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REVIEW

Cover cropping to prepare degraded lands for forestry: challenges and opportunities

Ilan Stavi[1,2] · Ieva Bebre[3] · Anastazija Dimitrova[4,5] · John Stanturf[6,7]

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Abstract
Cover cropping is practiced in conservation agriculture to preserve soil and water resources, alleviate soil compaction, sequester organic carbon, and control weeds. Meanwhile, cover cropping is rarely used in forestry, probably due to the lack of awareness of this management practice. In this short essay, we discuss the concept of utilizing cover crops to prepare degraded lands for afforestation or reforestation projects. The benefits of this practice are similar to those in agriculture. The risks of this practice are mostly related to plant-plant interactions, and particularly, to the potential competition for resources with the target trees. As such, this practice should be implemented cautiously, to prevent adverse impacts on the forest system. Also, attention should be paid to ensure the delivery of ecosystem services and functions by the target land. Further, the co-use of complementary practices may be considered to accelerate the success rate of cover cropping in degraded lands designated for afforestation and reforestation. Among these practices, application of soil additives, such as composts, manures, and biochars, may be useful in increasing soil concentrations of organic carbon and nutrients, thus improving soil quality and fertility. Additional complementary active practices may be the direct seeding or planting of nurse shrubs and trees, as well as the inoculation of soil surface with biocrust slurries, aimed to increase ecosystem complexity by forming a multi-story vegetation structure. Recommendations and guidelines for implementing cover crops in forestry should be site-specific and case-dependent, and consider both the desired benefits and potential risks.

Keywords Allelopathy · Climatic change · Facilitation · Leguminous species · Mixed cover crops · Nature-based solutions

Introduction

Cover cropping is a management technique in which plants are established to protect the soil, benefit a target plant, or both. This management practice serves primarily as a protective function, but cover crops may also be managed to produce food, fodder, or feedstocks. Cover crops serve several purposes. They control soil erosion, decrease soil compaction, sequester organic carbon, negate competing vegetation, protect the target plants against biophysical stressors such as herbivory, frost, solar irradiation, and more. Cover crops can

Extended author information available on the last page of the article also enhance soil fertility, improve soil and water quality, control pests and diseases, and enrich biodiversity and wildlife habitats. As such, cover cropping is frequently practiced in regenerative agriculture (Quintarelli et al. 2022; Khangura et al. 2023). One of the most prevalent cover cropping techniques is green manuring, in which a cover crop is plowed into the soil before sowing the main crop (Dong et al. 2021).

Alley cropping and silvopasture are two agroforestry methods that incorporate the cover cropping approach. In alley cropping, row crops or forage are planted in the alleys between widely spaced trees (Zamora et al. 2019; Honfy et al. 2023). Often, leguminous trees are planted because they fix nitrogen in the soil. In many alley cropping systems, the trees are periodically pruned to prevent crop shading. The pruning residues are then used as mulch, which protects the ground surface from the raindrop impact and from direct solar irradiation. Alley cropping in temperate regions is used with high-value timber trees, such as black walnut (*Juglans nigra* Linnaeus) and pecan (*Carya illinoensis* (Wangenh.) K.Koch) in North America, olive (*Olea* spp.) in Europe, and paulownia (*Paulownia* spp.) in China (Nair 2005; Zamora et al. 2019). The *taungya* system is a variation of alley cropping in which land is cleared and planted initially with food crops. Seedlings of a desirable woody species are then planted on the same land unit, either in combination with the food crops, or following several years of cultivation. The food crops are grown until the tree canopy closes, usually two to three years after planting, and the planted trees are managed for timber. The *taungya* system was developed in Southeast Asia and has spread throughout the tropics (Agyeman et al. 2003).

Silvopastoral systems combine trees with livestock production, using principles of managed grazing. These systems include trees spaced or planted in clusters throughout the pasture (Vrahnakis et al. 2014). Silvopastoral systems can be created by introducing forage into woodlands or tree plantations, or by planting trees within a pasture. In South America, cattle are excluded for a year or two until poplars (*Populus* spp.) planted to produce roundwood poles are established (Stanturf and van Oosten 2014). A specific advantage of silvopastoral systems, especially in warm climates, is the provision of shade, thus reducing heat stress for livestock animals (Deniz et al. 2023).

