Afforestation of Abandoned Agricultural and Degraded Land

LWS 548 Major Project

By
Haoyue Wang

Master of Land and Water Systems
Faculty of Land and Food Systems
University of British Columbia

Vancouver, British Columbia

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ABBREVIATION

The Grain for Green Project - GGP
Soil Beneficial Microbes - SBMs
Arbuscular Mycorrhizal Fungi - AMF
Plastic Film Mulching - PM
Straw Mulching – SM

EXECUTIVE SUMMARY

Afforestation helps to restore abandoned agricultural and degraded land into productive forests. Abandoned agricultural land and degraded land with improper use can have significant long-term losses of ecosystem function and services. Afforestation establishes a forest community on the land and helps the land recover to continue to provide ecological goods and services. The relationship between the microbial community and afforestation was found to be the most important factor for a successful outcome. Afforestation can increase microbial diversity, and the application of mulches, legumes, and biofertilizers are considered as good methods to adapt the microbe community and promote the success of afforestation. It is recommended that the general procedure for afforestation is by first defining the reference system and then describing a mix-species plantation with native tree species.

INTRODUCTION

Afforestation is to establish trees on the land that has not been managed for forests before or where forests have been missing for at least 50 years (UNFCCC) (Niu & Duiker, 2006; Emiliano, 2019). Afforestation is an important restoration method to recover abandoned agricultural and degraded land. Much agricultural land was once forested. With population growth and increasing demands for food and fiber, agricultural expansion occurred and caused the conversion from forest to agricultural land (Rudel et al., 2005). Agricultural land area in the world increased from $15.84*10^6$ km^2 in 1983 to $16.79*10^6$ km^2 in 2003 (Benayas et al., 2007). As shown in figure 1, with the growing demand for agricultural land, the world has lost about one-third of global forests in the millennia (Hannah, n.d.).

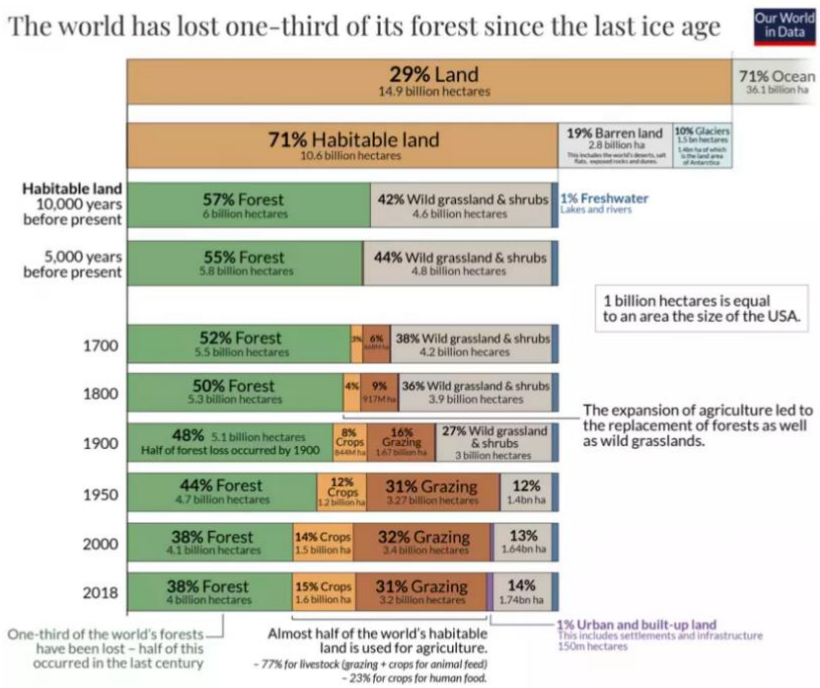

Figure1. Land use change over the millennia. (Source: https://www.weforum.org/agenda/2021/02/ice-age-forest-lost-demand-agriculture/)

However, much agricultural land is abandoned with world development. In this paper, abandoned agricultural land represents the land with the transition from frequently intensive traditional farming to less intensive land use or with the termination of farming and cultivation, but not converted to forest or urban areas (Pointereau et al., 2008; Kuliešis and Šalengaitė, 2010; Visockiene et al., 2019; Wiegmann et al., 2008). There are about 950 million to 1.1 billion acres of abandoned agricultural land around the world (Campbell et al., 2008). Global studies have suggested seven categories of factors for agricultural land abandonment, including demographic, household characteristics, farm characteristics, biophysical, economic, social-political, and regulatory (Subedi et al., 2021). There was increasing off-farm activity with urbanization and industrialization, and many mountain farmers migrated either temporarily or permanently to urban areas, so rural emigration and immigration stimulated land abandonment (Khanal & Watanabe, 2006). When agricultural land is abandoned, the number of harmful pests for the cultivated agricultural plant will grow several dozen times in the abandoned area (Visockiene et al., 2019). Abandoned agricultural land can result in environmental deficiencies, including loss of biodiversity, soil erosion, mobilization of stored carbon, soil nutrients loss, and usable water resources loss (Alcamo et al., 2005). Therefore, it is essential to restore abandoned agricultural land and reduce its negative impacts on ecosystems.

Degradation can be defined as a reduction in productivity of the land or soil due to human activity (Holmet al.,2003, Kniivila, 2004, Oldeman et al., 1990). The improper use of land can cause the long-term loss of ecosystem function and services and make the ecosystem unable to recover unaided (UNEP, 2007; Wiegmann et al, 2008). Land degradation reduces plant growth, causes the loss of protective soil cover, and increases the vulnerability of soil and vegetation functions (El-Beltagy, 2000). Land degradation will ultimately lead to a reduction in soil fertility and productivity (Wiegmann et al., 2008). Afforestation of abandoned and degraded land helps land to recover.

There is a need for afforestation of abandoned agricultural and degraded land. Afforestation is to establish tree plantations and encourage the return of native vegetation (Williamson et al., 2018). This paper will discuss afforestation from an ecological perspective, to establish a forest community, and then let nature take its course. Afforestation can bring several ecological benefits. Afforestation helps to increase biodiversity, decrease fragmentation, and do water protection (Bowen et al, 2007). Also, once trees are established, there is little need for management (Alig et al., 1997). Afforestation helps carbon sequestration, and carbon sequestration transfers atmospheric CO_2 into long-lived pools in the soil can keep CO_2 stored securely, and there is limited immediate re-emittance back to the atmosphere (Lal et al., 2003). Carbon sequestration is a viable option to slow the rise of greenhouse gas concentration in the atmosphere (Niu & Duiker, 2006). By 2050, 424 million acres of abandoned farmland can be restored and reduce about 14.1-30.8 $GtCO_2$-eq (Hawken, 2017).

This paper will also assess the potential success of afforestation. Although the importance of afforestation of abandoned agricultural land and degraded land is addressed by many authors, and previous studies have recorded several methods and results of different afforestation projects, there are few studies indicating a general solution of afforestation for abandoned agricultural and degraded land. A general framework is needed to guide people effectively restore the ecosystem by afforestation. The forest site must be analyzed in depth before afforestation to maintain the success of afforestation and the healthy growth of forests later (Duan & Abduwali, 2021). Suitable tree species for afforestation is a major challenge which require considerably more research. It is important to recognize that microbiomes in agricultural land and forests are different, so it is important to know the difference between microbiomes and manage the microbiome to promote the change from agricultural land and degraded land to forest. All the microbes of a community are called microbiomes.

