective method in which fast-growing nitrogen-fixing trees are planted and left to rest for one or more seasons to improve SQ in agricultural fields (Franzel, 1999). An example of fallowing is shown in Figure 1. Fallowing extends back to the ancient Romans, who depended on this method to improve crop yields (White, 1970). However, in contemporary times, as population sizes increase, fallow periods are reduced, and continuous cropping has become more frequent (Franzel, 1999). However, this does not mean that fallows are ineffective for agroforestry. In fact, the improved tree fallow is a more flexible approach than other practices, such as alley cropping, in which trees are grown simultaneously with crops (Franzel, 1999). This is because alley cropping is labor-intensive; hedges must be cut back repeatedly to avoid competition with crops. In clear contrast, trees in a fallow are less labor-intensive since they can be cut over a period of weeks before land preparation begins (Franzel, 1999). Understanding the economic viability of such methods is important for determining whether they are a suitable option for low-income farmers.

Figure 1. Maize cultivation in the Batéké Plateau, Republic of Congo, following a fallow year of Acacia auriculiformis. Source: Photograph by Dominique Louppe (2008).

5.2 The Economics of Improved Tree Fallowing

Because a segment of the agricultural field lies idle for a season or more, one would intuitively expect that a yield must be at least double to make up for the lost production during the fallow. However, improved fallowing yields require much less labor and thus less fiscal costs. Therefore, only a 21% increase following the fallow season is needed to break even (Franzel, 1999). Over a five-year period, a case in Zambia found that fallow plots used 11% less labor compared to unfertilized maize but harvested 83% more produce (Franzel, 1999). In some cases, returns to land were over 20 times higher on an improved fallow plot (Franzel, 1999). An economic analysis of improved fallows found that a two-year fallow yielded the most profitable results compared to a one- and three-year fallow (Franzel, 1999). Furthermore, the improved fallow offers impressive returns but requires minimal cash inputs (Franzel, 1999). Research has shown that low-income farmers across multiple developing countries are more likely to adopt improved tree fallows versus inorganic fertilizers, likely because the fallows require little cash (Franzel, 1999). This is especially appealing to cash-strapped communities struggling with soil degradation. In this way, improved tree fallows are a possible people-first approach to SQ restoration that utilizes tree-planting effectively. While these economic benefits are compelling, some farmers have developed even more cost-effective adaptations of the fallow approach.

5.3 The Invasive Tree Fallow

Low-income farmers have developed innovative, opportunistic approaches to restore SQ to further reduce the cost of improved tree fallows. Some researchers argue that, because improved tree fallows may still be too expensive for low-income farmers in some cases, they have not been widely adopted (Tassin et al., 2012). To remedy this problem, low-income farmers have "developed a novel approach to agroforestry fallows by taking advantage of spontaneous invasions of woody leguminous tree species present in the vicinity of their fields" (Tassin et al., 2012). This approach is particularly effective because the characteristics of tree species in improved fallows are shared by many invasive plants (Richardson et al., 2003). Though these trees are labelled as invasive by environmentalists, this does not discount their usefulness to the world's poorest communities (Tassin et al., 2012). Further, taking advantage of the characteristics of invasive species is a cost-effective and pragmatic strategy for restoring SQ (Tassin et al., 2012). It has also been shown that, compared to other methods of fallowing, opportunistic invasive fallowing is more efficient at restoring SQ over a shorter period and more profitable, making it a more viable solution for low-income farmers wishing to improve SQ, as illustrated in Figure 2. Beyond reducing costs through invasive species, farmers have also discovered ways to enhance the economic and nutritional value of fallows.

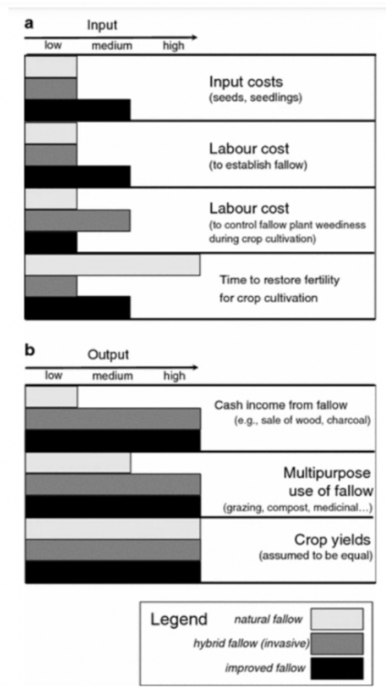

Figure 2. Hypothetical differences in input costs and outputs across natural, hybrid (invasive), and improved fallow systems influencing adoption decisions. Source: Reproduced from Tassin et al. (2012).

5.4 The Hybrid Fruit-Bearing Fallow

Through the use of fallows, farmers can increase the amount of economically valuable tree species without much labor or intense planting efforts. When farmers leave valuable trees standing, such as fruit and palm species, and clear the other varieties, these economically valuable trees will drop seeds that can grow well in newly created fertile soil (Unruh, 1990). Over many fallow cycles, the area will accumulate more useful species without requiring the individual planting of each tree (Unruh, 1990). This method can replenish nutrients in the soil and improve the rate of soil recovery (Unruh, 1990). In addition, a fruit-bearing fallow can yield many benefits beyond improving SQ, such as helping alleviate labor and capital constraints, as well as providing additional income through the sale of fruits at market (Szott et al., 1991). In addition, fruit may help to alleviate some susceptibility to malnutrition by restoring nutrients to produce. In turn, this could help the world's poorest communities avoid falling into poverty traps due to malnutrition, as mentioned above. The benefits of fallowing go beyond just soil fertility and nutrition and include significant pest management advantages.