Some ecological processes contribute to understanding the biotic mechanisms that increase the effectiveness of cover cropping. Ecological facilitation or probiosis describes species interactions that benefit at least one of the participants and cause no harm to either (Gómez-Aparicio et al. 2004). Facilitations can be categorized as mutualisms, in which both species benefit, or commensalisms, in which one species benefits and the other is unaffected (Lin et al. 2012). Facilitation describes many benefits associated with cover crops, at least from a plant's viewpoint. For example, in a study in southern California, USA, cover crops comprising white clover (*Trifolium repens* L.), buckwheat (*Fagopyrum esculentum* Moench), pigeon pea (*Cajanus cajan* (L.) Millsp.), and mixtures of them interseeded with corn (*Zea mays* L.) grown for silage, did not reduce the height and aboveground biomass of the corn plants (Aime et al. 2023).

However, in terms of controlling competing vegetation, wise use of cover crops can be viewed under Egler's concept of initial floristic composition or the somewhat related concept of competitive exclusion (Egler 1954; den Boer 1986). According to this concept, two species with identical niches cannot coexist indefinitely, and the species initially present has an advantage over the latecomer. Hence, artificially established cover crops that occupy a target site prevent other plants from establishing. Yet, this concept relies on the assumption that the cover crop species is easier to manage and competes less with the crop species than other vegetation, especially aggressive and invasive species. Further, it is acknowledged that a cover crop may change its impact on the main crop, e.g., favor its growth initially and later become more competitive for limited resources. Regardless, the stress-gradient hypothesis predicts that facilitation vs. competition interactions vary inversely over abiotic stress gradients; facilitative effects are more widespread under high abiotic stress (Maestre et al. 2009). One way or another, Maestre and colleagues stressed that the nature of facilitative vs. competitive interactions between plants of different life histories is co-determined by a range of biophysical conditions, and is predominantly regulated by stress factors.

Despite its extensive use in agriculture, the practice of cover cropping in forestry, and particularly in afforestation or reforestation of degraded lands, is rather scant. Relatively few exceptional examples for such use, specifically as a site-preparation practice prior to afforestation or reforestation, have been found. For example, in Quebec, eastern Canada, cover cropping was found to successfully compete with weeds in afforestation-assigned lands (Lemieux and Delisle 1998). In central France, Balandier et al. (2009) found that upon woodland establishment, cover crops could replace herbicide application, and simultaneously decrease runoff generation and surface soil frost. In addition to these benefits, Wiström et al. (2018) suggested that cover cropping in forestry lands may limit nutrient leaching, increase nutrient cyclying, improve soil quality, moderate microclimate, and support food webs and biodiversity.

Climatic change, with the forecasted increasing frequency and magnitude of severe droughts and intense rainstorms, alongside the growing anthropogenic pressures worldwide, highlight the need for more awareness and, potentially, more widespread implementation of cover cropping in forestry. Unlike in agriculture, the general exclusion of tillage activities and the comparatively extensive nature of management practices in afforestation and reforestation lands are likely to maximize the benefits of cover cropping in forests. Specifically, cover cropping in such lands seems to boost plant species richness and diversity, ecological complexity, and sequestration of organic carbon.

Therefore, this short essay aims to describe the potential use of cover cropping as a site preparation practice prior to afforestation or reforestation of dysfunctional and degraded lands, while highlighting the potential opportunities and challenges, both for the planted trees and the delivery of ecosystem services and functions. Here we define cover cropping in forestry as a practice of growing herbaceous vegetation crops to protect and enrich the soil, and/or to improve the growth conditions for trees. The manuscript's main sections discuss the mechanisms involved in the ameliorative effect of cover crops in the restoration of degraded lands; plant-plant interactions as opportunities for cover cropping in forest land; the major challenges involved with this management practice; and supplementary practices that could complement cover crops. Then, we end with practical guidelines for land managers.