OBJECTIVES

The main objective was to "to assess the potential success of afforestation". A systematic literature review was conducted to compare previous afforestation works. A general framework to do afforestation of abandoned agricultural land and degraded land will be summarized. Actions needed for afforestation will be discussed, and a suggested method for afforestation will be given. The main goal is to address the following questions:

- What are the main procedures of afforestation?
- How to choose the right tree species for afforestation?
- What are the microbiome differences between agricultural land and forests? How to modify microbiomes to stimulate the conversion?
- What are the challenges and opportunities faced by doing afforestation?

METHODS

A literature review and a synthesis were conducted on the advantages and limitations and using afforestation as a reclamation management tool and a review of previous afforestation projects. General applicable afforestation methods are summarized after doing the literature review. For each of the afforestation projects, the following questions are analyzed:

- What procedures were conducted in the project?
- What tree species are used for afforestation and what criteria decides the tree species (native species or exotic species)?
- Did this project manage the microbiome to stimulate the conversion to forest?
- What were the advantages and challenges identified?

To decide if an afforestation project is successful, the ecological benefits, social benefits, and financial benefits were assessed. The assessment is a subjective evaluation by the author:

- For ecological benefits, the following aspects were analyzed: What is the survival rate of planted trees? Did it stop any threats (e.g., fire)? Did it reduce soil erosion? Did it increase soil fertility? Did it contribute to carbon sequestration? Did it increase biodiversity? Did it increase ecosystem functionality?
- For social benefits, the following aspects were analyzed: Did it benefit local livelihoods? Did it do "provision" of local necessities such as food, water, timber, and fiber? How did this project affect surrounding communities (e.g., educate the surrounding communities)? Was it helpful to social development? Was it beneficial in solving social problems?
- For financial benefits, the following aspects were analyzed: How much did this project cost? Did it bring any economic benefits (e.g., provide jobs for people or stimulate local economic development)?

A decision matrix was used to assess the previous projects. For the weight of each criterion, the ecological benefit was assigned with the highest weight (5), and the social benefit is assigned with the second highest weight (3), and the economic benefit is assigned with the lowest weight (2). The individual score will be given for each criterion after reviewing the previous projects, and the individual score will multiply the weight of the criteria to get the total weighted score. A higher total weighted score means a more successful project.

Table 1. The decision matrix will be used to assess the previous projects.

Criteria:	Weight of criteria	Individual score	Weighted score=weight of criteria*individual score
Ecological benefit	5		
Social benefit	3		
Economic benefit	2		
			Total weighted score

RESULT AND DISCUSSION

A summary of restoring the forest in Uganda

Background information:

Uganda tropical moist broadleaf forests with 849 native tree species were selected. Agriculture, deforestation, urbanization, transportation, and industry had caused land degradation. Uganda has 52,416 ha (0.26%) area under restoration, and Uganda has pledged to restore 2,500,000 ha (12.47%) land by 2020 (Uganda Bonn Challenge). Uganda's forest cover decreased by approximately 300 000 hectares from 2000 to 2012 due to the increasing demand for forest products and agricultural expansion, which equals 1.8% of its total land area (Hansen et al., 2013). This project was led by Tooro Botanical Gardens (TBG), which is a non-profit organization (NGO). This project began in 2012-10 and plans to end in 2030-12.

Main procedures:

The project aim:

This project aimed to raise awareness of the diversity of native tree species in Uganda, increase the supply of genetically and species-diverse tree seedlings for restoration, restore degraded forest reserves to benefit biodiversity, and provide employment opportunities for rural communities.

The scale of the project:

This project worked on Central Forest Reserve and two Local Forest Reserves in Uganda, and then it was scaled up to projects across Uganda and established 4 new indigenous tree nurseries next to identified high priorities areas.

The reference ecosystem:

This project identified the reference ecosystem by conducting surveys in the nearest remaining forest area, examining the extent of forest sites, and analyzing field indicators and historical records. The project used the reference ecosystem to identify the tree species for restoration.

Tree Planting:

TBG produces around 40,000 native tree seedlings for restoration every year. TBG provided the largest native tree seedlings per year. This project plants on average 80 native trees at each site. This project also plants species to attract seed dispersers. Besides planting trees for restoration, this project allows people to plant leguminous vegetables in between young trees. This project employs people from nearby communities to plant trees, and TBG offers training courses to teach them how to do seed collection, propagation, and nursery management.

Monitoring and results:

This project monitored the conditions of the restored area and analyzes the restoration outcomes. TBG monitors the survival rate, height, canopy width, and root collar diameter of trees. The measurements are conducted at the end of each rainy season. As a result, the average survival rate of planted trees is 83%, and one tree species had a 99% survival rate in 2018. Encroachment of the planted sites has greatly reduced, the canopy cover has increased, soil erosion has decreased, the connectivity between restored areas and their surrounding forest patches has increased, and the bird diversity has increased significantly. According to the high survival rate of planted trees and the positive impacts identified above, this project can be identified as a successful project.

Summary and assessment of the project:

- **What tree species are used for afforestation?**

  Native tree species were used for afforestation. People decided which tree species by referencing the reference ecosystem. Reference ecosystems can provide the basis and benchmark for the project, and reference ecosystems usually have no interference from human activities and no exotic species invasion (TH, 2017). Reference ecosystems are expected to have potential natural vegetation in most areas (Dislich et al., 2017). After deciding the reference ecosystems, the manager can develop strategies to make disturbed sites and areas to emulate attributes in reference ecosystem and help the disturbed sites back to their natural states (Goebel et al., 2005). An average of 80 native tree species were planted at each site. Also, leguminous vegetables were planted in between the young trees, which can provide food for people and increase the soil properties. Legume seeds contain 20% to 30% protein and are Lys-rich, and they can complement the nutritional profiles of cereals and tubers in the diet (Duranti & Gius, 1997). Legumes offset increases in atmospheric CO_2 levels while enhancing soil quality and tilth (Graham & Vance, 2003).

- **Managing the microbiome to stimulate the conversion to forest**

People planted leguminous vegetables in the restoration areas between young trees, to help change the microbiome in the restoration area. In agricultural land, intensive agricultural practices and heavy use of inorganic fertilizers accelerate soil degradation and can cause the mineralization of soil organic matter and reduce soil beneficial microbes (SBMs) (Eka et al., 2020). Legumes can get N_2 from the atmosphere through symbiosis with Rhizobia bacteria (Van Kessel & Hartley, 2000).

The N addition in soil aggregates can increase the soil microbial carbon use efficiency (CUE), and the increase of CUE will stimulate terrestrial C cycling and increase soil organic carbon and microbial biomass carbon (Zhao et al., 2022). The N addition promotes the growth of microorganisms in macro-aggregates since it can increase the availability of nitrogen and alleviate nutrient limitations in microorganisms (Zhao et al., 2022).

- **Ecological benefits (Score: 8 out of 10)**

This project provided high ecological benefits. The planted seedlings had high survival rates, and the average survival rate was 83%. That's a high potential to significantly increase the number of trees in the restoration sites. This project improved the soil condition and reduced run-off. An average of 80 native tree species were planted at each site, which helps to improve the biodiversity of the restoration region. Some specific species were planted to attract seed dispersal. This project increased the canopy cover and improved the connectivity to its nearby forests. The bird diversity increased as the number of trees increased. Leguminous vegetables were planted during the restoration, and leguminous vegetables helped to improve soil properties, and diversify microscopic life, while not negatively influencing the growth of planted trees (Navarro-Cerrillo et al., 2009). Therefore, the ecological benefits score of this project was 8 out of 10.