5.5 Fallows and Pest Reduction

Research conducted by the United States Department of Agriculture found that in California peach orchards, one year of fallowing increased tree growth by 50% (Trout et al., 2001). Further, yields increased by an average of 20% after three to five years. The research found that after three years of fallowing, it was as effective as methyl bromide fumigation without a fallow period for removing pests (Trout et al., 2001). These findings demonstrate that fallowing is an effective method for improving tree growth, producing yields, and eliminating pests. Pest reduction is just one of several non-soil benefits that motivate farmers to adopt improved fallows.

5.6 Additional Benefits of Fallows

Improved fallows provide additional benefits beyond soil and pest-reduction benefits. For example, farmers who planted improved tree fallows also received additional benefits, including honey, stakes, and fuelwood, which can be sold at market (Degrande, 2005). In some cases, these products were so beneficial that farmers adopted tree fallows in the first place because of these additional benefits, and not primarily because of improved soil fertility (Degrande, 2005). This further demonstrates how improved tree fallowing benefits people while simultaneously improving SQ and contributing, in part, to tree-planting efforts. However, like many nature-based solutions, fallows should not be treated as a cure-all. Despite the numerous advantages, it is important to acknowledge that fallows are not universally applicable or without limitations.

5.7 The Pitfalls of Fallows

Fallows may not be attainable for all low-income farmers. This is because fallow plots require moderate to high amounts of land availability, which may be unrealistic to leave idle compared to continuous cropping in certain contexts (Szott et al., 1991). Research has shown that in systems with abundant land, fallowing is more feasible than in land-scarce areas (Franzel, 1999). Further, as shown previously in this paper, longer fallow periods are more profitable, but these plots lock land up for a long time, which may not be profitable for some low-income farmers. In addition, leaving segments of a field idle may contribute to food security risks, despite a 21% increase over a fallow field (Franzel, 1999). In this way, fallows might increase a community's income but not its food supply, which can be hazardous if they are self-sufficient (Franzel, 1999). This means that fallows can create short-term food insecurity. Furthermore, low-income communities that cannot afford to buy nitrogen-fixing trees for improved fallow may be forced to rely on invasive species, which could pose problems for weed suppression in the future. Lastly, the benefits of improved fallow may be overemphasized because the market value of these commodities is not uniform, which could be harmful if farmers rely on these by-products to support their livelihoods. These limitations demonstrate the importance of context-appropriate implementation.

Conclusion

This paper has examined the complex relationship among large-scale tree planting, SQ, and chronic poverty. It builds on previous unpublished findings that large-scale tree-planting yields mixed, context-dependent results regarding SQ. The evidence reviewed in this paper demonstrates that SQ and poverty can create feedback loops that trap the world's poorest communities into chronic poverty in multiple ways (Barrett and Bevis, 2015).

Given this relationship, the promotion of large-scale tree-planting as a global climate solution must be heavily scrutinized; if large-scale tree-planting does degrade SQ, which research has shown it does, these methods are no longer "solutions" but instead risk widening the poverty gap for the world's poorest communities. Therefore, a business-as-usual approach to large-scale tree-planting jeopardizes those who are dependent on soil to maintain their livelihoods. Further, this paper discusses how inorganic fertilizer is often inaccessible to the developing world, where the majority of soil degradation occurs (Kim and Bevis, 2019). Therefore, even though a solution to SQ may exist for these communities, it is often out of reach. In response to these challenges with both tree-planting and inorganic fertilization, this research has identified promising alternatives.

This paper then investigates the improved tree fallow, as well as hybrid and invasive fallowing methods. Based on research, the fallow seems like an effective, people-first alternative to improving SQ that works for the world's poorest communities. This is because these strategies require little cash, reduce labor efforts, and provide additional benefits that can be sold at market. These benefits help demonstrate the potential of fallows where other methods fail.

Importantly, the fallow approach is promising for poor farmers because it allows them to substitute resources they have (e.g., land and labor) in turn for cash, a scarce resource (Degrande, 2005). Fallowing is accessible for low-income farmers, as research has found chronically poor communities were able to successfully adopt improved fallows (Degrande, 2005). In clear contrast, inorganic fertilization efforts require cash investments upfront, which excludes chronically poor communities.

As the world continues to pursue large-scale tree-planting, policymakers must become increasingly cautious to prevent exposing the world's poorest communities to poverty traps caused by soil degradation. The improved, invasive, or hybrid tree fallow demonstrates a possibly effective approach that can improve SQ, alleviate the effects of poverty, and contribute, in part, to reforestation efforts. However, these methods must be implemented with much attention to local contexts, economic constraints, and farmer consent.

Moving forward, this paper recommends higher standards for large-scale tree planting to prevent inadvertently creating poverty traps for the world's poorest. In addition, educating more low-income farmers in the developing world about the benefits of tree-fallowing could be extremely beneficial; not only could more farmers improve the SQ in their fields, but they could also mitigate the effects of climate shocks, increase yields, and receive other non-soil-related benefits, which may bolster their income. Lastly, this paper calls for further research to understand the effects of soil carbon and sequestration in improved fallow plots, enabling a more effective examination of the climate-mitigation impact of improved fallows.

Statement of Generative AI Use

Generative AI (Claude) was used to assist with organisational structure and editing for clarity. All research, analysis, synthesis, and argumentation are entirely my own. Grammarly was used to spell-check work.

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