Mechanisms that enable the ameliorative effect of cover cropping in dysfunctional lands

Degraded lands may be restored either by passive or active means. Passive restoration relies mainly on prevention of anthropogenic impacts from human and livestock by fencing the target land. Such practices are considered relatively inexpensive and, therefore, are often the first choice (Morrison and Lindell 2011). In passive restoration, it is expected that once the target land unit is excluded from any anthropogenic use, soil functions and vegetation community will recover without additional interference

(Aradottir and Hagen 2013). However, while this practice may be effective in restoring slightly to moderately degraded or resource-abundant lands, it may be insufficient in severely degraded lands, under climate change, or where resources are scarce (Rohr et al. 2018). For example, passive restoration practices may be effective in moist regions such as tropical and temperate zones but may not be helpful in drylands (Miguel et al. 2020). At the same time, active means require a higher degree of intervention, where specific management practices are aimed at recovering the target ecosystem to a new stable or persistent state, which provides multiple ecological and social benefits (Ghazoul and Chazdon 2017). Whether passively or actively restored, one of the major indicators of land restoration is the increase in soil organic carbon pool and the resulting stimulation of microbial biomass and activity (Zhou et al. 2023), amelioration in macroaggregate formation and pedogenesis (Han et al. 2023), and increase in soil–water content (Stavi and Lal 2011). In terms of the carbon cycle, in addition to the edaphic and agronomic advantages of increasing stocks of organic carbon in the soil, the environment benefits from lower atmospheric concentrations of the carbon dioxide (CO_2) greenhouse gas (Lal et al. 2021), thereby mitigating climate change.

The most relevant land degradation processes are soil compaction and deformation, and soil organic carbon depletion. As such, cover cropping is perceived as a nature-based solution, which may effectively increase soil organic matter percentage, restore soil structure formation and aeration (Stavi et al. 2012), and improve infiltration capacity (Hudek et al. 2022). The increased soil organic matter stimulates microbial biomass and activity, and along with accelerated pedogenic processes and improvement of soil functions and health, increases the delivery of ecosystem services (Steenwerth and Belina 2008), thus contributing to the climate change adaptation properties of the forest system.

Simultaneously, the cover crops' aboveground biomass protects the ground surface from erosional processes. In terms of aeolian processes, the cover crops' shoots protect the soil surface from blowing winds, thus reducing soil erodibility (Darapuneni et al. 2021). Furthermore, similarly to the effect of other plants, the increased surface roughness imposed by the cover crops' aboveground biomass decreases wind velocity and augments turbulence at the ground level, thus intensifying trapping and deposition of wind-borne minerals and organic materials that build up the soil profile (Yan et al. 2011). Cover crops also protect the ground surface from raindrop impact, thus lowering the formation of mechanical crusts, and lessening surface sealing (Gabriel et al. 2021). Like native herbaceous vegetation, the cover crops' shoots increase surface roughness, thus decreasing the velocity of water overland flow and lessening hydrological connectivity. This increases the hydraulic conductivity and reduces the erosive power of runoff. As such, all types of non-mass soil movement, including interrill, rill, and gully erosion, subside (de Torres et al. 2018). This effect may be particularly prominent after wildfires, as water-repellant soils decrease infiltrability and increase ponding (Peppin et al. 2010). Cover cropping may also decrease off-site risks, such as siltation and contamination of surface water sources (Singh et al. 2018). For example, cover crops have been reported to decrease the leaching of agrochemicals, lessening the pollution of underground aquifers (Ortega et al. 2022).

Finally, cover crops' aboveground biomass can be harvested for livestock and biofuel production, reducing the reliance on crop residues, whose extraction from croplands is known to lessen the soil organic carbon pool, deplete soil quality, and generate land degradation (Blanco-Canqui et al. 2020). Harvesting cover crops certainly offers an additional incentive for their establishment in woody plantations but should be done cautiously in sites where more intricate restoration measures are applied.