- **Social benefits (Score: 5 out of 10)**

This project stopped the previous illegal cultivation in this region. Uganda has both regional and seasonal food insecurity and some people in Uganda suffer from malnutrition (Shively & Hao, 2012). This project worsened the food deficiency problem in the restoration region at the beginning and caused dissatisfaction from the public. However, the diverse planted trees provided fruit and non-timber forest products for residents in the restoration area. The planted leguminous vegetables provided food for people as well. The fruit and leguminous vegetables in this project helped to provide local food and solve the food deficiency problem, but the amount of food provided was still limited and the provided food was only fruit and leguminous vegetables. Rural communities in the restoration region had limited employment opportunities. As this project proceed, people in this region attended forest restoration training courses and were hired to do tree plantings, so this project contributed to the number of employment opportunities in this region. Also, government, NGOs, schools, and higher education groups have joined this project, and people can learn knowledge and skills from these organizations. Therefore, this project can educate the surrounding communities The social benefits score of this project is 5 out of 10.

- **Financial benefits (Score: 4 out of 10)**

Residents used part of the restoration area for illegal cultivation before this restoration project, so this project stopped the illegal cultivation which resulted in the reduction of crop production in this region and resulted in the reduction of the rural community's income. However, the planted trees can provide fruit and non-timber forest products, so people can earn money by selling these products. This project can improve the aesthetic value and can make the restoration area become a recreation area. People may travel to the restoration area due to the high aesthetic value, which has the potential to stimulate local economic development. Some people were employed to do seed collection and nursery work, so some people can get income from this project (100 people were employed for four nurseries). The funding for propagation and planting activities of this project is from Ashden Trust (2012 – 2018) and Darwin Initiative (2019 – 2021), and the founding is £10-£15,000 per year. This project can restore the ecological conditions with given funding. The financial benefits score is 4 out of 10.

Table 2. The decision matrix for the Uganda afforestation project.

Criteria:	Weight of criteria	Individual Score	Weighted scpre=weight of criteria*individual score
Ecological benefit	5	8	40
Social benefit	3	5	15
Economic benefit	2	4	8
		Total wighted score	63

A summary of restoring the forest in China

The Grain for Green Project (GGP)

Background information:

The forest exploitation and monoculture planting in China had led to species diversity decrease and soil erosion (Liu et al., 2013). China's eroded land increased by more than 10,000 km^2 every year during the 1990s, and at least 200 plant species were extinct since the 1950s, and more than 61% of wildlife species were facing habitat loss (Li, 2004). China's loess plateau area was with improper over-cultivation, overgrazing, and over-deforestation (Shi and Shao, 2000; Chen et al., 2007; An et al., 2005), has left the Loess plateau area with degraded land, desertification, and soil erosion problems. The Grain for Green Project (GGP) is the largest land afforestation program in China, and it is also the largest ecological restoration project in the world due to its scale and magnitude (Uchida et al., 2005). This project aims to stimulate sustainable development in China including ecological restoration. The GGP project started in 1999 and supported three types of land conversion, including cropland to the forest, cropland to grassland, and wasteland to the forest. The Loess Plateau area has a semi-arid climate. In the restoration area, the predicted average soil erosion rate is 15,000 tongs $km^{-2}year^{-1}$, the annual average temperature is 9.4 °C, and the annual average precipitation is 547.4mm. The topography of the restoration area is rough, and there were many steep slopes with an average of 50 to 200m relief. This project started early, so there were no sufficient sustainable ecosystem management methods and no guidelines available. This project's goal was to meet human needs while doing ecological restoration.

Main procedures:

The project aim:

This project was designed to restore the fragile ecosystem in the Loess Plateau area, which was damaged by unsustainable farming and grazing activities. This project aimed to reduce soil erosion, improve vegetation conditions, and improve the Loess Plateau environment condition in China. The government planned to spend US$40 billion on the project to restore 147 million ha of farmland into forest and grassland and restore 173 million ha of wasteland (grassland) into the forest in 25 provinces from 1999 to 2010 (Tao et al., 2004).

The scale of the project:

The GGP project aimed to do an ecological restoration of the Loess Plateau area. The restoration area includes the upstream regions of major river systems, including the Yellow, Yangtze, and Songhuajiang River basins. The restoration area was with severe land degradation. This project converted farmland, grassland, and wasteland into the forest in 25 provinces. This project focused mainly on restoring farmland with a steep slope (>=25°) since these steep slope lands were more likely to have soil erosion.

Monitoring and result:

This project altered the land cover patterns in a short time. The total vegetation cover in the restoration area increased 12.5% from 1998 to 2005. This project has increased the forested land coverage from 12.4% to 37.7% from 1995 to 2010, and cropland area decreased 46.3% and shrub-grassland area decreased 18.8% (Figure 2). 72 million ha of farmland has been transformed into forest or grassland (49% of 2010 target) and 79.3 million ha of grassland had been planted with trees (46% of 2010 target) by the end of 2003. The soil organic carbon has increased by 76% 23 years after the cropland restoration (Li & Pang., 2010), so this project has contributed to carbon sequestration. In the afforestation plots, R. pseudoacacia and P. armeniaca had greater areas of vegetation cover. The tree survival rate in the afforestation site was 55.7% in the first year and 49% in the 7th year, so nearly half of the planted trees survived after plantation. The mix-species plantation (R. pseudoacacia with C. korshinskii) and R. pseudoacacia showed the greatest canopy area, with 2.1 and 2.0 m^2 respectively.

However, the afforestation in the Loess Plateau area has deteriorated the water shortage problem, which can threaten the growth of trees in this region and result in a decrease in vegetation cover. The soil moisture of the afforestation plots was lower than that of abandoned plots (Table 3). The soil moisture increased during the first 2 years after afforestation, but it decreased after the third year. The reason for the decrease in soil moisture may be the use of exotic tree species. The use of exotic tree species in afforestation can affect biodiversity and break the ecosystem balance and stability. This project was in an arid and semi-arid region, so the low precipitation in this region cannot support the growth of these high-density planted exotic trees, so the tree species survival rate was low.

The number of plant species in the cultivation abandoned plots is higher than that in the afforestation plots. The afforestation plots have lower vegetation cover (32.3%) than the abandoned plots (44.6%). The lichen species showed a quicker development in the abandoned plots than in the afforestation plots. The average lichen cover in the afforestation plots was 38.4% in 2005, and the average lichen cover in the abandoned plots is 63.2%. Some of the natural vegetation is destructed and removed with the plantation activities since trenches were constructed to channel precipitation towards the tree. Some of the herbaceous vegetation was destroyed and removed under trees to ensure adequate moisture for trees as well. The decrease of soil moisture and reduction of sunlight due to the tree canopy can negatively affect the growth of vegetation as well. There is a about 30.5% decrease in vegetation cover in the afforestation area by year 7. This afforestation project had negatively affected the vegetation cover.

Therefore, planting exotic trees in vulnerable arid and semi-arid agricultural regions may result a decrease in total vegetation cover. The results of this project suggest that prohibition of cultivation and grazing in steep terrain is a better restoration method than exotic tree species afforestation.

Figure 2. The indication of cover changes with time caused by the GGP project. (Zhou et al., 2012)

Table 3. Soil moisture content (%) of cultivation abandoned plots and afforestation plots of GGP project 7 years after afforestation (the year 2005). (Cao et al., 2009)

Soil layer (m)	Abandoned plots	Soil moisture content (%)						
		Afforestation plot (based on % vegetation cover)						
		Average	<10	10·1–20	20·1–30	30·1–40	40·1–50	>50
0–1·0	16·60a	6·14c	8·49b	7·86b	5·78bc	5·30c	5·04c	3·50d
1·0–2·0	10·48a	5·99bc	11·28a	8·66ab	6·60b	4·12c	3·59c	3·35c
2·0–3·0	10·27a	7·49b	11·84a	9·77a	7·31a	5·85b	5·75ab	4·34b
3·0–4·0	11·42a	7·54b	12·39a	9·17a	7·22b	5·31bc	6·27b	4·65c
4·0–5·0	10·05a	8·13a	13·07b	9·58a	8·42a	6·40c	6·28c	4·77d
5·0–6·0	10·04a	8·10a	13·28b	9·20a	8·33a	6·42ac	6·27c	4·80d
Average	11·48a	7·23b	11·72a	9·04a	7·28b	5·57bc	5·53bc	4·23c

Summary and assessment of the project

- **What tree species are used for afforestation?**

Exotic species were used for afforestation in this project, including *Robinia pseudoacacia* (black locust), *Prunus armeniaca, Hippophae rhamnoides, Platycladus orientalis*, and *Caragana korshinskii. R. pseudoacacia* can grow under drought conditions and it can fix nitrogen (Grünewald et al., 2009), so it was chosen to be planted in the Loess Plateau region to fit the semi-arid climate. *Prunus armeniaca* is a common agricultural product of apricot species and it contains functional food components and high nutritional value, and it can grow in well-drained and organic matter rich soil (Akin et al., 2008). *Hippophae rhamnoides* is drought resistant, so it can be planted in arid and semiarid areas, and it can be used for food, medicine, and cosmetic purpose. (Suryakumar & Gupta, 2011). *Platycladus orientalis* is an evergreen coniferous tree and it is native to eastern Asia, and it is a common afforestation tree species since it is resistant to cold, dry, and salty soils (Li et al., 2016). In old *Platycladus orientalis* sites, they tend to have lower available phosphorus than in young tree sites (Li et al., 2018). *Caragana korshinskii* is widely distributed in northwest China and Mongolia and it belongs to the legume family, and it is tolerant to dry, cold, and salty environments, and can be used as a forage grass and feedstock (Yang et al., 2014).

The planted species are mostly drought resistant, which can help them grow well in a semi-arid environment. Some of the planted species can bring economic benefits, such as *Prunus armeniaca, Hippophae rhamnoides*, and *Caragana Korshinskii* can be used for food, medicine, cosmetics, or forage purposes. However, all the planted trees are exotic species, which can impact the ecosystem balance. These planted exotic tree species need more water to maintain their growth, resulting in a decrease in soil moisture. Also, some of the planted exotic tree species cannot adapt to the new environment, so the survival rate of the planted trees was only about 50%. Therefore, this project using exotic tree species for afforestation is not a good method.

- **Managing the microbiome to stimulate the conversion to forest**

The planted *Robinia pseudoacacia* and *Caragana korshinskii* belong to legume family. Legumes have a symbiotic relationship with rhizobia bacteria, and rhizobia bacteria help to fix atmospheric nitrogen into ammonia for plants and soil. Therefore, this project planted two legume species to increase the amount of rhizobia bacteria in the afforestation sites. Studies by Yao et al., (2019) proved that the planting of *C. Korshinskii* increased soil mineral nitrogen concentration and nitrogen mineralization. Gravel mulching was used in the Loess Plateau area as well. Gravel mulch helps to reduce surface runoff and increase soil moisture. Studies have proved that the gravel mulch on slopes in the Loess Plateau can improve soil physicochemical properties and benefit microbial communities, and small-sized gravel mulching is recommended for arid and semiarid areas (Lv et al., 2019).

- **Ecological benefits (Score: 3 out of 10)**

This project was assessed to have low ecological benefits. This project altered the land cover patterns and increased the forested land cover area in a short time. A large area of farmland and wasteland had been transformed into forests. Also, this project contributed to carbon sequestration. However, the survival rate of the planted trees is low. Furthermore, the ecological condition of the restoration site was further degraded after this project. The afforestation has caused water shortage problems and reduced soil moisture. The vegetation cover of the afforestation site is lower than it of the abandoned site as well, which means the afforestation activity had negatively affected the vegetation cover. According to the soil moisture condition, vegetation cover, and the number of plant species, the abandoned sites showed better performance than the afforestation site, so the afforestation activity of this project did not improve the ecological condition for the better, but to some extent deteriorated some ecological conditions. Therefore, the ecological benefits score of this project is 3 out of 10.

- **Social benefits (Score: 8 out of 10)**

This project is the largest land afforestation program in China, and it is of large scale and magnitude. This project is with large investment as well. The large investment showed the government’s concern for the natural environment, and the public can understand the importance of environmental protection. This project educated the public that the environment needs people's protection to make it more sustainable. This project started with a few afforestation guidelines and with no previously acceptable ecological restoration methods, so the initiation of this project can provide information for later restoration projects, and future projects can design restoration plans based on the results of the project. Although the result of this project is not perfect, this project is a good attempt. The results of this project are helpful to develop good restoration plans in the future, and this project helps people better understand nature. This project is beneficial to social development, and it can provide important information on solving similar problems in the future. In the meanwhile, the large scale of this project provided a large number of job opportunities for people, so this project is beneficial to local livelihoods. This project had stopped the agricultural activities and grazing actives in the restoration area, but some of the planted trees can provide fruit and food for people, and it can do provision of local necessities. The social benefits score of this project is 8 out of 10.

- **Financial benefits (Score: 2 out of 10)**

The government planned to spend US$40 billion on this project, so a large amount of money was allocated to this project. However, as discussed in the ecological benefits, this project did not successfully improve the ecological conditions of the restoration area, and the survival rate of planted tree species is low. This project with its high cost did not successfully restore the ecosystem, thus the project did not complete its goals and did not stimulate local economic development. This project had stopped the agricultural and grazing activities in the restoration region, so it reduced the income of local residents, and the foods provided by planted trees can help residents earn money by selling them. This project cost a large amount of money but did not successfully restore the ecosystem in the Loess Plateau, and it may need more money in the future to re-restore this area. Therefore, the financial benefits score is 2 out of 10.

Table 4. The decision matrix for the afforestation project in China.