Plant-plant interactions as opportunities for cover cropping in forest land restoration

The reintroduction of native species is a crucial part in restoration ecology (Wang et al. 2022). However, forest restoration is often still limited to tree planting (Mayfield 2016). When planning afforestation or reforestation activities, cover cropping should be strategically considered before or alongside tree planting, to increase ecosystem complexity and functioning. A holistic approach to cover cropping should consider not only single-species characteristics but also plant-plant interactions and species' phytosociological associations.

Species selection depends on the cover crop's purpose and is crucial in ensuring its functionality. While monospecific cover crops are generally used in agriculture, mixed cover cropping is more suitable for forestry and land restoration (Balandier et al. 2009). Mixed cover crops should strive to diversify species' functional traits, morphology, and life cycle (Wiström et al. 2018), with the aim of maximizing plant diversity, carbon sequestration, microbial activity, and nutrient cycling (Reicosky et al. 2021).

Though still understudied in the context of afforestation and reforestation, ecological facilitation and plant traits have been used to accelerate the delivery of ecosystem services and functions at multiple levels. Some of the most known methods of employing plant traits is broadcast seeding of leguminous species (*Fabaceae*), which fix nitrogen with their root nodules (e.g., *Trifolium spp., Lotus corniculatus* L.), and introducing plants with deep root system to prevent soil erosion (e.g., *Plantago spp., Anthyllis cytisoides* L.) (Boldt-Burisch et al. 2015; De Baets et al. 2007). Similarly, roots of *Medicago* spp. and *Poa* spp. are known to be colonized by a range of arbuscular endomycorrhizal species, which increase nutrient cycling and availability (Pivato et al. 2007; Göransson et al. 2008). Likewise, *Epilobium angustifolium* L. can improve nutrient cycling in target sites as it stores a large amount of nutrients in its aboveground parts, which regenerate annually (Göttlein 2014).

A cover crop composed of hardy and native forbs and grasses can potentially help foster the growth of trees by improving microclimatic and habitat conditions. Selecting hardy pioneer species with fast germination and growth may improve revegetation success, as they are expected to colonize the target area quickly (Wiström et al. 2018). Also, species with decumbent stems or vines effectively cover the soil, while their shoot stays relatively low and minimize interference with tree seedlings (Van Sambeek and Garret 2004).

Species' autochthony should also be considered when determining cover crop mixtures, primarily when used in forest or ecosystem restoration. Species selected for cover crops should fit the site conditions, resemble the local species pool, and ideally be locally sourced. Additionally, the local species pool should not be diluted with introduced or invasive species in such scenarios as this can present potential biotic risks and lead to adverse effects in the future.

Cover cropping as a strategy for forest restoration may resemble an early successional forest stage, where herbaceous and shrub species dominate the site. Early successional forest ecosystems are characterized by high species diversity composed of pioneers, opportunists, and generalists, as well as complex food webs and multiple ecosystem functions (Swanson et al. 2011). In conventional forestry, the ecological importance of this successional stage is often overlooked, yet it offers a period of high levels of structural complexity, with a high variability of foraging and nesting habitats for fauna, thus increasing local species diversity and food web complexity through habitat provision (Swanson et al. 2011).

A recent study from the Bavarian limestone Alps assessed the use of "an emergency seed mixture" in sites infested by spruce bark-beetle (*Ips typographus* L.). A mixture of light-demanding pioneer woody plants that are tolerant to a wide range of soil pH were selected, including silver birch (*Betula pendula* Roth), red raspberry (*Rubus idaeus* L.), red elderberry (*Sambucus racemosa* L.), whitebeam (*Sorbus aria* Crantz), and rowan (*Sorbus aucuparia* L.). Seeds of these species were pelleted and surface sown on site after a sanitary clear-cut, aiming for fast recolonization, thus minimizing nutrient loss, reducing humus decomposition, and creating better microclimatic conditions for tree regeneration. Seeding nurse shrubs and perennial herbaceous plants improved the germination rates of silver birch, suggesting that supplementary cover crop seeding can potentially benefit forest regeneration (Laniewski and Göttlein 2023).