Criteria:	Weight of criteria	Individual Score	Weighted scpre=weight of criteria*individual score
Ecological benefit	5	3	15
Social benefit	3	8	24
Economic benefit	2	2	4
		Total wighted score	43

How to manage microbiome to stimulate the conversion to forests

A microbiome can be defined as, all the microbes of a community, and in particular, for the plant microbiome, those microbial communities associated with the plant which can live, thrive, and interact with different tissues such as roots, shoots, leaves, flowers, and seeds (Bomberg & Ahonen, 2017). Soil microbiome affects the biogeochemical cycling of vital elements for plant growth, including macronutrients and micronutrients (Jansson & Hofmockel, 2020). Soil microorganisms always respond more rapidly to environmental changes than plant communities, and soil microorganisms affect ecosystem processes, including, litter decomposition, organic matter mineralization, nutrient cycling, and soil development (Van der Heijden et al., 2008; Cai et al., 2018; Delgado-Baquerizo et al., 2016). Microbial biodiversity and microbial community composition are important factors affecting plant growth. Microbial diversity is critical to maintaining multifunctionality (Delgado-Baquerizo et al., 2016) (Figure 3). Any loss in microbial diversity tends to reduce ecosystem functions (Delgado-Baquerizo et al., 2016). Land use type, plant community, soil properties, especially pH and available P and K, land-use intensity, and climate condition can affect microbial community composition (Cai et al., 2018; Fierer and Jackson, 2006; Tripathi et al., 2012; Xia et al., 2016; Yao et al., 2017; Jesus., 2009; Guo et al., 2016).

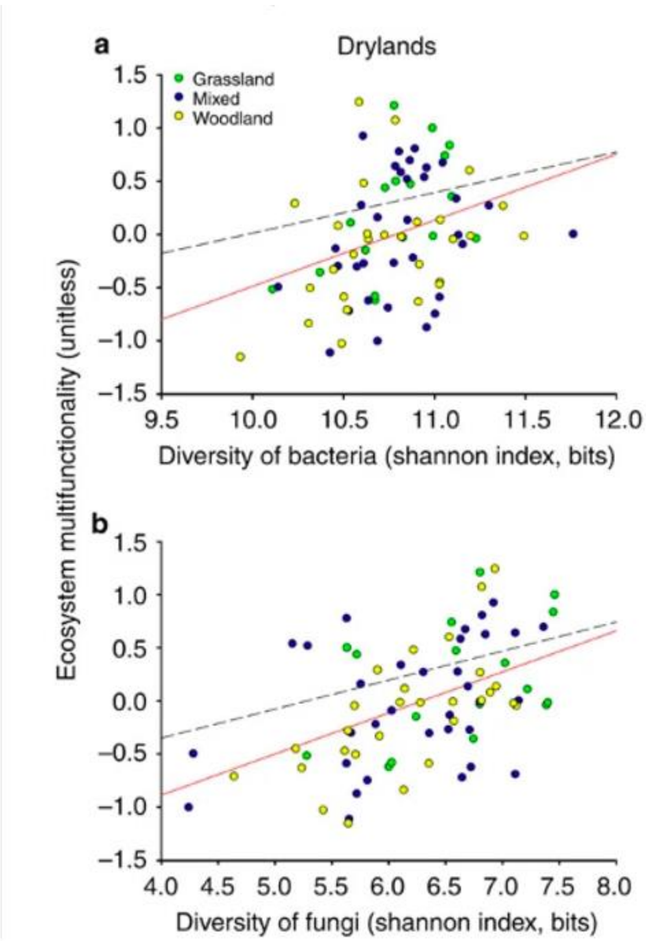

Figure 3. The relationship between microbial diversity and ecosystem multifunctionality (Delgado-Baquerizo et al., 2016)

Agricultural lands and forests have different environments and different symbiotic microbial communities. Forest lands tend to have higher soil C and lower pH than agricultural lands (Falkengren-Grerup et al., 2006). The reason for forest lands have lower pH is soil naturally becomes acidic through forest succession as forest litter decomposes on the soil surface and the acidic decomposition products leach into the soil, and also rainfall tends to leach bases from soils and both processes contribute to soils acidity (Rengel, 2003). The soil and crop productivities are linked to soil pH (Oshunsanya, 2018). The optimal soil pH range for agricultural crops is 5.5-7.5, and most agricultural crops perform optimally around a soil pH of 7.0 (Oshunsanya, 2018). Therefore, liming is a common method used to increase soil pH and ameliorate acidic soils in agricultural lands (Rengel, 2003). Soil pH is the best predictor of soil bacterial diversity and richness, and it is the best predictor of overall community composition (Fiere and Jackson, 2006). According to the research by Fiere and Jackson (2006), bacterial diversity is highest in neutral soils and lower in acidic soils (Figure 4). Agricultural lands tend to have higher bacterial diversity and richness than forest lands. Also, according to the research by Rousk et al (2009), fungal growth tends to increase, and bacterial growth tends to decrease with lower PH, so forest lands tend to have a higher ratio of fungal to bacterial biomass compared to agricultural lands. Also, the total P and available P and total K and available K tend to be lower in forests than in agricultural lands (Falkengren-Grerup et al., 2006; Cai et al., 2018). Total N and mineralizable N in the soil tend to be higher in soils in forests than in agricultural lands, and the leaching of N starts to appear in high concentrations when soil pH is lower than 4.5 (Falkengren-Grerup et al., 2006). Agricultural lands tend to have lower minimum air capacity than forest lands, and the somewhat poorly aerated soils of agricultural land tend to have low humus levels and low microbial activity (Lucas-Borja et al., 2019; Rejšek, 1999).

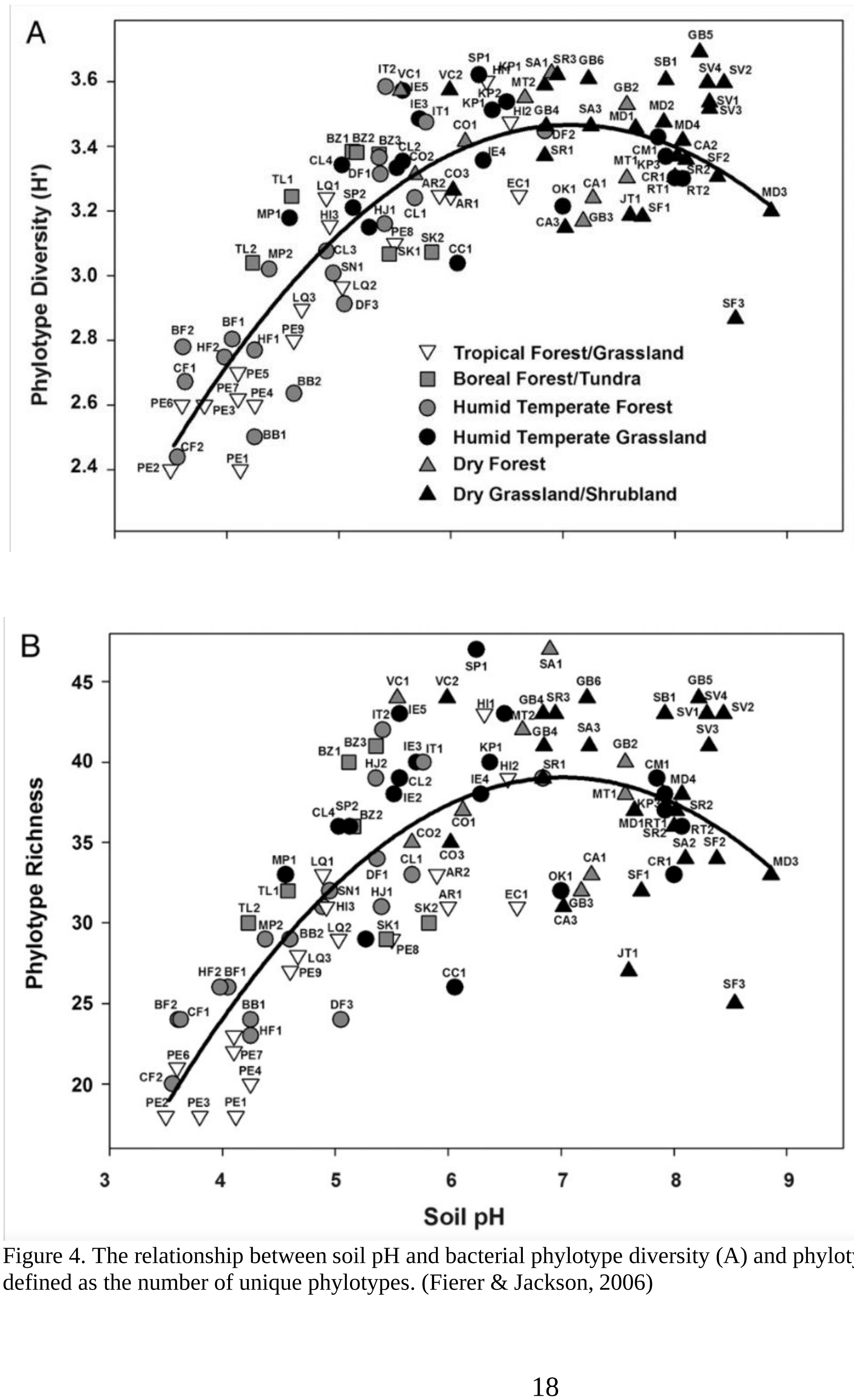

Figure 4. The relationship between soil pH and bacterial phylotype diversity (A) and phylotype richness (B), is defined as the number of unique phylotypes. (Fierer & Jackson, 2006)

When forest lands are deforested and converted into agricultural lands, bacterial community composition and structure are significantly altered by fertilization, and agricultural lands tend to have higher bacteria diversity in fertilized plots (O'Brien et al., 2016). Intensive agricultural practices and heavy use of inorganic fertilizers accelerate soil degradation, and mineralization of soil organic matter reduces soil beneficial microbes (SBMs) and affects soil health (Eka et al., 2020). Agricultural lands have higher bacterial richness, but lower fungal richness compared to the primary forest and secondary forest, and there is a distinct difference in soil microbes, especially in fungi taxonomic composition (Cai et al., 2018). Fungal diversity tends to have a predominant effect on multifunctionality in drylands (Delgado-Baquerizo et al., 2016). Also, fungi play an important role in C and N cycling in terrestrial ecosystems. Fungi tend to be more sensitive to changes in vegetation type than soil bacteria, especially arbuscular mycorrhizal fungi (AMF), and have a slower recovery of their communities following the disturbances that involve vegetation removal (Prescott and Grayston, 2013; Varenius et al., 2016). Fungi are sensitive to fertilizers and fungi tend to have decreased activity by management practices, including weeds control and fertilization (De Vries et al., 2006; Levy-Booth et al., 2016; Cai et al., 2018). When converting agricultural lands back to forest lands, pioneer vegetative species appear, which are the species that first colonize new habitats after disturbance, and pioneer species include plants, microbial and invertebrate species (Dalling, 2008). The pioneer stage has the lowest bacterial and fungal richness compared to the primary forest and secondary forest (Cai et al., 2018) since there is low available carbon for soil microbes (Högberg et al., 2007; De Graaff et al., 2010).

To stimulate the conversion from agricultural lands to forests, the amount of nitrogen in soil should be increased, the microbial community should be managed. It is beneficial to make restoration sites have higher bacterial and fungal richness, have more SBM, and have higher microbial activity, especially increase fungi diversity and richness. SBMs consist of total bacteria, phosphate-solubilizing bacteria, nitrogen-fixing bacteria, total actinomycetes, and total fungi (Eka et al., 2020).

There are two main methods to adapt the microbial community and stimulate the conversion to forests. The first is to add mulches or legumes in soils to increase the microbial diversity and richness. The second method is to add microbiomes to the soils directly by adding biofertilizer.

Method 1: Plant certain species to increase the amount of microbiome

Mulches:

Mulches are beneficial for forestry systems. Mulches create suitable environments for microbiomes and stimulate their growth. Mulches helps to improve seedling establishment, maintain optimal soil temperature, reduce soil erosion, and reduce overland flow (Navarro et al., 2010; García-Moreno et al., 2013; Alegre et al., 2013). When soil is exposed to heat, wind, and compacting forces, it may lose water through evaporation and it tends to absorb less rainfall since it is compressed (Chalker-Scott, 2007). Mulches can increase infiltration, percolation and water retention by reducing evaporation (Chalker-Scott, 2007). Some organic mulches act as a sponge and retain water inside the soil, thus, beneficial for water retention (Ipbal et al., 2020). The application of mulch can keep the soil cool under hot climate conditions and keep the soil warm on cold days (Kader et al., 2019; Ipbal et al., 2020), thus mulches can act as a buffer to regulate soil temperature and support plant growth. The application of organic mulches is beneficial to increase soil fertility since they are decomposed products and provide nutrients for soil (Ipbal et al., 2020). Mulches can increase the amount of organic C and N and provide substrates for microorganisms (Sainju et al., 2013; Fu et al., 2019; Guo et al., 2015). Mulches may benefit soil microorganisms by improving soil physicochemical properties.

There are different mulch materials, including straw, slash, chipped branches, cotton, haycarpet, biosolids, etc. (Jiménez et al., 2016). Competitive living mulches, such as turf, are not good choices for afforestation sites since they can affect the growth of planted trees (Chalker-Scott, 2007). Plastic, geotextiles, fine-textured organic mulches, sheet mulches, and waxy components mulches limit soil water recharge from rainwater so they are not suitable for arid and semi-arid areas (Chalker-Scott, 2007). Living and organic mulches are more temperature moderating than inorganic mulches (Chalker-Scott, 2007). Fu et al. (2019) found that plastic film mulching (PM) increased fungal diversity and richness but reduced bacterial diversity and richness, and straw mulching (SM) enhanced fungal diversity and richness while not affecting bacterial diversity and richness, so SM is more beneficial for soil microbial diversity and richness and soil environments compared to PM. Jiménez et al. (2016) have found that organic mulch treatment can improve the survival rate of planted tree species. Therefore, living and organic mulches are most recommended for afforestation sites. Living mulches are beneficial for soil micro-ecology development since living mulches tend to increase soil bacterial carbon metabolic activity and bacterial community diversity, but the effects of different living mulches are diverse (Qian et al., 2015). Investigations are needed before the application of living and organic mulches. Living and organic mulches' impact on soil nutrition is diverse and they require different climate and soil conditions (Qian et al., 2015), and it is important to ensure the applicated living and organic mulches will not negatively affect the growth of planted tree species.