In Scandinavia, cover crops have been used as an environmentally-friendly tool for weed control in woody plantings, replacing mechanical weeding. A mix of two-to-five cover crop species was reported to be optimal for weed control without adversely affecting the planted trees, but only when the cover crop did not include highly competitive species (Wiström et al. 2018). Another specific strategy is to use low-resource-demanding cover crop species to control resource-competitive weeds (Balandier et al. 2006).

Major potential challenges

The use of cover crops is not devoid of challenges, which are notably site-specific. In a comprehensive review study, Lamichhane and Alletto (2022) underlined several key challenges that reduce the success of cover crops in agriculture. These challenges included inappropriate species selection, poor seed quality, poor establishment rates, insufficient biomass production, knowledge gaps in ecophysiology and phenology, use of inappropriate mixtures of cover crop species, inappropriate management of cover crops, and insufficient knowledge on ecosystem disservices of cover crops. Because use of cover crops in forestry systems has not been thoroughly studied, each of these challenges must be considered. Currently, most relevant insights come from studies on agroforestry. However, cover crops in agroforestry are commonly introduced when the trees are already established rather than used for site preparation (Ben-Salem et al. 2018; López-Vicente and Wu 2019). Interviews with farmers practicing agroforestry revealed that cover crops increase the weed management workload (Brodt et al. 2020). Moreover, the higher soil moisture increased infestations of diseases and pests, including rodents, who damage the trees (Brodt et al. 2020).

When using cover crops as a preparatory practice for forestry establishment in dysfunctional and degraded lands, two contexts of potential challenges should be considered. First, similarly to the establishment of any plants, abiotic and biotic factors may limit the establishment of cover crops and, subsequently, the potential benefits they deliver to the trees. Specifically, climatic conditions at the target site must be considered during species selection (Grossnickle 2018). Second, the relationship between the cover crop and the tree seedlings must be considered, particularly the potentially negative impacts, e.g., competition for light, water, or nutrients between the trees and the cover crop (Balandier et al. 2006). One way or another, attention should be paid to prevent arrested succession, in which erroneous management hinders regeneration of the target ecosystem (see Soto and Puettmann 2020). Specifically, the risk of allelopathy – in which a specific plant species inhibits germination and growth of other plant species in its vicinity through the release of allelochemicals (Cummings et al. 2012), consequently limiting the ecosystem's species richness and diversity – should be thoroughly monitored. The scant knowledge of the potential impact of cover crops on native herbaceous vegetation and the planted trees further demonstrates these challenges.

In a rare study focused on the effects of cover cropping on tree seedling establishment in an afforestation project, Balandier et al. (2009) noted the low cover rate of sowed cover crops. The authors attributed this outcome to two main reasons: (i) the low emergence rate of the cover crops – possibly due to drought and elevated temperatures during the sowing period – and (ii) an inappropriate species mixture, which consisted of species with low competitiveness. Indeed, when selecting the seed mixture, it is preferable to choose species with high tolerance and flexibility to changing conditions (Balandier et al. 2009; de Blois et al. 2004). One way or another, judicious seed selection is a challenging aspect that requires further investigation, especially for species that do not co-exist in natural ecosystems (Balandier et al. 2009). Like other plants, the seed properties (e.g., viability, dormancy, and morphology) are additional factors that impact the success of cover crops. Seed priming, coating, and pelleting are some ways to increase the seeding success rate, but the limited controlled studies and the associated costs of these activities may be barriers to their implementation (Pedrini et al. 2020).

Granivory and herbivory may also challenge cover crop success. In the post-dispersal stage, seed predation by insects, birds, and rodents could lower the seed bank capacity (Schreiner et al. 2000). Grazing animals could also have an adverse impact (Adler et al. 2001). For example, while cattle grazing has shown to effectively control invasive species (Hillhouse 2019), it may be difficult to distinguish between the impact on these species vs. that on the cover crops. Other sites may be challenged by the presence of wild herbivores, which might cause substantial damage to the cover crops (SARE 2018).