Special Living Mulch-Legumes:

Legumes can bring direct benefit through symbiotic nitrogen fixation and contribute N to the soil (Rao, 2019; Haystead et al., 1988). Nitrogen (N) is considered the most important nutrient that can limit plants growth (Binkley et al., 1995). Legumes are able to form a symbiotic relationship with nitrogen-fixing soil bacteria called *Rhizobia*. The symbiosis can form nodules on the plant roots and bacteria can convert nitrogen from the atmosphere into ammonia, and plants can use the converted ammonia (Wang & Zhu, 2018). Also, when the bacteria are enclosed in the nodule cell by the membrane of plant origin, the bacteria will differentiate into nitrogen-fixing bacteroids, and bacteroids are better adapted to the intracellular environment and dedicated to nitrogen fixation than free-living bacteria (Jones et al., 2007; Mergaert et al., 2006; Prell and Poole, 2006; Haag et al., 2013). The N addition in soil can increase the soil microbial carbon use efficiency (CUE) and stimulate terrestrial C cycling and increase soil organic carbon and microbial biomass carbon (Zhao et al., 2022). The N addition promotes the growth of microorganisms in macro-aggregates since it can alleviate nutrient limitations in microorganisms (Zhao et al., 2022).

Despite providing bacteria to stimulate nitrogen fixation, legumes are less likely to affect the growth of planted trees. Legumes compete for less water in summer and their root systems are less competitive (Gordon and Wheeler, 1983). Also, the decaying leaves from legumes can increase the organic matter in soils, and increase the negative charge in soils, which can increase the soil's ability to retain positively charged ions and increase the CEC value (Raven et al., 1999; Barton & Karathanasis, 1997). The organic residues can provide substrates for microorganisms as well (Dai et al., 2017). Many legume species can be used as living mulches. Living mulch is recognized as a beneficial practice in forest plantation since it can suppress weed growth, increase organic matter and humus, promote biological activity, and improve soil structure (Alley et al., 1999; Dupraz et al., 1997).

Therefore, legumes can increase the amount of rhizobia soil bacteria and contribute to nitrogen fixation. Despite adding bacteria directly by symbiotic relationship, legumes can improve soil properties and build a good environment for microorganisms and stimulate the growth of microorganisms while not affecting the growth of planted trees.

Method 2: Biofertilization

Biofertilizers are highly useful for afforestation and reclamation of degraded lands (Revathi et al., 2013). Biofertilizers add microorganisms used for inoculation of seed and soil and thus supply nutrients directly to plants (Rao, 2019). Biofertilizers are biologically active products of bacteria, algae, and fungi, and they can help biological nitrogen fixation, phosphate solubilization and mobilization (Revathi et al., 2013). The most common biofertilizers include nitrogen fixers and vesicular-arbuscular mycorrhizae. Vesicular arbuscular mycorrhiza microorganisms help to translocate nitrogen from legume to non-legume (Rao, 2019). The plant-associated arbuscular mycorrhizal fungi (AMF) are important microbiome, and AMF form symbiotic associations with plants' roots, and they are common in secondary forests, and can greatly contribute to the high fungi richness in the secondary forests (Muthukumar et al., 2003; Cai et al., 2018; Cline and Zak, 2015). According to the research done in Baotou City in Inner Mongolia, China, the results show that the application of biofertilizers and super absorbent polymers significantly increased the height, ground diameter, or total biomass of planted species, and also, it increased the soil fertility (Zhao et al., 2018). Also, after 180 days of plant growth, the microbial population significantly increased (Zhao et al., 2018). Each tree species favors a specific group of microbes, which can optimally flourish plants' rhizosphere, improve the survival rate, and stimulate the growth of plants (Revathi et al., 2013). For forestry programs with multiple tree species, specific biofertilizers can be applied for each tree species, or a general biofertilizer with essential components can be applied, which should include mycorrhizal fungi, and nitrogen-fixing bacteria and phosphobacteria (Revathi et al., 2013). Biofertilizers help to increase the amount of SBMs in soil, improve soil properties, enhance nutrients uptake, improve seedling quality, and improve the growth and productivity of tree species (Revathi et al., 2013; Manjunath et al., 1984; Chang et al., 1986; Sahu and Manhot, 1989).

SUMMARY - THE MAIN PROCEDURES OF AFFORESTATION

Background investigation

Background investigation is necessary before the project starts. Ecological information, geographic information, and climate condition of the restoration site are needed. For ecological information, information about biodiversity, wildlife condition, soil condition, erosion rate, and former activities (e.g., over-cultivation, over-grazing, over-deforestation…) should be investigated. For geographic information, land area, topography, soil type, and steep slope condition are needed. For climate conditions, climate type, annual average, extreme temperatures, annual average, and extreme precipitations are needed. Collecting background information helps project managers understand how severely the ecosystem is damaged and the causes of ecosystem degradation, and it also helps them decide what plants are suitable for restoration in that area.

Decide project aim

The project aim should be decided after investigating the background information. Project managers should decide the area of the restoration land and the restoration methods. Project aims usually include increasing biodiversity, reducing soil erosion, improving vegetation coverage and condition, and restoring fragile systems, which can ultimately improve the environment's condition. It would be better to decide the investment of the project and decide how much land is planned to be restored at the beginning, which helps to make the aims more specific and clearer.

Decide project scale

For project scale, project managers should decide the restoration range and duration of the project. It is important to decide what lands are under restoration, which usually includes farmland, abandoned land, and degraded land. It is also crucial to decide which lands should be restored with priority, for example, the projects may mainly restore the steep slope lands to reduce soil erosion, or mainly restore the upstream to improve river water quality. It is beneficial to decide what lands are planned to restore at first and what lands may be restored when the project is scaled up, which can make the project plan more comprehensive. Setting the duration of the project help to set a deadline for the projects, which can help to improve the restoration efficiency.

Defining the reference ecosystem:

The reference ecosystem can be defined by conducting surveys in the surrounding remaining forest area, doing field analysis, and investigating historical records. Defining the reference ecosystem helps to select the non-degraded sites with similar environmental factors to the restoration lands, and the sites can be used as references to decide restoration goals and help project managers choose tree species for plantation (Durbecq et al., 2020).

Tree species for restoration

The background investigation and reference ecosystem identification help to decide the tree species for plantation in restoration sites. Native trees are recommended for ecological restoration projects. Native trees can re-establish the original ecosystems of that region, and they are better suited to the climate and soil type, also, they usually require less water and fertilizer than exotic species (Heeman, 2017). Native tree species tend to have long-term sustainability and are easier to maintain (Garen et al., 2008). Native trees are more adapted to the environment, and they are less susceptible to damage from diseases and pests, so they are recognized as more ecological valuable. Exotic tree species may provide timber or fruit products to stimulate the local economy, but they were found with the possibility to promote soil erosion and were more expensive to be maintained (Garen et al., 2008; Fischer & Vasseur, 2002; Wishnie, 2005). Planting exotic plant species can bring new biotic interactions and can alter the ecosystem composition and function, also, as the biological and abiotic responses to the exotic species, it may result in the reduction of carbon sequestration (Waller et al., 2020). Afforestation with exotic species may modify a biome and reduce biodiversity. The different exotic species may have different impacts on microbial communities, according to a global meta-analysis, exotic species increased soil microbial activity and disrupted the balance between native plants and soils, and reduced the plant diversity, richness, and evenness by 36.97%, 64.72%, and 47.21%, respectively, and with the diversity reduction, Soil pH, soil organic carbon, and total nitrogen were affected (Xu et al., 2022). In terms of ecological benefits, native tree species are more recommended for plantation. However, planting certain exotic tree species may bring more economic benefits, but it is with more uncertainty and may negatively influence the ecosystem, and it needs comprehensive investigations before plantation.

Mixed-species plantations are more recommended than monoculture plantations. Mixed native species afforestation is proved to have a more fully restored status than monoculture plantations (Kuang et al., 2021). Mixed-species plantations can increase the number of plants and animals since it can provide higher tree species diversity and increase the number of ecological niches for soil biota, which can provide better habitats for plants and animals (Larjavaara, 2008; Liu et al., 2018). Mixed-species plantations tend to have more stable, active, and resistant microbial communities, and there is more abundance of AMF in its sites (Kuang et al., 2021). Monocultures tend to be less resistant to biotic and abiotic disturbances (Felton, et al., 2010). The mixed-species plantation is found to have more benefits in biodiversity, economy, forest health, and sometimes in productivity compared with monospecific plantations (Liu et al, 2018). When doing mixed-species plantation, it is important to select tree species with complementary traits, which can help to maximize positive interactions and bring more advantages (Brooker et al., 2015). In the meanwhile, it is also beneficial to plants some native species with high ability to attract seed dispersers.

Microbiome modification (if necessary)

According to the vegetation conditions and plant conditions of the restoration site, mulches, legume species, or biofertilizers may be applied to the soil to affect the microbiomes in soil. If there is low microbial diversity in the restoration site. Suitable mulches can be applied to soils to stimulate the soil micro-ecology development and increase microbial diversity, but it is important to investigate the soil conditions and climate conditions to ensure the growth of applied mulches and ensure the mulches will not affect the growth of planted trees. In the meanwhile, biofertilizers can be applied to soils if the restoration sites are with low-quality soil and show a poor performance in tree growth. The composition of biofertilizers can be decided according to planting tree species and soil nutrient composition. Suitable biofertilizers can help to increase the number of microbiomes in soil, improve soil properties, enhance nutrient uptake, improve seedling quality, and improve the growth and productivity of tree species. If the soil of the restoration sites shows an apparent lack of nitrogen and the climate condition is good for legume growth, suitable legume species can be applied to restoration sites to increase the nitrogen content in soil and simultaneously improve soil properties and stimulate the growth of microorganisms.

Plantation process

When doing tree planting, it is necessary to do weed control as well, that is remove the unwanted plants, and thus provide reserve water and nutrients for the planted trees. During the plantation and in the process of tree growth, it is important to prohibit the cultivation and grazing in the restoration area, to provide a good and undisturbed environment for planted trees and stimulate their growth. When doing the plantation, it is also important to prohibit the destruction of natural vegetation. Natural vegetation helps to keep soil moisture, maintain soil temperature, and reduce soil erosion. The removal of natural vegetation results in the soil exposure to heat and wind and remains less water in the soil, which can weaken the seedling establishment and reduce the survival rate of planted species.

Monitoring/Result

The monitoring index includes tree survival rate, tree height, canopy area, root collar diameter, land cover (forest cover, cropland cover, grassland cover), soil organic carbon content, the amount of carbon sequestration, and soil moisture, soil erosion, biodiversity, amount of lichen species. These indexes should be monitored frequently. The value of these monitoring indexes should be recorded and used for comparison. Professional project managers should analyze the recoded data and make necessary adjustments to ensure the restoration projects are on the right track

CONCLUSIONS

Afforestation can return former ecological benefits lost by soil degradation with proper methods. The recommended procedures for afforestation projects summarized in this paper can help abandoned agricultural lands and degraded lands transfer into forests and promote success of restoration projects. Afforestation accelerates the colonization of tree species and enhances the CO_2 sink. Global scale restoration of trees is a most effective strategy for climate change mitigation, and the global potential canopy cover may shrink by ~223 million hectares by 2050 with insufficient tree restoration (Bastin et al., 2019). Afforestation with mixed native tree species has a high potential to restore plant species richness, plant biomass, soil biodiversity, and community composition to a similar level of an undisturbed native forests in about sixty years (Kuang et al., 2021). Afforestation positively affects the soil biota diversity, biomass and benefits ecosystem stability (Allesina & Tang, 2012). Afforestation with mixed native tree species had significant effects on increasing microbial biomass and community composition to the level of natural forests, and the relative abundance of fungi promoted the restoration efforts to natural forests level (Kuang et al., 2021). The microbiome modification methods, including mulches application and biofertilizer application can accelerate the restoration since the increase of microbes in the soil increases the soil biodiversity and enhances soil biota functioning and soil health (Lefcheck et al., 2015; Kuang et al., 2021).

There are controversies about afforestation and natural succession. Natural regrowth is considered a cheaper method than afforestation and it requires low management. Also, natural regrowth can select the suitable tree species for the sites by ecological succession. Researchers also found natural regrowth can store more carbon in soil and afforested lands can store more carbon in aboveground biomass, but either natural vegetation succession or afforestation, both methods can accumulate the same amount of carbon over 50 years (Thibault et al., 2022). However, natural regrowth is not a suitable method for all lands. Some highly degraded land with vulnerable soils may have long-term loss of ecosystem functions and services and be unable to recover unaided (UNEP, 2007; Wiegmann et al, 2008). For the lands with former intensive use of fertilizers, natural regrowth here may be slow and unproductive, and the native species may gain a foothold only after several decades. Active revegetation by afforestation could potentially have more successful results (Gvein, 2021). Also, soil microbes tend to have no significant change at the first 5 years stage of natural succession (Zhang et al., 2021). Degraded land afforestation can increase the diversity of vegetation in a short time, and the diversity of vegetation will beneficially affect soil fungi, which can increase soil microbial diversity, enzyme activity, and increase soil microbial richness (Huang et al., 2022). Natural regrowth may be a cheaper method than afforestation, but with climate change, natural regrowth may be slowed, while afforestation may accelerate the recovery of forests and help nature become more resilient.

RECOMMENDATIONS

Afforestation should be considered as an effective management strategy for reclaiming degraded and abandoned land as it is a proven method for and returning the soil's capability to increase or recover the providing of ecological goods and services, including greenhouse gas sequestration.

Afforestation plants should be compatible with the ecological site conditions, and suitable afforestation tree species should be considered according to reference ecosystems, which helps the disturbed sites recover to their natural states. Native tree species are recommended for afforestation projects, as they tend to be better suited to the climate and soil type. Also, in general they usually require less water and fertilizer than exotic species, thus low management required once established at the sites.

If native plants are not available exotic may be used, but it is important to make sure the exotic species can adapt to the environment and will not become an invasive species. Background investigations are indispensable to make sure the exotic species will not break the ecosystem balance and stability. In the meanwhile, if the environments are suitable, it will be beneficial to choose tree species have symbiotic N fixation capacity.

The microbial community is one of the most critical factors controlling the success of afforestation thus mulches and biofertilizers should be incorporated into the afforestation process. Mulches can improve the soil properties and create a better environment to stimulate the growth of microbes and increasing microbial biomass and microbial activity. Biofertilizers can increase the number of microbiomes and change the microbial community composition. The application of mulches and biofertilizers help to improve microbial community and stimulate plant growth, which can ultimately improve ecological environment and increase ecosystem functionality.

LIMITATIONS

The research about microbial community in forest sites and agricultural sites are insufficient and the composition and change of microbial community during the conversion from abandoned agricultural lands to forest lands are not integrally understood. Also, afforestation, natural regrowth, carbon sequestration, and climate change conditions interact with each other, so the relationship between them is complicated and not completely understood. More research is needed to find the relationships between carbon sequestration and climate change, to compare natural regrowth and afforestation, and to investigate the relationships among microbiomes, types of land use, and soil properties.

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