Finally, the economic aspect of cover crop establishment and management can impose a substantial burden. In agroforestry, farmers have voiced the increasing complexity in management, mainly the greater expenditures for labor (Brodt et al. 2020). Therefore, comprehensive economic analyses are needed to better understand the required inputs and possible outputs from using cover crops (Blanco-Canqui et al. 2020) as a preparation means for afforestation or reforestation of degraded lands. In such lands, cover crops may prolong the establishment phase of the trees and lengthen the economic rotation period.

Supplementary practices

Climatic change, with the forecasted increasing magnitude and frequency of extreme events, alongside growing anthropogenic stressors, exacerbates the extent and severity of land degradation. Under such circumstances, the success rate of afforestation and reforestation projects established in dysfunctional or degraded lands is expected to be reduced. These trends emphasize the need for implementing best management practices (BMPs) that are expected to further improve the climatic change adaptation of forest systems. We propose that cover cropping prior to tree planting may increase the success rate and net primary productivity (NPP) of afforestation and reforestation projects to be established in degraded lands. Further, to maximize success rates, cover cropping in degraded lands may be combined with complementary BMPs, aimed at further increasing soil quality and ecosystem functions, thus augmenting the establishment, survival, and growth of both the cover crops and the trees. As shown in Fig. 1, a judicious combination of cover cropping and complementary BMPs may increase the ecosystem's NPP, functions, and services.

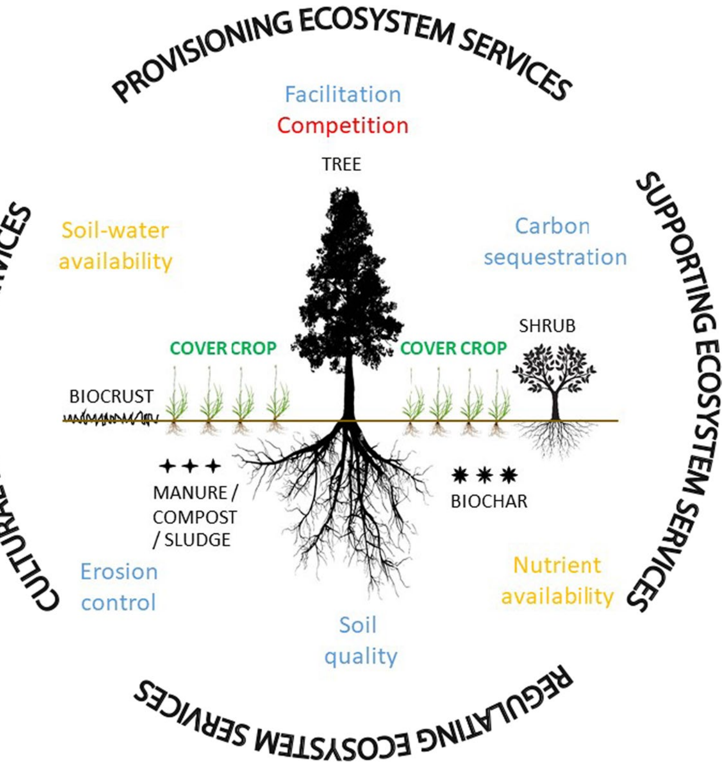

Fig. 1 Schematic illustration of cover cropping and complementary restoration practices in a multi-story forest, and their effects on ecosystem functions and services (positive effects in blue; negative effects in red; and case-dependent effects in orange)

Applying organic amendments to soil is predominant among the complementary management practices. As in agricultural systems, livestock manures and composts are the most common amendments. As shown in numerous studies in agricultural systems, the application of manure increases soil organic carbon concentration, microbial biomass and activity, aggregate stability, soil structure formation, nutritional status, and soil health (e.g., Wang et al. 2013; Jiang et al. 2022). The enhanced soil quality and functions are expected to boost vegetation productivity and overall ecosystem health (Rayne and Aula 2020; Miyamoto et al. 2023).

In addition to livestock manures, treated municipal sewage sludges have also been used as a source material for organic soil additives in agriculture. While many studies highlighted the potential environmental risks involved with this practice, some studies showed that considering the prevailing biophysical conditions and judicious use of complementary management practices, treated and composted sludges may be safe for agricultural use (e.g., Hamdi et al. 2019; Murray et al. 2019). In addition to the on-site benefits of organic amendments, treated sludge transforms an environmental burden into a valuable resource and conserves resources that would otherwise be disposed of through conventional means, such as incineration or landfilling (Healy et al. 2015). Nevertheless, attention should be paid to the concentrations of heavy metals, synthetic organic compounds, and organic contaminants in treated sludges, which may impose ecotoxicological risks even after composting (Wei and Liu 2005; Hudcová et al. 2019).

Also, the application of biochar—a solid (by)product of the carbon-negative pyrolysis technology for the production of bioenergy from biomass—as a complementary practice could improve soil quality and functions and substantially increase carbon sequestration capacity (Stavi 2013). Yet, under certain conditions, the biochar's properties—determined by the feedstock type, pre-processing treatments, pyrolysis temperature and duration, and post-processing treatments—may limit the availability of both macronutrients and micronutrients for vegetation uptake (Glaser and Lehr 2019; Rodríguez-Vila et al. 2022). Specifically, biochar immobilizes some elements due to adsorption on the biochar's surface and an alteration in the pH value of the amended soil (Rodríguez-Vila et al. 2022). Among the macronutrients, specific attention has been given to phosphorus (P) availability, which was shown to be adversely affected by the soil pH and biochar application rate (Glaser and Lehr 2019). Therefore, the use of biochar should be thoroughly controlled and monitored to detect and swiftly respond to any adverse impact (Thomas and Gale 2015).

Other practices could also be used alongside cover cropping. For example, the soil surface can be inoculated with cryptogamic biocrust slurries obtained from off-site source areas (Schultz et al. 2022). In addition to restoring biocrust communities in the target lands, this practice may also facilitate the growth of vascular plant communities that are seeded on the biocrusts (Bowker et al. 2022) and, specifically, accelerate the establishment of seeded cover crops. Also, biocrusted lands, particularly with a substantial share of moss, minimize soil erosional processes (Gao et al. 2020). However, depending on their composition, biocrusts may limit the growth of the seeded cover crops by lowering water infiltrability (Eldridge et al. 2000), an effect that may be particularly detrimental under limited soil–water conditions, such as in drylands. Therefore, biocrusts should be introduced cautiously, and favorable biocrust compositions should be selected.

Similar to natural systems, an additional complementary practice may be the direct seeding or planting of nurse shrub and tree species to improve nutrient turnover and cycling (Stark et al. 2015), as well as to increase spatial heterogeneity and ecosystem complexity (Feyera et al. 2002; Gómez-Aparicio et al. 2005), thus forming a multi-story vegetation structure (USDA-NRCS 2013). Additionally, the nurse shrub and trees may facilitate seedling development by providing shelter, refugia, or microhabitat sites with improved edaphic and microclimate conditions, protecting seedlings of the target trees against environmental and weather extremes (Feyera et al. 2002; Gómez-Aparicio et al. 2005, 2008). Further, planted or sown shrubs may be regarded as sacrificial plants, protecting the target tree seedlings from browsing animals, thus increasing seedling or sapling survivability (Maher et al. 2010; Perea et al. 2016). However, this effect can be site-dependent, determined by the nurse plants' shoot architecture and the target tree species' palatability, among other factors (Gómez-Aparicio et al. 2008). Sacrificial nurse shrubs and trees sown or planted very close (0–30 cm) to the target trees negate the need for fencing, a concern where browsing pressure is high. Further, some shrub species may be used as pest repellents, lessening the need for pesticide use. Also, in countries where herbicides are prohibited in forestry, fast-growing nurse shrubs and trees can control the growth of tree-competing weeds (Gardiner et al. 2001; Stanturf et al. 2009). Additionally, nurse shrubs and trees of fast-growing pioneer species, as well as the other complementary means, increase the ecosystem's carbon sequestration, further mitigating climatic change (Navarro-Cano et al. 2018).

Practical recommendations and guidelines

In agricultural applications, cover crops are usually terminated. Usually, this step can be omitted in forest regeneration to avoid unnecessary soil disturbance. Yet, under certain conditions, e.g., where ground surface is heavily compacted, disturbances such as plowing or disking may be needed. One way or another, in degraded lands, the cover crop should be perceived as a means to create better conditions for tree regeneration and soil protection and, to a lesser extent, as green manure. The established cover crop is expected to naturally disappear with time as the trees mature, the canopy closes, and the forest enters later successional stages.

Guidelines for using cover crops as a preparation means of degraded lands for afforestation or reforestation should be site-specific and case-dependent. Yet, as an overall concept, native annual species that are highly-tolerant to droughts, fast growing, and have low-resource demand should be selected. At the same time, perennial, exotic, allelopathic, and potentially invasive species should be avoided. Specifically, attention should be paid to grasses, which occasionally are aggressive colonizers, and can deplete available resources quickly (Balandier et al. 2009). Therefore, planning a lower ratio of grasses for a cover crop in areas prone to drought, or choosing less competitive (e.g., annual rather than perennial) species, may be beneficial. Seeding density is an additional factor to consider when planning a cover crop for forestry. The cover crop should be dense enough to reduce water evaporation from the soil, while not adversely affecting resource availability (Sharma et al. 2018). Regardless, practicing complementary/supplementary BMPs, such as application of livestock manures, sewage sludge, or biochars as soil amendments, should consider a wide range of logistic and economic issues, for example, transportation and access limitations, existing irrigation pipelines and other infrastructures, and the feasibility and cost of application.

One way or another, cover cropping, alongside complementary BMPs, should be first validated in controlled or semi-controlled environments. Later on, field studies conducted under a range of biomes, climatic regions, and biophysical conditions, can safely assess the geo-ecological benefits and risks. If the cover crops compete with the planted trees despite cautious implementation, the cover crops should be removed, and the system should be reassessed. It is expected that over time, increasing awareness of the cover cropping practices, supported by context-specific research, could assist in restoring extensive dysfunctional lands and alleviating global land degradation. Climatic change, with the increase in duration and severity of droughts on the one hand, and increasing magnitude and frequency of intense rainstorms on the other hand, with the consequent acceleration in soil erosion and land degradation processes, emphasizes the global relevance of this management practice.

Conclusions

In this short essay, cover cropping is discussed as an active restoration practice of degraded lands before afforestation or reforestation, aiming to substantially improve the climatic change mitigation and adaptation properties of forest systems. While this management practice encompasses some substantial benefits for the delivery of ecosystem services and functions, such as soil erosion control and carbon sequestration, it may also challenge the planted trees. Therefore, wherever applied, this practice should consider the prevailing biophysical conditions and be thoroughly monitored to track potential risks. Overall, it is expected that increasing awareness of this practice, coupled with its judicious use, may assist in restoration of degraded lands worldwide. The increasing climatic and (other) anthropogenic stressors worldwide over the recent decades emphasize the relevance of this track.

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Authors and Affiliations

Ilan Stavi[1,2] · Ieva Bebre[3] · Anastazija Dimitrova[4,5] · John Stanturf[6,7]

✉ Ilan Stavi
istavi@adssc.org

1 Dead Sea and Arava Science Center, 88820 Yotvata, Israel

2 Ben-Gurion University of the Negev, Eilat Campus, 88100 Eilat, Israel

3 Skyseed LLC, Rollbergstraße 28a, 12053 Berlin, Germany

4 Department of Seed Science and Forest Stands, Hans Em Faculty of Forest Sciences, Landscape Architecture and Environmental Engineering, Ss. Cyril and Methodius University in Skopje, Skopje, North Macedonia

5 Department of Bioscience and Territory, University of Molise, Pesche, Italy

6 InNovaSilva, 7100 Vejle, Denmark

7 Estonian University of Life Science, 51014 Tartu, Estonia